THE VALUE OF FLEXIBLE DESIGN:
REAL ESTATE DEVELOPMENT AND INVESTMENT STRATEGY UNDER UNCERTAINTY

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ABSTRACT:
Utilizing recent research into building life cycle analysis and option valuation theory, this thesis develops an architectural methodology for analyzing buildings’ “capacity for change,” and economic models for valuing this capacity. Together these can be used to evaluate strategies for the design, investment, and development of new and existing buildings.

Two hypothetical case studies illustrate the methods and models, and produce results which challenge conventional wisdom. One case study suggests that including a redevelopment option can increase the valuation of moderately performing assets by up to 25% over conventional discounted cash flow analysis, even when redevelopment is not economically feasible in the near term. The other case study finds that when zoning allows, the design and construction of a building which can flexibly switch between multiple uses can be economically viable, even when substantial additional costs are incurred.

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1. INTRODUCTION

1.1. MOTIVATIONS

There are two explicit motivations behind this thesis. Architecturally, the intention is to examine building “flexibility” – that is, the capacity that buildings have to change over time – and discover some of the implications this has for the revitalization of existing buildings and the design of new. On the financial side, the motivation is to show how the application of alternative valuation methods – in this case, option valuation theory – to real estate investments can correct some of the deficiencies in conventional discounted cash flow (DCF) analysis.

However, there is a deeper motivation which underlies both of these overt intentions. The building industry seems, to me at least, to be excessively shortsighted. Perhaps the industry is no more myopic than any other – but then again, most industries don’t produce assets which last for generations. And whether this myopia is intrinsic to the development industry or is a function of the legal and financial systems in place for building production, the effect on the environment is the same: a surfeit of cheaply built, disposable buildings which age poorly and often become obsolete very quickly. Moreover, real estate investments that do not “pay off” within the first few years tend not to be made. This leads to difficulties for all sorts of progressive projects, from pedestrian oriented urban developments\(^1\) to energy-efficient, environmentally sound buildings.\(^2\)

While I in no way claim to provide a broad-based solution, or even attempt to address the question in any fundamental way, this work is an attempt to grapple with the some of the architectural and economic issues that are involved in creating a longer-lasting, more humanistic built environment.

1.1.1. BUILDING FLEXIBILITY

There are at least three reasons to be interested in the capacity for buildings to change, and especially in their capacity to accommodate new uses. The most practical is simply the increase in the number of revitalization projects in recent decades, a trend that is expected to grow as reinvestment in central business districts and other existing urban areas becomes a focus of development. The second reason is related to this reinvestment in urban areas, which tends to create or sustain diverse, mixed-use environments. In such situations buildings which can accommodate multiple

\(^1\) Gyourko & Rybczynski (2000); Leinberger (2001).
\(^2\) Wann (1996).
uses, either through the adaptive reuse of an existing facility or through the creation of a new building, often act as critical elements in an area's economic growth and sense of vitality. Finally, finding ways to introduce more flexibility into new buildings or to adapt existing buildings to new uses is an apt strategy for reducing waste caused by the building industry, thereby creating a more sustainable built environment.

Recent surveys provide some empirical evidence that buildings change far more often than is usually thought. From the simple replacement of building components to full-on building conversions, it is clear that buildings continue to be adjusted to their environment long after the initial construction phase has ended. Currently, half of all construction expenditures go towards building revitalization, which suggests a huge amount of churn in existing buildings and an economic incentive for better understanding how these costs can be minimized (or, alternatively, their benefits maximized). At the extreme end of the spectrum is the complete redevelopment of obsolete buildings—a growing niche in many segments of the real estate market, with high profile conversions of factory, warehouse, and office buildings becoming almost commonplace in highly urbanized areas. Moreover, revitalization and redevelopment are expected to grow even more over the next few decades, creating a “category of business opportunities that will dominate the rest of the 21st century.” Such is the economic argument for a better understanding of flexibility in architecture.

However, this argument has a social dimension as well, especially since many of these redevelopments occur as part of concerted efforts to revitalize urban areas and are connected to current movements in the planning and design professions. Both the “smart growth” and “new urbanist” movements call for a more livable, walkable, sustainable, and community-oriented urbanism—to be achieved at least partly through mixed-use developments and investment in existing urban areas. The smart growth movement in particular has been adopted by many municipalities and planning agencies, who are interested in ways to revitalize urban cores that suffer from varying degrees of neglect. Districts that had formerly been purely business oriented, such as Wall Street in New York and Chicago’s Loop, are now being touted as areas where the full range of urban life can exist. Likewise, smaller cities throughout the nation are finding that revitalizing their downtowns entails the

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3 Slaughter (2001), p 212.
6 Cunningham (2002), p 5.
redevelopment of existing real estate assets and the creation of mixed-use districts and buildings.\(^8\)

To the extent that the smart growth and new urbanist movements are naturally connected to the environmental movement,\(^9\) so is any study of buildings' capacity for change. Both building revitalization and new flexible, mixed-use developments are integral to the smart growth agenda to reduce land consumption through building more densely and investing in existing urban areas. Likewise, the pedestrian-oriented nature of these movements' recommendations is also intended to cut energy consumption by reducing dependency on the automobile. More directly, though, much of the existing research into buildings' ability to change over time is aimed at reducing the waste associated with the construction industry. Where possible, for example, adaptive reuse of existing obsolete buildings can reduce the amount of materials needed for new construction, along with the waste associated with demolition of the existing buildings.\(^10\) Likewise, other recent research into methods for the orchestration of change within new buildings has environmental sustainability as at least part of its stated agenda.\(^11\)

All of these reasons for examining the capability of buildings, both old and new, to adapt over the long term hence coalesce into a single interconnected argument, with economic, social, and environmental imperatives. And while the social and environmental agendas are beyond the scope of this thesis, the economic argument is an integral part of the financial modeling component of this work.

1.1.2. **SHORTCOMINGS OF DISCOUNTED CASH FLOW ANALYSIS**

The net present value (NPV) investment rule, along with the discounted cash flow (DCF) methodology for determining “present values” of uncertain future cash receipts (or payments), has become standard practice in business and finance over the last half century. In short, the NPV rule states that if (and only if) the “present value” of a potential investment is larger than the cost (i.e., if the “net present value is greater than 0”) then the investment should be taken. In turn, the present value of future cash flows is determined by discounting them according to how far in the future they occur and how much risk is involved. The rate at which they are discounted (the “discount rate”) is in turn based on the market’s analysis of risk and current prices for similar investments.\(^12\)

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\(^8\) Hudnut (2002); Hudnut (2003).
\(^10\) Ball (1999).
\(^11\) Brand (1994); Fernandez (2002).
\(^12\) see Sharpe et al (1999) or Brealy & Myers (2000) for a fuller explanation of NPV analysis.
The process is straightforward enough, and the rule produces good decisions in a large number of situations. However, it does have shortcomings, as well as an history of criticism. This dissatisfaction ranges from the polemic writings of Christopher Leinberger, claiming that the DCF methodology is one of the root causes for the lack of progressive and long-lasting urban environments, to more staid arguments about the lack of ability for DCF to account for strategic considerations. In any case, academics have been making recommendations for alternative valuation techniques since the 1960s, and managers have been intuitively grappling with the problems inherent in NPV analysis since the method first became commonplace.

The problem with NPV analysis boils down to its implicit assumptions: “traditional NPV makes implicit assumptions concerning an ‘expected scenario’ of cash flows and presumes management’s passive commitment to a certain ‘operating strategy.’” In reality, though, management usually has the ability to change its ‘operating strategy’ as uncertainty about the future unfolds and is resolved – this can change possible investment payoffs radically.

Of course, DCF is sensible in many situations: for valuing bonds or other fixed-income securities, and for valuing relatively safe, low-growth stocks. Similarly, it can be readily applied to corporate projects which are “cash cows,” or to financial leases and the like. However, for valuing financial calls or puts, high-growth stocks, or business opportunities with important growth opportunities or managerial flexibility, DCF analysis falls flat. Essentially this is because “management’s flexibility…expands an investment opportunity’s value by improving its upside potential while limiting potential downside losses relative to management’s initial expectations.”

In the financial markets, option valuation theory (OVT) holds the key to valuing high growth stocks and traded calls and puts. Likewise, “real options analysis” provides an alternative to NPV analysis in real-world business applications. Most proponents of the real options alternative, though, do not propose to lose NPV analysis altogether, but rather to use options analysis to enhance the traditional method. In effect, real options analysis allows the quantification of strategic issues involved with a potential investment, and aims to supplant the traditional NPV value with the following:

\[
\text{Strategic NPV} = \text{passive (traditional) NPV} + \text{value of options from active management}
\] (1.1)

\[\text{Leinberger (2001).}\]
\[\text{Trigeorgis (2001), p 103.}\]
\[\text{Trigeorgis (2001), p 103.}\]
\[\text{Trigeorgis (2001), p 103.}\]
Alternatively, the premiums associated with significant options involved in a potential investment could simply be viewed as part of the benefits or costs in an NPV equation\(^7\) – in any case, the many of the insights gleaned from NPV are still meaningful in a real options framework, but supplemented with the strategic considerations engendered by options analysis.

Interestingly, it has been shown that some of the investment criteria followed by many managers, such as hurdle rates, payback rules, and profitability indices, create heuristics that approximate the results of a real options analysis, at least under certain typical parameters.\(^8\) While reasoning for such heuristics is specious at best, and they can be shown to produce suboptimal investment decisions under some reasonable parameters,\(^9\) the fact that their use continues even after widespread adoption of the mathematically more correct NPV rule suggests that managers do perceive some shortcomings with the latter. And the fact that the decisions adopted due to the heuristics follow those given by a real options analysis suggests that many managers intuitively grasp the need for considering options as part of the investment equation.

In short, since most real-world business opportunities, in real estate or otherwise, involve active management, real options analysis provides better strategic decision rules than traditional NPV. This is especially true in the realm of development, where uncertainties about future values and competitive interactions are critical. And it is not unreasonable to imagine that its widespread application would go some way towards ameliorating the apparent myopia of the development industry.

\section{1.2. Methodologies}

This thesis uses two methodologies in conjunction: financial modeling and hypothetic design work. Appropriate to the issues raised by shortcomings of DCF analysis, option valuation theory is employed to create a real option based model. Appropriate to the architectural questions raised by the notion of "flexible buildings," the research herein leads to a means for determining capacity of change, and to the development of hypothetical cases - which can then be used to test the efficacy of both the architectural analysis and the financial models.

\subsection*{1.2.1. The Auguries of Modeling}

Financial modeling to determine and value a future stream of cash flows is a dangerous business, and economic forecasts made using even finely tuned

\footnotesize{\(^7\) Geltner & Fisher (2001), p 757.\(^8\) McDonald (2000).\(^9\) Brealy & Myers (2000).}
econometric models have notoriously questionable value.\textsuperscript{20} The failures of expectation which arise from such ventures can lead to the idea that “modeling is a dark art”\textsuperscript{21} – and perhaps no better than the examination of cracked turtle shells.

On the other hand, another purpose of modeling, and the purpose to which it is employed here, is to illuminate the situation being modeled. A lot is to be gained by rigorously modeling hypothesized relationships between a number of variables. At the very least, a mathematical model allows one to follow a complex chain of logic to its conclusion in a way impossible without the model. And in the case of valuation, financial modeling can provide as objective a value as possible of a given asset.

This latter is the purpose behind the modeling in this research. Given the assumptions of the models, as laid out in Chapters 2 & 6 of this thesis, and a set of inputs, the two models described herein are of capable generating very precise estimates of value. However, even when the inputs are very precisely and objectively determined, the assumptions used to simplify reality for the sake of the model will cause the outputs to be just “best guesses” as to value. Hence, the approach here is to use the model in order to illuminate the key variables and relationships that give a building’s “flexibility” value. The results are meaningful, certainly, and provide approximate valuations with important implications that investors, developers, and architects would do well to observe. But obtaining precise values is not the purpose here, nor is empirical testing of the model’s predictions.

\section*{1.2.2. The Hypothetical Case Study}

In line with this type of modeling, the conventional case study approach is less appropriate than an approach of “hypothetical” case studies. Similar to other research methods that involve new design as part of the process, the approach used here concentrates more on possibility than actuality. Two sites, one vacant and one with an existing building, are used to hypothesize the possible forms of development which could occur. The hypothetical developments are grounded in reality, of course, and based on the background research and design recommendations laid out in the first few chapters of the thesis. However, given the nature of option valuation, which is forward looking and intrinsically about the probability of future events and values, and given the nature of the thesis’s architectural agenda, which remains largely theoretical and has few existing examples to use as test beds, the hypothetical case study approach seems appropriate.

\textsuperscript{20} Ormerod (1997); Ormerod (1999).
\textsuperscript{21} William Porter, conversation.
1.3. RELEVANCE

The research presented here has important implications for real estate strategy. In particular, the results suggest that this work should be of interest to three primary players in the real estate industry: investors, developers, and architects.

1.3.1. INVESTMENT

From an investor's viewpoint the results of the models suggest that a value premium may exist in buildings which are capable of accommodating multiple uses. The redevelopment premium associated with existing buildings is commonly recognized when urban areas are rapidly changing and a building is vacant or seriously underperforming. However, the results from this study suggest that even when a building is performing moderately, and redevelopment is not optimal within the typical investment horizon of 3-5 years, the value associated with the redevelopment option can be quite high, especially if the zoning allows for multiple uses on the site and the demographics of the area is changing. This suggests that the market as a whole may not recognize the value afforded by possible redevelopment.

Given that this redevelopment option is hidden from conventional DCF, and that the typical real estate investor does not explicitly consider long-term redevelopment opportunities when purchasing existing buildings,22 a potential strategy emerges. The opportunity seems to exist for long-term investors to buy and hold stabilized assets with high redevelopment premiums without having to pay the true value of the premium. At the very least, investors should take the redevelopment premium into account strategically when analyzing potential purchases.

1.3.2. DEVELOPMENT

The results from the second model have implications for development strategy, at least in developments that are, or can be, mixed-use. Generally speaking, they suggest that strategies which allow the developer to postpone decisions about the exact type of building to create for as long as possible in the development process have substantial value. In particular, when zoning and market conditions allow, the benefits of designing and permitting multiple buildings, multiple variations of the same building, or "flexible" buildings capable of switching between different types of uses will almost always outweigh the costs. Especially in markets where long delays in the permitting process are typical, and supply is in danger of increasing due to other players, the value of flexibility is keen. In addition, the model suggests that the order of investments in the development process can affect the value of being

22 Jillson, interview
able to switch building types or abandon a project. Most strikingly, the models presented here are capable of providing some measure of the value obtained by holding off actual purchase of land.

1.3.3. ARCHITECTURE

Architects should also have an interest in the results of the models, as well as the more qualitative study of how buildings change. In addition to outlining some key considerations in the growing niche of building redevelopment, this thesis provides economic justification for design work that goes beyond the traditional contract. Thus the architectural profession as a whole should perhaps have the most selfish interest in this work, as it suggests that the design process can add tremendous value to the development process.

While the models here specifically communicate the value associated with additional design work in mixed-use developments, the results can be generalized. In effect, one view of the design process is that of option creation. At least in the schematic stages, the design process is one of creating and evaluating many alternative strategies. And though architects are well versed in methods for giving such strategies physical form, the strategies also have economic value associated with them due to the options they create. Given the high degree of risk in most developments, especially in the early stages, these “design options” probably have more value than architects realize, and this thesis provides some justification for attempting to capitalize on them.

1.4. STRUCTURE

The rest of this paper is divided into six chapters and two appendices. Chapter 2 presents the concept of options, including valuation and existing applications in real estate, in a way that should be understandable to anyone with a basic grounding in algebra. Chapter 3 outlines the ways in which buildings can be expected to change over time, as well as some established methods for analyzing such changes, and design approaches which have been used to more readily accommodate them. Chapter 4 presents a method for analyzing a building’s ability to change, concentrating on the needs of various types of representative building users. Chapter 5 gets into the heart of the thesis, and uses insights from chapters 3 and 4 to examine two cases where substantial options exist for accommodating multiple types of users, in addition to reviewing three similar cases from the past. Chapter 6 presents and applies two option-based models for determining the economic value associated with

23 And one outlined in Baldwin & Clark (2000).
the cases of the previous chapter, while Appendices A & B are used to mathematically derive the models. Finally, chapter 7 concludes the paper with an overview of the results, important caveats, and suggestions for further research.
2. OPTIONS

To the extent that this thesis revolves around the application of option valuation theory to real estate development, it derives from three primary research domains: financial derivative valuation, capital budgeting analysis, and urban economics. Urban economics has the longest history, with modern origins in Von Thunen’s work of the early 1800s. Research into the valuation of financial derivatives began in the 1950s, along with modern portfolio theory and other advances in financial theory. By the 1970s the valuation of financial options had reached a high level of sophistication, and the analogy between financial options and managerial decision-making became an obvious area for research, giving rise to the field of “real options.” The earliest direct application of OVT to real estate came in the late 1980s, in the area of land valuation, and a significant field of research has since developed, including models for land valuation, development cycles, and mortgage analysis. This work builds on, and adds to, all three of these strands of research.

Before presenting the models and findings in chapter 6, this chapter will present option basics, valuation, and existing applications in real estate. The first two sections are meant primarily for readers unfamiliar with options, and presents the basics required to understand the results of this research in an accessible manner. Readers familiar with options can probably skip directly to section 2.3, which describes a number of existing real estate option models relevant to this thesis. Readers not familiar with options should find this chapter accessible enough to understand the

2.1. OPTION BASICS

An option is a “right without obligation” to do something, whether that something is to purchase an amount of stock or develop a piece of land. The essential phrase here, “right without obligation,” is included in virtually every introduction to options and is the key to understanding the use and valuation of options. The owner of a financial option on a company’s stock, for example, has the right to purchase a stock under conditions stated in the option contract, but is not required to purchase the stock and therefore has quite a different interest in the company than the owner of common stock. Likewise, one real option in real estate would be the option to renew a lease at a contractually determined rate, common in commercial leases. Clearly the owner of a 5-year lease with three options to renew for 5 years has a substantially different contract than an owner of a 20-year lease. In fact, if the leases are otherwise the same, it should be intuitive that the former lease with the renewal options is quite a bit more valuable.
2.1.1. **FINANCIAL OPTIONS**

Before discussing real options, it is important to understand the abstract (but simpler) world of financial options.\(^{24}\) A financial option is called a derivative because it is a claim on another financial asset, such as a stock, and therefore derives its value from the underlying asset to which it refers.

2.1.1.1. **CALLS, PUTS, AND OTHER JARGON**

There are two basic types of options: a *call* and a *put*. A call option is the right to buy an *underlying asset* (for example, a stock) at a specific price (called the *strike price*), whereas a put is the right to sell an underlying asset at a contractual strike price. This act of trading one’s option for the underlying asset is referred to as *exercising* the option – options give one the right to hold either the option or the underlying, not both, and that exercising the option is irreversible. Most financial options come in one of two types: *European* or *American*. The owner of a European option has the right to trade exercise their option only on a specific date, known as the *expiration date*. The owner of an American option, on the other hand, can exercise at any time on or before the expiration date.

Holding all else constant, the value of a call option will increase as the underlying asset value increases, while the value of a put will decrease as the underlying asset value increases (remember that the call is the right to *buy* at a fixed price, while the put is the right to *sell* should make this relationship intuitive). For a similar reason, the value of a call decreases as the strike price goes up, while the value of a put increases. However, with regards to expiration date and the type of option (American or European), call and put values move in the same direction. The further away the expiration date, the more valuable the option. Likewise, American options will never be worth less than European options. The intuition behind these two relationships is that both a longer time to expiration and the right to exercise at any time provide more strategies, which in turn means more “options.”

But it is uncertainty about the future that really drives option prices: as uncertainty about the future value of the underlying asset increases, so does the value of any option. This stands in sharp contrast to most assets, where uncertainty about future prices or cash flows would decrease the present value of the asset – most of modern financial theory is built on the fact that the more uncertainty, or risk, there is in something, the lower should be its price. For those steeped in financial theory and analysis, therefore, options can be highly counter-intuitive things. But uncertainty increases the value of an option because an option is a “right without obligation,” as stated above. Therefore, the value of an option can never be less than zero. This

creates an asymmetric payoff, in which there is very limited downside risk and a very high upside potential. In such circumstances, uncertainty will drive values up.

2.1.1.2. THE OPTION PAYOFF

A few diagrams may help in understanding the asymmetry of option payoffs. Figures 2.1 and 2.2 show the payoffs of an example call and put as a function of the value of the underlying asset. The payoff of the call upon exercise can be seen to be

\[ C = \max (S - K, 0) \]  

while the put payoff is

\[ P = \max (K - S, 0) \]  

where \( K \) is the strike price, and \( S \) is the value of the underlying. So if, for example, both options had a strike price of 100, the call will pay 20 when the underlying is worth 120, while the call payoff when the stock is worth 80 would be 0. Conversely, the put payoff when the underlying is worth 120 would be 0, while the put would pay 20 when the underlying is at 80.

![Figure 2.1 - Call Payoff as a Function of the Underlying Asset Value](image)

![Figure 2.2 - Put Payoff as a Function of the Underlying Asset Value](image)

Figures 2.3 through 2.6, which simply have bell curves overlaid on the previous show how uncertainty and the payoff asymmetry work together to create an option’s value. The bell curves represent uncertainty surrounding the value of the underlying at expiration, and show the relative probability of any particular value occurring. If one owns the underlying asset directly, one has the right and obligation to all values and probabilities under the curve. If the mean of the probability distribution is 90, for example, then that is also the expected value. However, an option will only be exercised if the underlying asset’s value is above the strike price (in the case of a call - in the case of a put, it will be exercised only if the underlying’s value is below the

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25 Assuming a normalized distribution of probability.
strike). Thus an option holder has the rights to all of the probable values above (or below) the strike price, but is not required to share in the other probable values. The value of the option can be visualized (and in fact calculated) as the sum of all values the underlying might take above the strike price, multiplied by their probabilities of occurrence. So, even when the underlying asset is currently worth less than the call's strike price (as in Figure 2.3), the option still has some value - and likewise for a put with a strike lower than the expected value of the underlying at expiration (Figure 2.4).

![Figure 2.3 - Call's claim when Asset Value is Probabilistic](image)

![Figure 2.4 - Put's claim when Asset Value is Probabilistic](image)

![Figure 2.5 - More Uncertainty means more Value](image)

![Figure 2.6 - More Uncertainty means more Value](image)

Figures 2.5 and 2.6 show the same payoff diagrams and mean values for the underlying, but with a change in the level of uncertainty. In these instances, the distribution of probabilities has a higher standard deviation, meaning that the price of the underlying asset is expected to move more, even though the expected value is still the same. It should be visually apparent from these two diagrams that increasing the uncertainty of the underlying asset's price has increased the value of the option, since there is now more area under the curves which are “in the money” (within the payoff zones of the respective options).
Finally, Figures 2.7 and 2.8 show the value of an option as a function of uncertain asset prices. The value of the option, relative to the underlying asset, is generally highest when the strike price is the same as the underlying asset’s expected value. As the expected value of the underlying approaches 0, so does the call option’s value. Likewise, as the expected price of the underlying gets very large, the value of the call option approaches the value of the underlying minus the strike (though, in the case of non-dividend paying assets, the option value will always be higher than the net value of the underlying after the strike price is paid). The inverse is the case for puts.

2.1.1.3. USING OPTIONS

Financial options are typically used as way of hedging investment risk, and are often called the “building blocks” of financial engineering. One can combine calls and puts in any number of ways and proportions to create virtually any payoff diagram an investor might want. Some simple strategies are quite common, and shown in Figure 2.9.26 Two important diagrams to note are the last two. In these cases the underlying asset is bought or sold short, along with an opposite call position, in order to create the same payoff function as a buying or selling a put. This is known as put-call parity and is used in option valuation.

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Another thing which becomes clear upon close examination of these option combinations, is that options can be seen to exist intrinsically in all financial instruments. As shown in Figures 2.10 and 2.11, it is possible to view the payoff of common stock or a corporate bond as a function of the value of the firm (or sticking with real estate, Figures 2.10 and 2.11 can be seen as payoff diagrams for the building equity owner and mortgage holder respectively, as functions of the building value). A company's stock is simply a call option on the firm value with a strike price of the total outstanding debt owed by the firm. And the holder of a corporate bond essentially holds the firm value after the equity holder's call option is subtracted out. Thus even the most basic breakdown of an investment into equity and debt can be viewed (and therefore valued) as options.
Similarly, more complex financial instruments such as warrants and convertible or preferred stock, can be seen and valued as complex option combinations. Figure 2.12 shows the payoff to an hypothetical convertible preferred stock, which can be modeled as an adding of up of the underlying firm value, a sold call with strike price K1, and 0.25 purchased calls with strike K2. Such a payoff diagram is typical in venture capital, and also typical of mezzanine debt instruments used in development. And, just as it has been shown that entrepreneurs and larger companies both have a tendency to undervalue such financial instruments,\(^\text{27}\) one must wonder if developers truly understand the value they give up when accepting mezzanine debt or issuing preferred equity returns.

**2.1.2. REAL OPTIONS**

Before moving on to option valuation, this section will describe the modeling of real-world decision making as options. The notion behind real options is really just

\(^{27}\) Gompers & Lerner (2001); The Economist (2003).
an extension of the shift in the last subsection from the analysis of financial derivatives to the modeling of conventional financial instruments as options. Rather than speaking of derivatives now, real options are typically considered "contingent claims" - that is, real options are claims on an underlying asset which will only be made contingent on certain events happening in the future.

2.1.2.1. THE REAL OPTION SOLUTION

Real options, like their financial cousins, derive value from three primary factors: uncertainty about the future, an asymmetric payoff, and decision-making ability.\textsuperscript{28} These are precisely the types of factors that come into play in some of the most important investment decisions - those that affect firm strategy, growth opportunities, product development, and the like. However, when these factors significantly affect a potential investment, the decision-maker's typical tool - conventional DCF analysis - cannot properly value the investment.

DCF rests on the concept of dividing all future expected cash flows by a discount rate which reflects both the riskiness of the cash flow and the point in time in which it will occur. By collapsing all possible future cash flows into a single "expected" cash flow, the DCF method assumes a passive investor who will simply buy and hold the asset, without any ability to change the cash flow outcomes. This collapsing of probabilities also prohibits DCF analysis from being able to deal with the asymmetric payoffs inherent to options. And while DCF analysis does deal with uncertainty, it does so implicitly, though the choice of a discount rate which is usually based on yields the market demands for taking certain types of risk, rather than directly based on the probabilistic returns of the project.

Option valuation theory, on the other hand, was explicitly designed for these highly uncertain situations with asymmetric payoffs. Rather than simply increasing the rate at which future cash flows are discounted as uncertainty increases, OVT uses a risk neutral discounting method combined with probabilistic expectations about the future. This is a critical distinction, especially when there is potential asymmetry in the investment payoffs.

Now, when no significant options are involved in an investment, the results are the same. Thus OVT is able to become a natural extension of DCF. The "real option analysis" valuation method for situations with options still uses DCF methodology to find the base value of the asset or project, assuming no flexibility to change over time. However, real option analysis then adds in the value of any options that substantially affect the investment. Of course, as an option can never be worth less

\textsuperscript{28} In the discussion of financial options, the payoff equations (which maximize one of two values) implicitly assume a decision is being made.
than zero, real option analysis will never value an investment less than would a conventional DCF analysis. But as options grow in importance relative to the base project, the revised calculation will grow relative to the original. Mathematically, real option analysis adheres to the following equation:

\[ \text{NPV}_{\text{ROA}} = \text{NPV}_{\text{conventional}} + \text{options} \quad (2.3) \]

Note that the NPV investment rule still holds, but that the value of any real options are now included as part of the NPV equation. Since applying conventional NPV analysis is a relatively straightforward process for any student of basic finance theory, the critical question becomes how to value a real world option.

**2.1.2.2. MAPPING DECISIONS TO OPTIONS**

In its simplest form, valuing a real option is merely a process of mapping real world situations to the variables that affect a financial option. As laid out earlier, the variables that play into an option’s value are its type, the value of the underlying asset, the strike price, the length of time in which the option is open, and the uncertainty surrounding the underlying asset. By mapping the real world situation to an appropriate financial option, it can be valued via standard OVT.

Most real world decisions can be mapped as a simple call or a put option, depending on the type of decision. Likewise, the decision can be made at any time (as with an American option) or only at precise moments (like a European option). The underlying asset is what one obtains through the decision to make their claim, and the strike price is the cost that must be incurred to obtain the underlying asset. Uncertainty is usually measured as the volatility of the asset prices. This assumes a normal or lognormal distribution, though through the simulation method of option pricing one can assume other distributions to model the uncertainty of an investment.

**2.1.2.3 CLASSIC REAL OPTIONS**

Various authors classify real options in various ways, and any taxonomy invariably leaves some holes and loose ends. However, there are a number of classic real options, the discussion of which should lead to a better understanding of the mapping process just laid out.

A *timing option*, which allows the investor to decide when to invest, can be modeled as a call option. For example, the decision to develop a piece of raw land is basically an American call option, where the underlying asset is the proposed building for the site, the strike price is the cost of constructing the building, and uncertainty can be measured as the volatility of the price of the underlying building.

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29 See, for example, Copeland & Antikarov (2001), Brealy & Myers (2000), or Hevert (2001).
Depending on the decision-maker’s claim on the land, the option could be perpetual (with a fee simple ownership, for example), or could have an expiration date (as in the case of a ground lease).

A growth option is also a call, with parameters very similar to the timing option. If, in the previous example, the site owner had built on only part of the site, he or she would still retain the ability to add capacity – a growth option.

An abandonment option is the option to disinvest in a project, either by selling it off to another investor, or by simply quitting the process of investment. An example would be a 5-yr lease which has an option to renew for another 5 years. This situation could be modeled as a 10-year lease with a European put that expires in 5 years.

A more complex real option is the switching option, which involves, for example, switching a factory between one of two modes of production and which can be modeled as a portfolio of calls and puts. Both of the cases and models used in this thesis involve switching options, and will be more deeply discussed in Chapter 6.

Another type of real option is called a compound option - an option on an option. Compound options come in two types: simultaneous or sequential. An example of a simultaneous compound option would be a financial option on a stock, when viewed at the level of the firm. Since, as we mentioned previously, equity is basically a call option on the value of the firm, a stock option is an option on an option – an option to claim equity, which is in turn an option on a firm’s value. Quite different is a sequential compound option, in which the exercise of an option gives the investor another option to be exercised at a later date. The second model in this thesis, which models the development process as a series of investments, is just such a compound option.

Finally, some authors discuss rainbow options. These are options which depend on more than one type of uncertainty. For example, both models in this thesis are dependent on two values which vary stochastically over time. The first model could therefore be called a “rainbow switching option,” and the second could be considered a “compound rainbow switching option.” While all these layers of complexity make the valuation more difficult, it is still essentially built up from basic option valuation procedures.

2.2. Option Valuation

First, some background: OVT is itself founded on Arbitrage Pricing Theory. Arbitrage is defined as “the process of earning riskless profits by taking advantage of
differential pricing for the same physical asset or security." Similarly, “almost arbitrage” opportunities involve differential pricing for very similar assets or portfolios. Arbitrage Pricing Theory assumes that as arbitrage (or almost arbitrage) opportunities emerge in the marketplace, investors will quickly take advantage of them and cause their elimination. Equilibrium in market prices is thus achieved as all arbitrage opportunities are removed. This is more than just academic theory, as hedge funds and other market participants routinely create hedge portfolios to take advantage of mispriced securities.  

Arbitrage Pricing Theory should be seen as the umbrella theory for OVT, because both rest on the assumption that arbitrage opportunities cannot exist in a well-functioning marketplace, and both establish prices through the creation of arbitrage portfolios. For financial options, the relevant portfolio for valuing options consists of the stock which is being optioned and riskfree bonds. By maintaining a constantly shifting portfolio of these two securities, an investor can mimic the payoffs associated with the option. And, since the stock and bond both have established and observable market prices, the value of the option can be determined. As it rests on OVT, real options analysis therefore also uses this “no-arbitrage” assumption. And though real estate markets do not have the same level of efficiency or (for the most part) securitization that exists in other public markets, one can use the NPV of the “inflexible” project in lieu of a marketable security. After all, the DCF methodology for determining value rests on similarly restrictive assumptions about market efficiency, and the act of establishing an asset’s value implicitly assumes that one is dealing with a marketable security. 

The following three sections discuss the three primary methods for valuing options: recombining lattices, stochastic calculus, and simulation. Since this thesis employs the lattice methodology, an short example valuation is walked through with it. The other two sections briefly discuss the same example and value that would be obtained using the other methodologies, just for the purposes of comparison and contrast. Note that all of these methods assume that asset prices follow a stochastic process, though they each model that process differently. Likewise, since OVT relies on the construction of “no arbitrage” hedge portfolios, the methods all employ the riskfree rate as part of the process for modeling option values. 

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31 A very recent example is laid out in The Economist (2003).
33 The riskfree rate is in fact the last variable affecting option prices, which we had ignored until now for ease of exposition.
2.2.1. LATTICES

The simplest method for valuing options is the recombining binomial tree (or lattice). It is intuitive, straightforward and clear, though it also has some definite limitations. Despite the simplicity of the approach, though, lattices do a remarkable job of valuing options that can be fitted within its assumptions.

2.2.1.1. THE MODEL

Lattices rely on modeling the price movements that an underlying asset could follow discretely, assuming that prices probabilistically jump between specific states at specific points in time. For an example with the underlying asset initially equal to 100, see Figure 2.13. The option payoff at any point in the lattice is given by equation 2.1 or 2.2, depending on whether the option is a call or a put. The terminal option values for a call with a strike of 90 are also shown in Figure 2.13.

![Figure 2.13 - An example two-step binomial lattice, or recombining tree.](image)

Note that the lattice is basically a tree-like structure with branches that recombine. This causes the distribution of possible prices at any given timestep to approximate that of a normal distribution—a bell curved shape where the middle values are far more likely to occur than extreme values. Even within Figure 2.12, which only goes out two steps, this effect can be observed: at the end state, two paths reach the middle node, while only one path reaches the two end nodes. If taken out just a few more steps, the end state would have even more of a bell-shape, with (always) only one possible path reaching the extreme nodes, and more and more possible paths reaching the interior nodes. This (log)normalized distribution of potential asset prices becomes an important, if implicit, assumption within the framework.

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34 Thus my preference for the more technically illuminating term lattice rather than the term tree, which is more conventional.
There are several methods of determining the exact prices the underlying asset can take, and the associated probabilities of the price moving to that state. The JR lattice, developed by Jarrow and Rudd, represents the mean of the possible asset prices drifting over time at the riskfree rate. On the other hand, the CRR lattice, which was presented in 1979 by Cox, Ross and Rubenstein and is probably the most common, represents the lattice's prices as centering on the initial value, and adjust for the riskfree drift by changing the probabilities of “up” versus “down” moves. A three-dimensional version of the CRR lattice is the method used in this thesis, and Figure 2.13 can be seen to conform to the CRR method of centering mean prices around the initial asset value. The final type of lattice, the so-called LR lattice, was developed by Leisen and Reimer in the 1990s, as a means of more quickly converging to the values that would be obtained using calculus.

2.2.1.2. Example: The Two-Step

An example should help to clarify how the lattice pricing method works, as well as more of its assumptions. Since it is beyond the scope of this paper to go into the detailed creation of hedge portfolios, and since the end results are probably more intuitively grasped, we will directly use the parameters set forth by the CRR lattice.

Assume an asset currently has a price of $100, and that there is an American call option with a strike price of $90, which expires in two years. Assume further that the asset is known to have a 20% annual volatility ($\sigma = 20\%$), and that the relevant riskfree rate is 4% ($r = 4\%$). Then, the equations

$$u = e^{\sigma} \quad \text{and} \quad d = e^{-\sigma}$$

represent the respective up and down movements (multipliers) that the asset can take from one year to the next, assuming each step in the tree represents a year. A quick calculation with our variable values and equations 2.4 & 2.5 will reveal that the price movements our asset can take are those represented in Figure 2.13.

Figure 2.13 also shows the option payoffs at expiration in year 2. All that remains to be done is to take the statistical expectation of these values back to the present. This is done by applying the equations

$$p = \left( e^{\sigma} - d \right) / (u - d) \quad \text{and} \quad q = 1 - p$$

(2.6, 2.7)

to get the respective probabilities of moving up or down in the tree. Note that both because of the use of the riskfree rate as well as the use of the natural log in calculation of the up and down movements, $p$ will be a little higher than 0.5 (and $q$ a little lower). This has the effect of probabilistically “drifting” the expected value of

35 For a fuller explanation of these methods, see Jackson & Staunton (2001).
36 “$e$” is the natural log. Its use here is to facilitate continuous compounding.
the option higher. In this case, $p=0.552$ and $q=0.448$. Thus, in year 1 (the second timestep), the higher of the possible values our option can take would be calculated as: $(0.552 \times 59.18) + (0.448 \times 10)$, or 37.12, and the lower value would be equal to $(0.552 \times 10) + (0.448 \times 0)$, which is 5.51. The same step can taken back to the present (year 0). All of these call values are shown in Figure 2.14.

![Figure 2.14 - Call option values (K=90) for the underlying asset in Figure 2.12.](image)

Thus, according to this model, the call today is worth $22.95, which is considerably more than the $10 difference between the strike price and the underlying asset value. This additional value, of course, comes from the asymmetric payoffs of the option at the terminal points in the tree — the “right without obligation” to exercise the option and receive the underlying asset.

**2.2.1.3. ADVANTAGES AND DISADVANTAGES**

Lattices have two main advantages relative to other valuation techniques. The most important is their ease of use. In addition to being relatively straightforward to implement, requiring very little advanced math, they are visually understandable and illustrate the underlying mechanics very well. Lattices can be easily created within a spreadsheet program, and provide the ability to literally see the valuation process occur over time and in different states of the world. Especially in the case of real options, the lattice allows a level of understanding about key decisions that might not be afforded with the other methods.

In a related manner, the second main advantage of the lattice methodology is its modularity and extendibility. They easily value American options, something which the other methods cannot so easily do. They can also be modified so as to value path

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37 Of course the “expected” difference in two years is some $18.33, due to the use of the riskfree rate in the hedge portfolio. But even still, the call options has considerably more value.
dependant and other exotic options, and to change the possible distribution of outcomes.

The primary disadvantages are closely related to these advantages. The first stems from the tree-like nature of the framework, and is the fact that lattices are not capable of valuing perpetual options: some termination is required in order to work backwards to an initial value. The other disadvantages come from the separation of continuous time into discrete steps. While this discretization is responsible for the advantages mentioned above, it also causes a number of problems. For starters, the approach is one of brute force: when the problem begins to involve more than one unknown, the number of dimensions in the lattice increases, causing the number of possible states to grow exponentially. With three dimensions (two assets), spreadsheet implementation becomes cumbersome; with four dimensions (three underlying assets), spreadsheet implementation is impossible and programming required; any more dimensions, and the computing time likely becomes so long as to make the method impractical.

The last potential problem associated with the discrete nature of the framework is that it is only capable of approximating "true" value. In some cases, this might not be a problem – the approximations can be remarkably close even with a coarse granularity – but in other cases, it may not suffice. This is where stochastic calculus steps in.

2.2.2. STOCHASTIC CALCULUS & BLACK-SCHOLES

Stochastic calculus, like all calculus, involves continuous time. In fact the most famous option formula, the Black-Scholes formula, is essentially the type of tree we just built, except with the time steps taken to the limit where of being infinitesimally small. Rather than modeling asset prices as jumping in fits and starts, as in the lattice framework, most stochastic calculus approaches assume that asset prices vary stochastically over time, following geometric Brownian motion. That is,

\[ \frac{\Delta S}{S} = \mu \Delta t + \sigma \epsilon \sqrt{\Delta t} \]  \hspace{1cm} (2.8)

Where \( \Delta S \) is the change in asset price of a very small interval of time, \( \Delta t \), and \( \epsilon \) is a random variable, normally distributed. The parameters \( \mu \) and \( \sigma \) are the expected rate of return on the stock and its volatility, respectively. This is the continuous version of the lattice framework employed in the last example.

Now it turns out that a simple European call option on a stock which follows the above randomized motion can be determined by the following formula,
\[ c = S e^{-qT} N(d_1) - K e^{-rT} N(d_2) \] (2.9)

named the Black-Scholes formula after its inventors. \( S \) and \( K \) are the current stock and strike prices, respectively. \( T \) is the amount of time until the option expires, and \( q \) and \( r \) are the stock’s (continuous) dividend rate and the riskfree rate, respectively. \( N(d_1) \) and \( N(d_2) \) are two normalized distribution functions which are too frightening-looking to include in this paper. Put simply, the Black-Scholes equation states that the value of a call is equal to the cumulative probable prices of the stock at expiration minus the probability that the option will be exercised.

Applying the same parameter values to the Black-Scholes equation as in the previous two-step lattice example, we get a value of $20.87. This means that the two-step valuation of $22.95 was off from the “true” value it was trying to approximate by almost 10%. This is a considerable error - although considering the lack of granularity in the example, the two-step did get remarkably close. In fact, if broken down into 9 steps over the two year period, the lattice would produce a value of $20.72 – less than 1% off, which is accurate enough for almost any real option.

The main advantages to stochastic calculus are its elegance and precision. It can be used to model processes, such as autocorrelation and mean reversion, that can’t be modeled with lattices, can value perpetual options, and can generate values which are very precise. Moreover, once the work is done to generate solution formulae, applying real world values to the variables is straightforward.

However, in the real world the precision which stochastic calculus can generate is almost never necessary, and the difficulties involved with learning this complex branch of mathematics prevents it from ever being useful to a wide range of people. Not only is the math difficult, but many, if not most, of the equations generated to value options via stochastic calculus do not have analytical solutions and must be solved through dynamic programming. This is a methodology best left to the academics.

### 2.2.3. SIMULATION & MONTE CARLO SAMPLING

When option valuation involves a large number of uncertainties, or asset prices move in ways not easily modeled mathematically, simulation can provide a good alternative valuation method. Simulation basically involves creating a model (a pro forma in a spreadsheet, for example) and then choosing relevant uncertainties to be random variables. By randomizing important inputs, the important outputs become randomized as well, although of course subject to whatever relationships have been set up between the inputs and the outputs. Performed over hundreds or thousands of trials, a value (or range of values at least) can be obtained for the option.
In the simplest form of option simulation, a Monte Carlo sampling of randomized underlying asset prices could be fed into equations 2.1 or 2.2, to generate option payoffs. Using the same parameters as for the examples above, I ran a number of simulations. With samples of 1000 trials each, running the simulation 3 times generated the following three values for the option: 21.81, 21.61, and 20.57. As can be seen, all three of these values are within 5% of the "true" Black-Scholes value of $20.87, although there is a lot of variation from one simulation to the next. This is inherent to the Monte Carlo method, and the results typically has fairly high standard deviations.

The primary advantages of simulation include the ability to model situations which are too complex to be modeled using the other methods. Options dependant on multiple sources of uncertainty, and options whose asset prices do not follow standardized stochastic movements (such as those with mean reversion or autocorrelation) are two examples where simulation might be the best valuation method. However, implementing the decision rules associated with American options can be difficult using simulation, and often simplifications to the forms of uncertainty or asset price motion do not significantly affect the outcome of the option analysis. Moreover, the simplification can in some cases improve the ability of the model to clarify important relationships between the option’s value and the underlying variables affecting it.

2.3. OPTIONS IN REAL ESTATE DEVELOPMENT

There are a number of existing applications of OVT to various aspects of real estate, from commercial mortgage analysis to land use planning. Three are especially relevant to this thesis: land valuation, development cycles, and mixed uses.

2.3.1. OPTION MODELS OF LAND VALUE

The first option models directly related to real estate concerned land value, and were developed from the observation that "the fact that investors choose to keep valuable land vacant or underutilized for prolonged periods of time suggests that the land is more valuable as a potential site for development in the future than it is as an actual site for constructing any particular building at the present time." Since land has value primarily because of the ability to develop on it, it includes an option which we referred to earlier as a "timing option," which is effectively an American call. The underlying asset is the "highest and best use" (HBU) building for the site, the strike price is the cost of constructing the building, and uncertainty is measured as the

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38 Titman (1985), p 505.
volatility of the price of the underlying building. The value of a vacant piece of land, then, can be modeled as the value of the HBU building which can be built on it (which would be the conventional DCF value), plus the value of this timing option.

However, four things distinguish this development option from the standard financial options discussed previously. First, the option is perpetual: thus optimal exercise of the option rests solely on the expected cash payouts of the project, and not on the need to exercise the option at some specific date. Second, exercising the option is not immediate as it would be with a financial option; rather, it takes “time to build.” Third, the underlying asset's value cannot be determined with the same accuracy as with a stock option. Since real estate is a thin market where all assets are unique and do not regularly trade, one can never have a precise value for the hypothetical building project. Finally, there is a gaming dimension to exercise of the option: developing a building adds to the supply, and therefore is capable of reducing asset value. Moreover, other development opportunities likely exist in the same market, which others could exercise as well, further affecting the value of the underlying asset.

Even though the above factors can conceivably radically affect the development option, an approximated option value of vacant land still can be determined by any of the methods described in section 2.2. One existing model is especially relevant for simple raw land valuation. Based on the Samuelson-McKean formula for warrant pricing it could be referred to as “the Black-Scholes of land development,” and it provides a useful approximation of the value for land which includes the option to develop.

There is also some empirical evidence which supports the option model of land values. A study in the early nineties of Seattle land transactions from 1977 – 79 contrasted actual transaction prices with the residual value of the land. The difference between the transaction price and the residual value is the option premium, the price paid by the buyer in order to obtain the development timing option. Consistent with the theory, all of these transactions included an option premium, with a mean premium of 6% above the residual value, and a range from 1-30%. The author also noted that these premia are probably on the low side, given the conditions in Seattle during the time for which data was available. However, the important finding of consistent premia suggests that the option model of land valuation better predicts prices than the older “residual value” theory.

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39 As explained in Geltner & Miller (2001), pp 757-759.
40 This model is described in Geltner & Miller (2001), pp 764-770.
41 Quigg (1993).
42 The residual value of the land is the difference between the value of the HBU development on a site and the sum of all costs necessary to produce the development.
2.3.2. Option Models of Development Cycles

Option models have also been used to explain real estate cycles of overbuilding. Traditional economic models have had to assume that developers are myopic in order to explain the chronic overbuilding that is the hallmark of most real estate cycles, and this myopia does not gibe well with the orthodox economics assumption about a rational “Homo economicus.” However, at least two option-based arguments can be put forward to explain why rational developers might overbuild.

The first argument is based on the gaming dimension inherent in the land development option, as mentioned previously. Simply stated, since exercise of the land development option increases the supply of space (driving down prices), an owner’s theoretically perpetual option can, for all intents and purposes, expire as others exercise their options. Thus, rather than waiting until development is truly optimal, “everyone is under pressure to develop as soon as their development option is in the money.” In short, the rush to build which is often responsible for the overbuilding characteristic of many real estate cycles is the result of rational behavior by the individual investors, when viewed through the dual lenses of option and game theory.

The second, and more involved, argument takes a different tack and creates interconnected option models - one for leasing and one for construction. These try to explain why both rent “stickiness” (i.e., hysteresis – the tendency to remain the same) and the recurrence of overbuilding cycles occurs differently among different types of markets, something for which previous explanations were unable to account.

The leasing model considers the option an owner has to lease (or not lease) units in his or her building. The model suggests that two variables significantly affect rent stickiness: demand volatility and the costs of incurring or filling a vacancy. As demand volatility increases, the option to wait for an increase in demand (and thus rents) increases in value, causing an owner to wait for an increase in rents rather than fill existing vacancies at too low a rent. Similarly, as the costs of filling or incurring vacancies increases, it is in the owner’s best interest to maintain the current level of occupancy within a building - and this tendency is increased as uncertainty about the future means that the adjustment costs are potentially recurring. Empirical evidence supports both of these conclusions. The relative stickiness of rents in office space, as

opposed to apartments, for example, meshes with the fact that office demand is much more volatile than apartments. Apartment demand is based primarily on easily predicted demographics changes in the market, whereas office demand, which is based on profit growth, is much more volatile than the economy as a whole. Likewise, the costs of filling office vacancies includes significant tenant improvement costs, whereas apartments can be filled with typically only minor repair of finishes – causing yet more stickiness in office rents versus apartments.

The construction model builds on the leasing model, and introduces a few more variables which explain overbuilding. Here, there are three factors which can increase the probability of overbuilding: longer construction time, and (as before) volatility demand and leasing costs. An increase in construction time increases the odds of overbuilding in part for the intuitively obvious notion that demand upon completion can change more with a longer time to build. But, deeper than that is the asymmetric payoff of building versus not building: since an owner can wait to lease even if demand is low when the building is complete, developers will err on the side of overbuilding. This same asymmetry holds as leasing costs are increased. Likewise, when demand volatility is high, the costs of excess capacity become lower – thus the incentive to err on the side of overbuilding. And again, this model is supported by observable market behavior: office markets are more prone to overbuilding than apartments, for example, not only because of the increase in volatility and leasing costs, but also because the construction time for offices tends to be greater than that for housing.

These arguments show the value that option modeling can potentially hold for economic theory. Phenomena that economists were previously unable to adequately explain, have been (in this case at least) clarified through the use of option valuation techniques.

2.3.3. OPTION MODELS OF MIXED USES

There are also two existing studies which examine the options involved when multiple uses are allowed on a site. Given the focus of this thesis, the results of both of these models are particularly relevant and worth mentioning.

The first study involves the option that is created when a site is zoned to allow for more than one use, and examines the additional value that is given to the land as a result of this option. Creating a model which values the irreversible choice to construct one of two buildings, the authors find that with a reasonable set of parameters, the option to choose between two uses can add as much as 40% to the land value. The land use choice adds the most value when the cost of land is low.

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relative to construction costs. However, even when land costs are very high - as much as construction cost, for example - the option can still add upwards of 7% to the land value.

The second study\textsuperscript{48} looks specifically at mixed-use buildings, and examines cases where there is an option to mix two uses on a site and redevelop at will. Using a set of reasonable assumptions - including the assumption that both uses are very close in value - the authors find that property values increase by 15% as redevelopment costs approach zero. In addition, their model suggests that a number of variables affect this option value in ways which should now be intuitively clear. As returns become less certain and uses less correlated, the option to redevelop increases in value. In addition, according to this model, the development of mixed use buildings will be more common in markets which are supply sensitive, either because of competitive constraints, or when the new project is large relative to the existing supply.

However, the most relevant finding for this thesis is the previously mentioned fact that property values increase as redevelopment costs become lower. Generalizing a bit, it seems that attempts to design buildings in such a way that they can cheaply and flexibly change should add to their value. A study of how buildings change over time, and how they can be made to change more easily over time, therefore seems in order. Coincidentally, just such a study is conducted in the next two chapters:

\textsuperscript{48} Childs et al (1996).
3. THE FOUR-DIMENSIONAL BUILDING

Despite the words and drawings of a few avant-garde architects, not many architects have actually dealt with what will happen to their designs after they are built (or, for that matter, even performed basic performance analysis on their buildings). Until recently, fewer still had attempted to design flexible buildings which might gracefully change over time, and the few examples of renowned "flexible buildings" are far better at illustrating the idea of flexibility than at the reality of actually conforming to users’ needs for change.⁴⁹

Nonetheless, there has been some research into the ways in which buildings change over time, and proposals for how to make buildings more “flexible” - that is, more readily and easily changed. This chapter will present the basic ideas of obsolescence and revitalization, life-cycle analysis, and some existing approaches and strategies which aim to make buildings more flexible.

3.1. THE LIVES OF A BUILDING

There are two complementary forms of change that occur during the life (or lives) of a building: obsolescence and revitalization. Obsolescence occurs largely through day-to-day building use and the passage of time, while revitalization consists of a concerted effort to counter the effects of obsolescence. Designing a building to be long-lasting requires a thorough appreciation of obsolescence, while designing a flexible building requires a knowledge of the types of revitalization which buildings typically undergo. And since revitalization is really a response to obsolescence, both must be understood in order to make a deeply flexible building.

3.1.1. OBSOLESCENCE

Building obsolescence occurs when a building becomes unable to meet the demands placed on it by its users. Social, regulatory, technological, and market forces, among others, can all cause obsolescence - and some of these forces occasionally move so quickly that aspects of a design can be obsolete before the building is even completed.⁵⁰ A number of authors have examined the forms and stages of obsolescence which buildings undergo, with taxonomies that are largely artificial and findings that are mostly obvious. However, there is enough subtlety to

⁴⁹ Renzo & Piano’s Pompidou Center comes immediately to mind. And of course Archigram’s proposals, wonderful as they are, have even less to do with the realities of flexible building.
⁵⁰ The Media Lab building on MIT’s campus is an apt example, as detailed in Brand (1994).
the concept of obsolescence that these taxonomies and findings are worth examining.

Obsolescence occurs in many forms, and different authors classify the forms of obsolescence which act on buildings differently. But first it is important to distinguish between obsolescence and deterioration. Deterioration is continuous, predictable, and largely controllable — it also tends to occur primarily at a physical level. Physical factors such as use, weathering, stress, and microbiology are all acting fairly continuously on a building and its components, and the deterioration they cause can be prevented, or at least forestalled, through regular maintenance. One can see the economic accounting for deterioration in the line items for operating maintenance and capital reserves on typical operating pro formas. Obsolescence, on the other hand, is not easily controlled and very difficult to forecast. In contrast to deterioration, it is not primarily physical but rather comes in several forms.

Obsolescence can be divided into three basic types: physical, economic, and functional. Physical obsolescence should be considered as distinct from deterioration in that it occurs when physical forces cause problems beyond normal repair. A simple example of the contrast would be the difference between a beam that has begun to deflect from the expected loads placed on it (obsolescence) versus a beam whose steel has rusted away (deterioration).

Economic obsolescence occurs when the nature of the building is no longer suited its site. Interestingly, economic obsolescence is in fact a function of appreciation, not depreciation — though the appreciation actually accrues to the site, and not the building. Over time the HBU of a site is likely to change, at least eventually, to the point where the existing building simply does not meet the market demands for that site any longer, no matter how well it has been physically maintained. Whether new market demands call for more density than that to which the site is currently built or whether the site’s optimal use has changed, it is a very flexible building indeed which can accommodate economic obsolescence.

Functional obsolescence occurs when the original designed use is no longer in demand, and can be broken down into four types: technological, social, legal, and aesthetic. Technological obsolescence occurs as a result of advances in science and engineering which make new building forms and services possible, rendering older buildings less useful. Especially in the realm of electrical and communication systems, technological obsolescence can be quite swift and is notoriously hard to predict. Social obsolescence occurs when the use or location is no longer needed.

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52 Following the breakdown of Geltner & Miller (2001), p 98.
53 Following the definitions of Ashworth (1999), pp 339-41.
The low-cost high-rise housing of the fifties is a good example of a building type whose social acceptability has declined, resulting in the demolition of many buildings which were otherwise in acceptable condition. Legal obsolescence occurs when regulatory or legislative requirements change and a building or some of its components no longer meet standards: one example of such legal changes is the American Disabilities Act passed in the 1990s, which now requires that buildings be more “accessible.” Lastly, aesthetic obsolescence is the intuitively obvious obsolescence that occurs as styles and tastes shift. This can be a very blatant form of obsolescence when buildings are designed according to an highly willful or avant-garde aesthetic standard.

3.1.2. REVITALIZATION

Given all of these forms of obsolescence, it is no surprise that constant repair, upgrading, and remodeling is normal for most buildings, and in fact such revitalization occurs much more frequently can is commonly recognized. As with obsolescence, reviewing some of the types of revitalization that can be made to a building will introduce some of the nuances of, and reasons for, the revitalization of buildings that are approaching obsolescence of one form or another.

Some recent empirical research into the changes that buildings undergo during revitalization has found three major types, and categorized them as changes of function, capacity, and flow. A function in this context is defined as the “set of activities or components to achieve a specific objective” and can be changed through upgrading (e.g., replacing windows), adding a function (e.g., adding air conditioning), or modification (e.g., adaptive reuse). Capacity is the “ability of the facility to meet certain performance requirements,” and both the load (e.g., structural or electrical) or volume (e.g., room or floor) of a capacity can undergo change. Lastly, flow is the “movements within and around a building relating to the surrounding environment and its usage population.” An example of changing environmental flow would be the replacement of fixed windows with operable, whereas an example of changing population flow would be the addition of a new staircase between two floors.

In addition, common parlance often classifies different forms of revitalization as one of four basic types: repair, renovation, remodeling, and reuse. Repair is chiefly

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58 Slaughter (2001), p 211.
59 My own taxonomy.
concerned with deterioration and physical obsolescence, and tends to occur little by little, on a relatively frequent basis. Renovation, on the other hand, occurs less frequently and is meant to make the building more accommodating to its current users - it responds to physical and functional obsolescence. It is also typically thought of as primarily upgrading and or modifying existing functions, perhaps adding load capacities, and is generally less extensive than remodeling. Remodeling involves many types of changes, and is often done in an attempt to attract new users of the same type - repositioning a tired mall with new facades, interior fountains, and the like is a typical form of remodeling. The most radical form of revitalization, however, is reuse (sometime called “adaptive reuse”), which implies remodeling for an entirely new type of user. This is a response to economic or social obsolescence, and typically involves every type of change mentioned in the previous paragraph. A familiar example of reuse is the warehouse loft conversions which have become one of the fundamental signs of gentrification – this is a response to economic obsolescence. A less familiar example would be the recent trend of converting smaller, older churches being to theaters, offices, or residential uses – a response to social obsolescence.

Reasons for revitalizing buildings are as varied as the different forms revitalization can take. However, in addition to revitalization being a response to changing user needs, revitalization has a number of advantages as a development strategy. First of all, simple revitalizations are frequently positive NPV transaction, and so plainly make economic sense. Repairs, renovations, and remodelings will often translate to immediately higher rents, thereby providing a net economic gain to the building. The reasoning is similar for adaptive reuse projects, at least when they are occurring to buildings that are readily capable of accommodating change.

However, even when the reuse switch seems questionable (as with the church to office switch) and the net value is not clearly positive, there can be reasons that adaptive reuse make strategic sense. Development time may be greatly shortened. In addition to lowering carrying costs, this also allows the project to get to market sooner – possibly a critical strategy, as demonstrated by the option models of real estate cycles. When sensitively done, reuse can also pose advantages for the permitting and the community approval processes. There are often tax benefits to reuse, especially when older, potentially historic buildings are being adapted. Similarly, legislative or community constraints may limit the amount of demolition that can occur, legally necessitating a remodeling or reuse project.

Just as revitalization can take a strategic role in the development process, it is also critical to real estate investment, especially with regards to long-term asset
management. However, understanding this aspect of real estate strategy requires some knowledge of life-cycle analysis in buildings.

3.2. LIFE-CYCLE ANALYSIS

A number of methods for analyzing buildings over time have emerged in the last few decades, and bear a close enough relationship to the work in this thesis to warrant description. The first two methods, scenario planning and life-cycle costing, are related to the real options side of this work. The last methodology, a “shearing layers” framework of classifying building systems, forms the basis for this thesis’s work in analyzing and measuring a building’s change capacity.

3.2.1. SCENARIO PLANNING

Scenario planning is an approach to forward-looking strategy which grew out of US military planning at the end of World War II, and blossomed in the 1960s and 1970s under futurist Herman Kahn and the work of Pierre Wack at Royal Dutch/Shell.60 Deliberately not a form of prediction, scenario planning is rather about “making choices today with an understanding of how they might turn out,” 61 and a scenario, in turn, is “a tool for ordering one’s perceptions about alternative future environments in which one’s decisions might play out.” 62 In the context of business management, where scenario planning has achieved its highest level of sophistication, the aim is to prepare managers and decision makers for any of the possible outcomes of their strategy, rather than honing their strategy to current expectations.

When applied to the design of buildings, scenario planning stands in sharp contrast to conventional architectural programming, and is meant to be used as a complement to it during the early design stages. Programming is one of the great creations of modern architectural theory, and is a very useful tool during schematic design, but it has a number of limitations. An architectural program sets out to establish the design problem facing the architect through a careful establishment of the owner’s current and future needs. The program, then, is an attempt to predict and control the future, and so subject to the following syllogism: “All buildings are predictions. All predictions are wrong.”63 While programming is a necessary part of

60 Schwartz (1990), p 7.
the design process, and valuable as far as it goes, it also has a tendency to create highly restrictive designs based on the myopic needs and concerns of first owners.

In contrast, scenario planning is meant to delve deeper into the future — not to determine a forecast, but to determine possible futures. While the essence of programming is convergence, the essence of scenario planning is divergence, as shown in Figure 3.1. Scenario planning is meant to be pursued in addition to programming, and should delve more deeply into the future: from 5 to perhaps as many as 20 years. The basic plan is as follows: building owners and designers identify the focal issue the proposed building is trying to solve as well as the driving forces shaping the future of the building’s users. This is typically an iterative process, and one which might include the identification and naming of basic plot lines or the development of a matrix which shows the interaction between major forces as a final form of representing several possible futures. Accommodating this set of possible futures then becomes part of the design problem, along with the conventional program. The end result should be a reasonably flexible building, one which is able to respond gracefully as the future unfolds.

**Figure 3.1 - Programming versus Scenario Planning**

Scenario planning bears a number of similarities with real option analysis, and the two might be viewed as qualitative and quantitative versions of the same thing. Both seek to complement an existing practice (programming and DCF analysis, respectively) which collapses all possible futures into a single “expected” future. Accordingly, both are fundamentally built on the notion of divergence, which is visually apparent when comparing Figure 3.1 with the lattice framework in Figure

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64 from Brand (1994), p 178.
2.13. Basically, real option analysis is an economic model meant to value a type of simple scenario planning based on DCF analysis. As such, real option analysis can also be used to complement an existing economic methodology of analyzing future building performance called life-cycle costing.

3.2.2. LIFE-CYCLE COSTING

Life-cycle costing (LCC) was first developed in the mid-1960s for military procurement, but has more recently been used by those involved in building production – and though there are a number of difficulties in its practical and widespread use, LCC is becoming a more common methodology in the building industry, especially with the rise of interest in sustainable design approaches.\(^{66}\) It essentially boils down to a DCF analysis of the building.

Life-cycle costing is meant to be used by those responsible for estimating building costs and, in contrast to conventional cost estimation, includes future operational and dispositional costs as part of the equation. Its primary use is therefore as a means of comparing design alternatives by considering more than simply initial construction cost. For example, will the reduced heating and cooling costs offset the added cost of better insulation? Unfortunately, a question such as this is very hard to answer, in part because of a lack of data and difficulty in forecasting. Of course, since those issues have never stopped developers from forecasting rents, there is little reason they shouldn’t be using LCC as part of their cost equation.

Life-cycle cost consists of three main components: initial cost, costs-in-use, and final disposition cost.\(^{67}\) Initial cost is obvious enough, while costs-in-use and disposition account for the operation and obsolescence of the building. Costs-in-use are recurring costs, and includes such items as maintenance, energy, cleaning, insurance, and redecoration – all of which can be affected by the initial design of the building. Disposition costs refer to the selling or abandonment of the building, and include market transaction costs as well as the cumulative effects of deterioration and obsolescence which haven’t been forestalled through costs-in-use.

Since life-cycle costing is a form of DCF analysis, there are two major components to its calculation: the cash flow outlays over time, which form the numerator, and the discount rate, which forms the denominator and brings future costs to their present equivalent. The choice of discount rate will depend on the type of cost being forecasted: maintenance and cleaning costs should probably be discounted at or slightly above the riskfree rate, as they tend to be predictable and

\(^{66}\) Cole & Sterner (2000).

\(^{67}\) Ashworth (1999), pp 331-334.
move almost lock-step with inflation. Expected redecorations and tenant improvements are examples of costs that should be discounted at the same rate that is being used to forecast rents and other cash flows directly related to the real estate market. On the other hand, energy and perhaps insurance costs might use yet another discount rate, one which could be determined by looking at the relevant markets’ expected yields.

As it is conventionally practiced, LCC suffers from the same problems that plague a DCF analysis of a non-passive investment. And real options analysis is capable of providing the same solution when it is appropriate — namely, when there are asymmetric payoffs and a high level of uncertainty and decision-making ability. This thesis in particular looks at the option of changing uses in a building, which could be added to a conventional LCC analysis, although other real options could also be examined (for example, fitting out office spaces with raised floors in order to decrease the costs of tenant churn). Used in conjunction with scenario planning, real option analysis could be used to determine the probabilistic costs of various possible scenarios.

3.2.3. SHEARING LAYERS

There is a long history of considering buildings as a set of interconnected, and often hierarchical, systems. There is also an intuitive logic behind this: the sequence in which a building is put together, along with the number of different specialists that exist for many of a building’s components, lends some observable credibility to the notion that a building is a set of systems and subsystems. However, the concept of categorizing building systems as “shearing layers” is especially relevant to the concept of the four-dimensional building. This framework of shearing layers classifies building systems by their rates of change. The fundamental insight is that different building systems obsolesce at different rates, and that these different parts of a building require different forms and levels of revitalization.

The shearing layer taxonomy used in this thesis is adapted from Stewart Brand’s classification, which was in turn adapted from the work of Frank Duffy.68 As shown in Figure 3.2, there are five layers in this categorization: site, structure, skin, services, and space plan. As we move from “site” to “space plan,” each system tends to change more frequently: while a site may not change for hundreds of years, some space plans change as often as every few months.

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Figure 3.2 - The “Shearing Layers” taxonomy of building components

3.2.3.1. SITE

Since, unlike the other building layers, site has no inherent forms of physical deterioration or obsolescence, it is in one sense eternal. However, viewed at a long enough time scale, and with economic obsolescence in mind, it is clear that site does change, and that the effective economic lifespan of a site can in some cases be as short as fifty years or so. Neighborhood succession theory accounts for this by noting the systemic behaviors of the city as a whole. After a site’s initial development, presumably at its highest and best use, changes to the surrounding city create forces which act on the site. If these forces become strong enough, they can change the HBU of the site to the point where the existing development is obsolete.

Succession theory holds two implications for the analysis of site, as laid out by Geltner and Miller: “first, land rents and land value will tend to remain constant, at least in real terms, over long periods of time... second, the possibility exists of occasional sharp, sudden changes in land rent and land value, due to changes in the optimal role and function of the neighborhood within the metropolitan area.” To the extent that these changes are predictable, they will be represented by the market value of the land. However, to the extent that radical site changes are sudden and unpredictable, it represents a potentially valuable real option: this is essentially the option that is modeled in the redevelopment model of Chapter 6.

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In addition to changes in the economics of the region and metropolitan area, the other key characteristic that affect site include local externalities, zoning and other legal restrictions on the site, and of course its physical size and shape. Externalities is an economic term which refers to nearby things which might affect the site but which are not an intrinsic part of it. Some positive externalities (at least for most uses) include proximity to transportation, natural features, or public places. A clearly negative externality (again, for most uses) is proximity to noxious industrial uses. Legal restrictions on a site range from the zoning controls which exists almost everywhere to rights of way, ground leases, and, less common, deed covenants – almost all of which are never permanent, though often very long-lived. In any case, most all of these characteristics cause site to change more slowly than a building’s next layer of change - structure.

3.2.3.2. STRUCTURE

A building’s structure not only holds the building up, but also gives it its basic size and shape, and thus does much to determine the uses that a building can accommodate. The structure layer consists of both the sub-structural system below ground and the super-structural systems (columns, beams, slabs, and bearing walls) above ground. Key characteristics include the structural materials, loading ability, clear spans (the distance between vertical supports), floor-to-floor (or floor-to-ceiling) heights, and floorplate size and depth.

Depending on the type of use for which it was originally built, a structure can be expected to have a useful life of 30 to 300 years – but this lifespan often has to do with functional obsolescence as it does physical deterioration. A building’s structure, like its site, is less likely to undergo physical obsolescence than other forms of obsolescence, because it is usually well protected from the root causes of deterioration and obsolescence. On the other hand, structure can easily become functionally obsolete as standards and technologies change.

3.2.3.3. SKIN

The skin layer refers to a building’s exterior closure, and contains components such as the roof, exterior walls, cladding, and openings (such as doors, windows, and atriums). A building’s skin essentially acts as a filter: it serves the dual roles of keeping out water and inclement weather while still creating connections with the outside world for the flow of people, energy, and goods. Another chief characteristic of the skin layer is aesthetic, both in terms of the image that the building’s facade presents, as well as its ability to provide the right types and amounts of light, ventilation, and views.
The skin layer is highly subject to physical deterioration and obsolescence, precisely because of the function it serves to the building as whole. In addition, the aesthetic function that a building skin serves means that it is also subject to aesthetic obsolescence as tastes and dominant styles change. All in all, major changes to a building skin can be expected every 20 - 40 years, though wholesale replacement rarely happens.

3.2.3.4. SERVICES

The services layer of a building consists of heating and cooling systems, plumbing, electrical and communication systems, vertical transportation, security and fire safety systems, and so on. The half life of most components in the services layer is less than a decade, primarily due to functional obsolescence, although the skeleton of some systems can last upwards of a hundred years. In addition, certain components of service systems (especially mechanical equipment) can physically deteriorate fairly rapidly without proper maintenance.

3.2.3.5. SPACE PLAN

The space plan layer in this taxonomy is basically the interior equivalent of the skin layer. The space plan consists of floors, walls, ceilings, openings, and interior finishes. Space plans obsolesce almost entirely due to social and aesthetic expectations, although many interior finishes (floor finishes, for example) are subject to physical deterioration as well. The expected rate of change for space plans varies widely depending on the type of user: a retail user is likely to create major space plan changes every 3 years or so, while a residential building might go over 30 years without any significant changes.

3.2.3.6. SYSTEM INTERACTIONS

The interaction between these five shearing layers is also critically important, and part of the reason for the classifying building systems in this way is to recognize the important fact that “because of the differing rates of change of its components, a building is always tearing itself apart.” Slaughter identifies three types of system interaction: physical, functional, and spatial. Physical interaction is straightforward and simply occurs through connection, intersection, or adjacency. Functional interaction occurs when building components on different layers work together to achieve a goal - for example, when a wall panel provides shear capacity to a structural frame. Spatial interaction occurs when two systems act independently, but occupy the same space - for example, when a vertical riser contains conduits for HVAC, electrical, and plumbing.

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72 Slaughter (2001).
Empirical research into revitalization projects has shown that there is a certain "cascading" effect in building changes - meaning that changes to a slow-moving building system often necessitates changes to all or most of the more quickly changing layers. Likewise, as might be expected, reuse projects are the most likely to require change to the structural system (and thus to all of the other systems as well), and changes to the service and space plan layers are almost always coupled, in part because the systems interact extensively. Such findings suggest that one approach for making buildings more easily changeable would be to find ways of decoupling building systems from one another, especially those that tend to change at different rates.

3.3. BUILDING FLEXIBILITY

For the purposes of this thesis, a building will be considered flexible to the extent that it can be easily changed. There are therefore gradients of flexibility, and different types of flexibility: an office that can readily change workstation layouts as projects change is a very different type of flexibility than a building which has been designed to allow a floor of offices to be easily switched to a floor of hotel rooms. Nevertheless, ease of changeability, or alternatively "capacity for change," is a reasonable and intuitive measure of flexibility, and one which can also be readily translated into economic terms.

Current literature on the design flexible buildings tends to concentrate on one of three general approaches for accommodating change: the prefabrication of major system components, designing to exceed expected load capacity, and the physical separation of systems (sometimes referred to as "slippage"). In addition, a recent survey by Michael Keymer into actual revitalizations conducted over the past few years has empirically determined over 30 strategies which have been applied to specific systems to increase flexibility. Several of these strategies often occur in tandem, suggesting even more general approaches to designing a flexible building than the three that are commonly considered.

3.3.1. DESIGN APPROACHES

A design approach can be defined as a "goal or set of goals to enable a facility to accommodate future changes" An approach therefore consists of many specific

73 Maary (1999), p 82.
74 Maury (1999), p 86.
75 Keymer (2000), p 34.
76 Keymer (2000).
77 Keymer (2000), p 34.
strategies applied to specific building systems in pursuit of a common goal. Based on his survey, Keymer identified 13 distinct approaches, all of which are briefly discussed below.  

3.3.1.1. PREFABRICATION

Behind the idea for prefabricating major systems components is the expectation that prefabricated components will have less interactions among each other, making their replacement simpler. However, procurement of such systems is likely to create concerns, and specific strategies within this approach tend to create higher cost increases than others within the sample, averaging around 3%. Some important strategies within this approach include raised flooring, partition systems, and panel cladding.

3.3.1.2. OVERCAPACITY

An obvious, though often overlooked, approach is simply designing systems to accept loads over and above what is immediately needed. Creating additional capacity during the initial building construction is much easier and less costly than trying to make the changes later. Other advantages to this approach is that most strategies require little additional labor or skill, and use conventional construction techniques - resulting in the fact that most strategies here add less than 1% to the total cost of the building. Some strategies within this approach include column over capacity, oversized vertical distribution, extra conduit, floor VAV units, and exterior knockout panels. This approach seems to be of such high potential value, that Keymer suggests that “owners would do well to specify that their building systems incorporate some additional capacity beyond what is immediately needed.”

3.3.1.3. BUILDING SYSTEM SEPARATION

The separation of major building systems is an approach rooted in the idea of shearing layers - knowing that different systems will require different amounts of change, this approach seeks to separate them as much as possible. Closely related to the prefabrication approach, with many of the same specific strategies, this approach also has procurement concerns and relatively high costs - on the order of 4% of the total for the average strategy. Strategies in this approach tend to focus on the separation of services and finishes, and include raceways, cable trays, raised flooring, and office pods, among others.

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78 Unless noted otherwise, all data and most analysis in section 3.3.1 is from Keymer (2000).
3.3.1.4. Inter-System Interaction Reduction

This approach involves using “specific components to reduce interdependency with other systems.” An example would be modular cladding panel which can be easily removed from the structure. Other strategies include raised flooring, partition systems, and raceways. The strategies here tend to be fairly high cost (3% of total construction), but also tend to increase accessibility for operations and maintenance, which could still make them worthwhile for certain applications.

3.3.1.5. Intra-System Interaction Reduction

Given that one of critical areas in which change occurs is within a system, this approach aims to reduce interactions within a single system. Strategies here tend to concentrate on simplifying connections, and raise cost by 1% on average. Some empirical examples of specific strategies include modular wiring, task lighting, partition systems, and floor rack systems.

3.3.1.6. Interchangeable System Components

Interchangeable system components are modular components that combine several components or systems - for example a raised flooring system data boxes in certain panels. This approach is especially appropriate for buildings or systems that undergo regular changing or maintenance, though implementation of the strategies can cause procurement concerns and raise costs by 3% on average. Some examples of this approach include raised flooring, office pods, partition systems, and modular wiring.

3.3.1.7. Layout Predictability

Increasing layout predictability is meant to reduce the demolition necessary to find components. There is usually no cost increase to this approach, and savings will only accrue during renovations, not during regular maintenance and changes. Some strategies for increasing layout predictability include distributing services at columns, knockout panels, core configurations, and exposed ceilings.

3.3.1.8. Physical Access

Improving physical access to building systems can often have a direct payback and shorten downtimes, with potentially high cost savings during changes. Strategies here often involve special components, with average cost increases of around 1%. Some specific strategies include demountable drywall panels, false slabs, raceways, oversized vertical distribution shafts, fixed panel partitions, poke-through floors, and raised flooring.

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3.3.1.9. **SYSTEM ZONE DEDICATION**

Dedicating specific areas or volumes for systems has a high average cost savings during the first set of changes to the building, and the initial cost increase tends to be very small, near zero. Some strategies within this approach are the false slab, electrical baseboard, modular wiring, and cable trays.

3.3.1.10. **SYSTEM ACCESS PROXIMITY**

The approach of enhancing proximity access to systems is meant to reduce the need for extensive renovations when spaces or usage flows change. Strategies here tend to cost very little and provide significant savings upon the first set of major changes. An example of a strategy to increase system access proximity would be the inclusion of plumbing risers at every column.

3.3.1.11. **FLOW IMPROVEMENT**

An example of the approach to improving flow within the building is the choice of placing cores at the ends of buildings in order to open the center of the floor plan. While there aren’t any cost increases or procurement concerns to speak of within this approach, there is obviously an irrevocable commitment to the strategy.

3.3.1.12. **SYSTEM INSTALLATION PHASING**

This approach involves waiting to install systems or portions of systems until after initial construction. All of the strategies Keymer found within this approach involve the structural system and incorporate components designed to accommodate growth or change. Strategies such as floor rack systems, structural ladder assembly, and column overcapacity increase costs very little and can allow for usage class changes that would otherwise not be possible.

3.3.1.13. **DEMOLITION SIMPLIFICATION**

The approach of simplifying demolition had the largest number of strategies of all the approaches identified. Strategies often incorporate components designed for easy removal, and, like the previous approach, this approach consists of strategies which, for the most part, costs very little and allow for usage class changes that would otherwise not be possible. One example of a strategy within this approach is false slab - a concrete slab on sand fill (within which utilities are run) above the real structural slab.
4. CHANGE CAPACITY

This chapter creates a framework for assessing a building’s “change capacity” – that is, ability to accommodate change. Since flexibility can mean different things and change capacity measurements can have different requirements, the framework presented here is specific to the design and development of buildings with a high capacity for changing uses. However, this framework is general enough to be applied to other forms flexibility; and, since use changes are the most radical type of change a building could undergo, the findings here will be applicable to other analyses of change capacity as well.

The basic idea is to determine correspondences between the needs of potential users with the design of each of a building’s primary systems, or shearing layers. Broadly speaking, higher levels of correspondence will mean greater flexibility, and a higher change capacity. This chapter is broken into two sections. The first describes the standard building needs of major types of users. The second develops a matrix for comparing these needs and determines which general design approaches are best suited to allowing a building to accommodate the needs of multiple users.

4.1. USE NEEDS

For the purposes of this study, building users have been divided into six basic types, following the conventional breakdown of real estate markets into offices, retail, residential, industrial, and hotel, and the emerging R&D/lab space. This section contains descriptions of the basic requirements and forms for the first four of these uses, according to the shearing layer taxonomy introduced in the last chapter. The concentration here is primarily on the four uses which are most likely to occur in an urban mid- to high-rise building: offices, retail, residential, and hotel. While neither industrial nor R&D lab space is included in this survey, the breakdown and analysis that follows would be just as applicable to these uses.

4.1.1. OFFICE

4.1.1.1. SITE

The driving factors for office location are best represented by the monocentric and agglomeration economic models\(^\text{81}\) – both of which suggest that offices will tend to move to existing central business districts (CBDs) or cluster around each other and form subcenters outside the CBD. A recent study\(^\text{82}\) by the Chicago Department of Planning also found that offices are attracted to sites with proximity to mass

\(^{81}\) DiPasquale & Wheaton (1996)
\(^{82}\) City of Chicago (2003), p 19.
transit, clients, and technology infrastructure. While suburban markets will likely be
dominant areas for office development in the next few decades, downtown markets
are expected to continue the rebound that began in the 90s, and CBDs continue to
be preferred the locations for major service firms and governments.\textsuperscript{83} Externalities
which positively affect an office site include retail services, housing, and mixed-use
environments,\textsuperscript{84} while one of the most important on-site amenities is parking
availability.\textsuperscript{85}

Generally speaking, lot size and shape is not critical for offices, so long as it can
support the required floorplate sizes (at least 18,000 sf) within a reasonable shape.
Finally, the zoning and public issues most likely to affect office sites include FAR
(floor-to-area ratio) restrictions, height limits, and traffic impacts. And while there
are rules of thumb for parking that suggest 3-4 spaces are required for each 1000 sf
of floor space,\textsuperscript{86} these are not really useful, and parking requirements should be
derived from a calculation of actual occupancy and drive rates,\textsuperscript{87} which will be quite
different in a CBD than in a suburban office park.

4.1.1.2. \textbf{STRUCTURE}

The optimal size and shape of an office structure balances cost, zoning, rents,
and efficiency of the space plan — flexibility in the floor space is becoming
increasingly important.\textsuperscript{88} Generally speaking, 18,000 sf is about as small as a
floorplate can become before core requirements cause it to lose efficiency, while
floorplates over 40,000 begin to add to cost because egress requirements will likely
force the addition of more vertical transport.\textsuperscript{89} In order to allow the greatest range of
office layouts, uniformity is important in building depths, and 25-40 feet from
building edge to the core is typical (with the lower end being more typical in Europe,
and the higher end more typical in the United States).\textsuperscript{90} Partly because of this
difference in typical depths, floor to floor heights are typically about 12'-6" in
Europe, but 13'-0" to 14'-0" in America - however, both are meant to accommodate
9'-0" high dropped ceilings.\textsuperscript{91}

\textsuperscript{83} Gause (1998), p 7, 328-9.
\textsuperscript{84} Kohn & Katz (2002), p 49.
\textsuperscript{85} City of Chicago (2003), p 19.
\textsuperscript{86} Kohn & Katx (2002), p 41.
\textsuperscript{87} Gause (1998), p 133.
\textsuperscript{88} Gause (1998), p 8.
\textsuperscript{89} Gause (1998), p 144.
\textsuperscript{90} Kohn & Katz (2002), p 45.
\textsuperscript{91} Kohn & Katz (2002), p xx.
Building codes require the structure to accept 50 psf floor loads (100 psf in lobbies and corridors), and structures are often strengthened near the core for storage and equipment. In addition, when offices become very tall, wind and shear loads become critical. To accommodate both of these loading conditions, structural bays of 25 to 30 feet square have been traditionally used, although the trend is towards larger bays of 30' x 40' or even 30' x 45'.

4.1.1.3. SKIN

The image presented by an office's skin is generally thought to be of fairly high importance, as it can positively or negatively affect rents. While styles have changed over the years, projecting an image of wealth, and perhaps solidity, is generally an advantage. In addition, the skin can affect the interior aesthetics and comfort levels through its means of controlling light, vent, and view. Natural light is considerably important, particularly because of the typical office's depths and the potential savings in energy and productivity. View is typically of moderate importance in the building as a whole, but having a good view in at least a few sections of the building can help sell higher rents to the executives that choose office locations. Ventilation is typically handled primarily through mechanical means, and only recently have operable windows begun to make a comeback. However, in open office layouts, operable windows can cause problems for HVAC balancing systems and should be avoided.

4.1.1.4. SERVICES

Most of an office building's services are supplied vertically through the core, along with vertical transportation. There are two types of cores: distributed, which is better for multiple tenant building, and compact, which is better suited buildings where tenants occupy at least an entire floor. Cores can be located in the center or on the side of a building, both of which carry certain advantages and disadvantages. Generally speaking, a core should take up at most 15% of the floor area, while a core which is 10% of the floor area would be considered very efficient.

The HVAC system is one of the most critical systems in an office building – HVAC typically accounts for 15% of the construction cost, and 90% of the tenant complaints. Building codes require at least 15 cubic feet of fresh air per minute per
occupant, which is always provided in modern buildings by means of a forced air heating and cooling system. There are four main types of HVAC systems that can be used in an office building. Central plants, typically used in high-rises over 500,000 sf, are initially more expensive and have mechanical systems on each floor, but very efficient, especially for standard patterns of office use. Rooftop package units are typically found in buildings of five stories or less, with large vertical duct shafts rather than mechanical rooms on each floor. Heat Pumps are less expensive to install than either of the above two, and good for buildings under 7 stories - they are highly energy efficient, and the higher initial equipment costs can be offset by energy rebates. Individual floor units, which are typically most appropriate for 4-30 story buildings, allow for a reduction in the size of air shafts and are economical when there is a lot of off-hour cooling requirements.

Electrical requirements for offices typically hover around 10-13 watts per square foot, with almost half of that coming from HVAC, a quarter from lighting, and the rest for devices, elevators, and other uses. These requirements have increased so much recently that many buildings built during the 80s do not have the requirements needed by high-tech office space. Telecommunication requirements have also been changing rapidly, and most office users now simply want a system that will be easy to change when the “next big thing” arrives.

Plumbing requirements have traditionally been served by stacking bathrooms in the core, though office tenants often want extra plumbing and remote wet stacks can add to the usefulness of space for some tenants. In addition, sprinkler systems are almost always required in an office building of any size.

Vertical transportation requirements for an office tend to be higher than for many other uses, in part because of the peak loads that occur in the morning and early evening as people arrive and leave their offices. Elevators will therefore typically be gearless or hydraulically powered, though geared might work in some circumstances, and the system should be designed so that it can move 30% of the user population in 5 minutes, with wait times not to exceed 30 seconds.

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101 BOCA (1999).
104 Gause (1998), p 159-60.
4.1.1.5. SPACE PLAN

Churn rates in office space plans tend to be fairly short, due to organizational changes, offices moving as leases run out, and constantly shifting workplace trends. Likewise, since offices tend to fit out their own spaces, owners of office buildings do not have any great demands directly regarding space plans. The most important rules regarding office space plans revolve around typical planning modules, which are 5 feet for furniture and 2 feet for ceiling grids.\(^{111}\)

4.1.2. RETAIL

4.1.2.1. SITE

The driving force determining the appropriateness of a site for retail uses is visibility and accessibility.\(^{112}\) The demographics within a retail user’s market radius is also critical, though the relevant market radius changes by retailer. Downtown locations can provide an advantage to retail because of their established market bases, though proximity to public transport becomes critical.\(^{113}\) Positive externalities for a retail site include just about any other attraction, including cultural centers, parks, and (in most cases) other retail.

Regularity of lots is important, in order to efficiently lay out stores. In suburban locations, only 20-25% lot coverage is typically achieved because of the extensive need for parking (about 4-5 spaces per 1000 sf).\(^{114}\) Even in urban locations, the need for parking suggests that on-site or nearby structured parking can be critical to retail success. The most critical public issues facing potential retail development is traffic analysis and integration with the surrounding neighborhood, which is becoming increasingly important.\(^{115}\)

4.1.2.2. STRUCTURE

The overall floorplate of a retail center depends on the type of center (i.e., mall, strip, etc.). Likewise, tenant areas vary wildly, from 100,000 or more square feet for discounters, to 35-50,000 sf for white goods stores, to 9-15,000 square feet for typical drugstores, and even smaller for boutique and local retail.\(^{116}\) An ability to provide varying depths is therefore an asset. 120 feet is the maximum desirable depth

\(^{111}\) Kohn & Katz (2002), p 35. 
\(^{112}\) Beyard & O’Mara (1999), p 59. 
\(^{113}\) Beyard & O’Mara (1999), p 62, 144. 
\(^{114}\) Beyard & O’Mara (1999), p 63. 
\(^{115}\) Beyard & O’Mara (1999), p 96. 
\(^{116}\) Beyard & O’Mara (1999), p 135.
for any large store in a mall for example, while smaller stores will typically want 60-100 foot depths, and some stores may successfully be as shallow 15-30 feet.\textsuperscript{117}

Structural clear spans should be as large as is efficiently possible, and should not be governed by initial tenant locations: due to the high turnover rate in retail tenants, partitions between them should be non-loadbearing – with fire wall spacing governed by local codes.\textsuperscript{118} Many stores have 11 ft finished ceilings, though 9 ft and 13 ft are common as well, and the trend is towards lower ceilings as it reduces both initial and operating (especially heating) costs.\textsuperscript{119} Load requirements for retail is higher than for other uses, typically around 75 psf on upper floors and 100 psf on the first floor by code.\textsuperscript{120}

\textbf{4.1.2.3. SKIN}

Retail is dominated more than anything else by trends and fashion, which dictates frequent updating. Therefore durability is less important in a retail exterior than for other uses, especially with accessories such as awnings and signage.\textsuperscript{121} Likewise, windows provide the opposite function for retail than for other uses – providing a view into the interior space rather than a view out. Similarly, natural light and ventilation are not critical for retail. While trends and fashion will dictate retail image, regional based themes are common, and signage and entry are always critical concerns.\textsuperscript{122}

\textbf{4.1.2.4. SERVICES}

Mechanical, electrical, and plumbing services are typically provided on a tenant by tenant basis, with no centralized provision as is common with other use types. Code requirements for HVAC are the same 15 cubic feet of fresh air per minute per occupant as for offices (but with higher expected occupancy per square foot), while most retail (food service excluded) have minimal plumbing needs relative to their size. Electrical requirements are around 11 w /sf excluding vertical transportation, with half of that going toward HVAC, and 2.5 towards lighting.\textsuperscript{123} In multilevel retail, vertical transportation should be located to achieve maximum visibility of as many tenants as possible.

\textsuperscript{117} Beyard & O’Mara (1999), p 71, 96, 135.
\textsuperscript{118} Beyard & O’Mara (1999), p 128.
\textsuperscript{119} Beyard & O’Mara (1999), p 136.
\textsuperscript{120} BOCA (1999).
\textsuperscript{121} Beyard & O’Mara (1999), p 121.
\textsuperscript{122} Beyard & O’Mara (1999), p 122, 123.
\textsuperscript{123} R.S. Means (2002), p 483.
4.1.2.5. Space Plan

Since retailing is so centered on trends, constant space plan updating is the norm. Similarly, leases for retail users tend to be around 3-5 years, often with renewal options. Common spaces in malls are updated less often, but store spaces will be updated very frequently. There are no standard planning modules for retail, though widths should never be more than 40 feet.\(^{124}\)

4.1.3. Residential

4.1.3.1. Site

The driving force behind gross housing decisions is well represented by the economic monocentric model of the city: proximity to employment.\(^{125}\) Not just distance, though, determines proximity to employment, but also ease of access, congestion, and established commuting patterns. In addition, political subdivisions play an important role in peoples’ choices of where to live – tax rates and civic services are important, and, for many segments of the market, the city or town’s school system can override all other concerns.

Positive externalities for residential uses include cultural services, walkable retail and entertainment, and parks and recreation.\(^{126}\) Negative externalities such as industrial uses and noise generators, however, can affect residential sites far more than other uses. On site amenities are also very important for residential uses, and can include business centers, health clubs, pools, and landscaping.\(^{127}\) Probably the most important amenity for residential users is view.\(^{128}\) Rules of thumb for parking requirements range between 1 and 1.75 cars per unit, and (if the FAR and height limitations allow it), extra garage capacity often costs very little and can provide added rent in urban locations.\(^{129}\) And while other types of users such as office or retail may be willing to accept nearby (but not on site) parking, a lack of on site parking is a major drawback for most segments of the residential market, even in urban locations.

Residential uses are probably one of the most forgiving in terms of lot size and shape, although in order to support onsite staff, a lot will need to be capable of accommodating at least 150 units.\(^{130}\) Along with zoning FAR and height restrictions, other public issues affecting the site tend to include utilities, traffic, and the tax

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\(^{125}\) DiPasquale & Wheaton (1996).
\(^{126}\) Schmitz (2001), p 37, 44.
\(^{127}\) Schmitz (2001), p 22.
\(^{128}\) Linnane, interview.
\(^{130}\) Schmitz (2001), 47.
revenue which will be generated relative to the expected amount of services required by the users.

4.1.3.2. STRUCTURE

While there are few area requirements for a residential floorplate, depth is critical because of the need for natural light and ventilation. A unit should almost never have any part of it more than 30 feet from an exterior window, meaning that, in most cases, total building depth should not exceed much more than 60 feet. Ceiling heights, while once acceptable at 8 feet, are moving towards a norm of 9 feet, especially at the high end of the market\textsuperscript{131} - this translates to a minimum floor-to-floor height of between 10 and 11 feet. Floors must be capable of holding 40 psf by code, with requirements of 100 psf capability in corridors and other semi-public spaces.\textsuperscript{132} Clear spans between columns would ideally conform with unit sizes, but residential uses are more forgiving in this regard than, say, office or retail uses.

4.1.3.3. SKIN

Unlike commercial uses, the skin layer of a residential building is expected to supply ventilation, at least to living spaces and bedrooms. Code requirements and user expectations almost guarantee that windows will be operable. Likewise, view to the outside world (and preferably to some natural or cultural amenity) is especially prized by residential users and large amounts of natural light can be used to make small spaces appear bigger.\textsuperscript{133} Large windows and balconies are therefore desirable components in a residential facade, which should also provide an image of solidity.\textsuperscript{134}

4.1.3.4. SERVICES

Because of the multiplicity of units, services in residential buildings typically run in multiple vertical chases. For most floorplate layouts, a single centralized core for vertical transportation will suffice. Typical high-rises with around 150 units will have 3 to 4 elevators, including a part time freight, while a 800 unit building might have 6 or 7, although the relationship between number of units and number of elevators is not strictly linear.\textsuperscript{135}

Individually controlled and metered HVAC is the norm, and the typical approach is to locate all mechanical equipment for a floor together.\textsuperscript{136} When natural light and ventilation cannot be provided to a space, codes require fresh air circulation of 15

\textsuperscript{131} Schmitz (2001), p 111.
\textsuperscript{132} BOCA (1999).
\textsuperscript{133} Schmitz (2001), p 113.
\textsuperscript{134} Linnane, interview.
\textsuperscript{135} Linnane, interview.
\textsuperscript{136} Schmitz (2001), p 114.
cubic feet per minute per occupant, with slightly higher requirements in kitchens and baths.\textsuperscript{137} Electrical requirements for residential uses can be estimated at around 10 watts per square foot, with HVAC comprising 3, and lighting 2 - the rest goes to devices and elevators.\textsuperscript{138} Plumbing requirements mostly go towards baths, kitchens, and laundry. The trend is towards more baths and laundry facilities than has traditionally been the case, with two bedroom units typically having two baths, and most units having separate laundry facilities, especially nearer the high end of the market.

\textbf{4.1.3.5. SPACE PLAN}

Also unlike all of the commercial uses previously discussed, the residential use is the only one likely to have space plans commonly built out by the building developer. The planning module is therefore not as rigid as with some uses, and the only real module might be said to be the unit. In urban locations, studios, 1- and 2-bedroom units are most typical, while unit sizes tend to get bigger as the site becomes further away from central locations.\textsuperscript{139} In apartment buildings, the one-year lease demands that durable materials be used for finishes that receive a lot of wear. And especially in mid- to high-rise buildings with smaller units, the chief objective of the space plan is to make the unit and spaces look bigger - typical strategies for achieving this include open plans, high ceilings, natural light, location of storage space towards the building interior, and providing ample storage.\textsuperscript{140}

\textbf{4.1.4. HOTEL}

An interesting aspect of research into use needs is the extent to which some uses overlap regarding their building needs: the difference between a hotel and residential use, for example, is primarily one of management. The following subsections on shearing layers for a hotel, therefore, only describe differences between a hotel's needs versus residential; otherwise, the notes regarding residential uses can be expected to hold for hotels as well.

\textbf{4.1.4.1. SITE}

The primary difference in site requirements is that hotels will tend to need even closer proximity than residential to offices, tourist attractions, and the like. Vibrant, walkable entertainment and retail districts are more positive an externality, and some degree of noise is less of a negative. All else equal, parking requirements will tend to be higher per square foot than in residential buildings, though in urban locations the

\textsuperscript{137} BOCA (1999).
\textsuperscript{139} Schmitz (2001), p 112.
\textsuperscript{140} Schmitz (2001), p 113-4.
need for parking will be lessened and may be met off site. On-site amenities will be even more of a draw for hotel users than residential. Meeting or convention facilities can be important, and grand lobbies and retail on the first floor are the norm.

4.1.4.2. STRUCTURE

Since unit sizes tend to be smaller, it is difficult to design efficient units with as deep a building as might be achievable with residential, although a 60 foot total depth (assuming a double-loaded corridor) is still quite workable.

4.1.4.3. SKIN

Natural ventilation is not as strong a requirement in hotel uses as it is with residential, and mechanical ventilation is an acceptable and common means of getting fresh air into units. Similarly, a higher range of images can be successfully conveyed with hotel facades, depending on the site and target market.

4.1.4.4. SERVICES

Unless natural ventilation is provided (and in some cases even if it is), HVAC requirements will be higher than for residential - with 15 cu.ft/min/occ of fresh air being required throughout all spaces. Plumbing requirements will tend to be slightly less for hotel uses, due to the smaller number of kitchens and laundry facilities. On the other hand, electrical requirements for hotels tends to be higher: around 11 watts per square foot, with the main differences being that HVAC requirements go up to 5 w/sf, while wattage for devices is reduced by only 1 w/sf.141 Elevator requirements are much the same in hotels as they are in residential buildings, though in some cases additional capacity will be warranted.

4.1.4.5. SPACE PLAN

Unit sizes for hotel rooms will tend to be quite smaller than for residential, and the daily lease contract means that all finishes need to be highly durable.

4.2. MEASURING CHANGE CAPACITY

Defining a building’s change capacity depends on an analysis of potential user needs such as was presented in the last section. Of course, as mentioned before, there are multiple forms of flexibility just as there are multiple types of potential users, and an office which has been designed to easily reconfigure workstations and associated services has quite a different flexibility than a building which can accommodate both office and residential users.

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This thesis concentrates on the latter. Part of the reasoning for this is that a building which can accommodate multiple user types is more “deeply” flexible than others. While the difference between two office users, for example, is probably mostly focused on the space plan and perhaps services, these are fairly superficial changes, as elucidated by the shearing layers framework. On the other hand, the differences between, say, retail and residential uses reverberate all the way down to the site and structure – the longest lasting and most dominating features of a building. Thus, the most flexible buildings of all will be those which can accommodate multiple uses. The more practical part of the reasoning for this work’s concentration has to do with the relative option value of changing uses versus other inherent option, and the ability to obtain relevant data and make meaningful conclusions about the value of the option.

4.2.1. CORRESPONDENCES

Determining an existing building’s or potential design’s “capacity for change” essentially boils down to noting where there are correspondences between the form of the building and the needs of potential users. This analysis can be done with every building system, and the shearing layers approach has the advantage of breaking the building down into components by the relative amount in which they change – giving a sense of how deep the change capacity is, and the type of work which would be required in order to accommodate different users.

In the case of existing buildings, this framework can be used to analyze which uses a building could most readily be redeveloped to serve, as well as provide initial design direction and the ability to determine rough cost estimates. From there, the economic value of possible redevelopment can be calculated using the option valuation theory outlined in chapter 2. In the case of new developments, the framework can be used to both analyze existing proposals and, more importantly, help establish the program for new buildings.

4.2.2. COMPARISONS

On the next page is Figure 4.1, a matrix which shows in condensed form the various typical needs of different users arrayed against a building’s primary layers. The matrix is meant as a visual aid for comparing the characteristics of an existing building or proposed design with the needs of the major users. The matrix only outlines very general requirements, and likewise stereotypes the needs of any individual user. So, while it would be dangerous to blindly apply such a matrix’s
# Figure 4.1 - Use Needs by Shearing Layer, for Major Commercial Uses

<table>
<thead>
<tr>
<th>Layer</th>
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- **Office**:
  - Floor Plate: 10-20 ft
  - Lease Terms: 5-20 years

- **Retail**:
  - Floor Plate: 10-15 ft
  - Lease Terms: 5-20 years

- **Hotel**:
  - Floor Plate: 10-15 ft
  - Lease Terms: 5-20 years

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**SITE**:
- **Lot Shape**:
  - Minimum width or depth: 6 min
- **Position**:
  - Lot Size: 20,000 sf
- **Churn**:
  - FAR: 1.0
- **Traffic**:
  - Parking: 200-500 ft
- **Utilities**:
  - Water, Gas: 1000 cu ft
- **Technology**:
  - Infrastructure: 100,000 ft

**STRUCTURE**:
- **Clear Spans**:
  - 9-11 feet
- **Heights**:
  - 12-16 feet
- **Floor Plate Size**:
  - 1500 sf
- **Service Loads**:
  - 100 psf
- **Mechanical**:
  - 10000 sf
- **Electrical**:
  - 4000 sf
- **Aesthetics**:
  - 10000 sf

**ELEVATOR**:
- **Floor-to-Floor**:
  - 30-45 feet
- **Transportation**:
  - 100 sf/occ
- **Loads**:
  - Light: 12-16 feet
- **Loads**:
  - Medium: 9-12 feet
- **Loads**:
  - Heavy: 6-9 feet

**SERVICES**:
- **Planning Modules**:
  - Central
- **Tenant Shapes**:
  - Core
- **Tenant Mileage**:
  - 5-20 years

**SITE**:
- **Location**:
  - Core
- **Zone Requirements**:
  - Large zones
- **Positive Externalities**:
  - Retail services, educational centers, parks, other retail cultural services, recreation walkable retail/entertainment
- **Public Issues**:
  - Plan, Public view, Natural light

**SKIN**:
- **Lot Shape**:
  - 6 min width or depth
- **Light**:
  - Very important
- **Mechanical**:
  - Upper 30-45 feet
- **Electrical**:
  - Lower 30-45 feet
- **Aesthetics**:
  - 9-11 feet
- **Vent**:
  - Natural vent not important
- **View**:
  - Moderately important
- **Vent**:
  - Natural vent not required
- **Light**:
  - Natural light very important
- **View**:
  - Natural light very important
- **Light**:
  - Natural light very important
- **Light**:
  - Natural light very important
requirements to a building form looking for correspondences, the diagram does allow quick comparisons to be made between the typical needs of different classes of users.

4.2.3. APPROACHES

In determining a building’s capacity for holding more than one type of use, the most critical layers of building systems are also the slowest moving. The existing space plan is the least important – except in the case of a carefully designed hotel or apartment building, no plan is ever going meet the needs of a user in a different usage class. This is in sharp contrast to proposals for the design of a more flexible, easily reconfigured office space, for example, which of necessity concentrate on the space plan, as well as services – to the extent that they interact with the space plan.

Though it is so obvious an observation as to be easily overlooked, site is the most critical component in determining a building’s capacity for change – even though it is paradoxically the layer least within the control of a building owner, developer, or designer. If the site is not right, a building which is in all other ways perfect for a particular use is actually useless. Structure, too, has a very dominating effect on a building’s capacity for change. Floor-to-floor heights that are too low for a particular use are almost impossible to change. Likewise with loading constraints. In many cases shape and size can be altered through the addition and removal of sections of buildings, but these characteristics of structure can often prevent the economic viability of a conversion.

On the other hand, skin (when it is not physically coupled with the structure, as in a load-bearing masonry wall) and services are relatively easy to change. While not necessarily cheap, altering a building’s facade or fenestration is not nearly as difficult as attempting to alter structure or as Sisyphean a task as trying to alter site. And, though incoming service capacity, equipment location, primary trunk lines, and the like go a long way to determining change capacity, actual service layouts are so tied to space plan as to be unimportant.

Thus some of the best approaches for designing a building capable of switching uses include designing for overcapacity, demolition simplification, and system separation. Likewise, when examining existing buildings, it is the deeper layers that most determine a facility’s capacity for changing uses. Both of these ideas are forefront in the next chapter.
5. FLEXIBLE BUILDING CASE STUDIES

This chapter examines five case studies. The last two are hypothetical case studies based in Chicago’s Loop: the first of these is an adaptive reuse project, and the second is a new development. These two case studies use insights gained from chapters 3 & 4 for their analysis design, and are valued in the next chapter using the real option analysis discussed in chapter 2.

The first three case studies are much shorter and meant as an introduction to some of the issues faced in the two main cases: all three are based on projects in downtown Chicago similar to the hypothetical cases. In keeping with the focus of the last chapter, all of these projects are mid- to high-rise buildings (12 stories and up) situated within a CBD, though similar analyses could be applied to any type of building.

5.1. EXISTING CASE STUDIES

Each of these first three case studies includes a discussion of the development strategy, physical issues, and economic analysis relevant to the notions of flexible buildings and change capacity. The first two projects are redevelopments of turn-of-the-century Chicago skyscrapers, and the last is a new mixed-use high-rise developed in the mid-1980s on Michigan Avenue.

5.1.1. THE ROOKERY: OFFICE REMODELING

The Rookery originally opened in 1886 as one of the tallest and most expensive office spaces of its time, as well as the one of the first to be built speculatively. Originally designed by the well-known Chicago firm of Burnham and Root, it was also famous because of the two-story covered light court renovated and modernized by Frank Lloyd Wright in 1905. The building was further modernized in 1931 by William Drummond, including elevator replacement, significant structural alterations, and the addition of mezzanine floors in what were originally two story lobbies. Further makeshift alterations occurred over the years, including the tarring over of the light court’s glass roof. By the early 1980s, when ownership reverted to the city (the site had a 99-year ground lease), the building was vacant and in a severe state of disrepair.

5.1.1.1. DEVELOPMENT STRATEGY

In 1988 Thomas Baldwin bought the building for $27 million. His expressed aim was to disprove the notion that historic buildings couldn’t achieve Class A rents and

142 All development data in this case study is from Urban Land Institute (1995).
that costs of restoration couldn’t be recouped. His strategy was to restore the building’s historic architectural features and feeling while also incorporating the state-of-the-art services required by Class A tenants. In the parlance of revitalization strategies outlined earlier, this was therefore a remodeling, and most of the required work accordingly involved the services and space plan.

5.1.1.2. Physical Issues

The site, still in the heart of Chicago’s Loop and financial district, is quite capable of attracting very high quality office tenants. The structure of the building, though designed some 100 years earlier, is likewise still appropriate for office use. The design of the existing office floors (3-12) is as that of a hollow square, 165’ on a side, with a light court in the middle, which is about 60’ square. Thus the office floorplates have an area of approximately 24,000 sf and depths from exterior to the light court of approximately 55’. While these dimensions (along with the varying floor-to-floor heights) are on the small side, they still meet office needs rather well. The building also meet the needs of retail on the first two floors, especially given the restoration of the Wrightian light court. Similarly, the exterior skin was well designed and provides abundant natural light and good views. And after restoration of the exterior’s historic features, the skin also provides the appropriate image of both opulence and timelessness for the tenants. Services, of course, needed upgrading, and in many cases, complete replacement. Combining this work with the extensive work restoring interior finishes to former glory was obviously a challenge, but did not necessitate work to the other building layers - there was, so to speak, sufficient slippage between the systems.

5.1.1.3. Economic Issues

The timeframe from planning to completion was almost 3 1/2 years, with just under 2 1/2 years of construction time. Construction costs were just under $47 million, including tenant improvements, but qualified for a federal tax credit of 20% because of the historic restoration involved. In addition, site improvement costs totaled almost $2 million, and soft costs (also subject to the 20% tax credit, and including some hefty financing fees and interest) came out to $33 million. Net development costs, excluding land and accounting for the tax credits, thus came out to $66 million, which was about $225 per square foot of Gross Building Area (GBA), and $270 per square foot of Net Rentable Area (NRA). If the unusually high $20 million of financing costs are also removed from the equation, net development costs drop to $50 million total, and to $170 and $204 per square foot of GBA and NRA, respectively.143

143 All of these figures are in nominal dollars, spent between 1988 and 1992.
Most likely, the high financing costs result from the fact that the Rookery reopened in 1992, at the bottom of a recession and in an office market still oversupplied by the excesses of the 1980s, with a 52% vacancy. Within three years, by 1995, vacancy had dropped to 14%, with average asking lease rates at $26/sf for office and up to $52/sf for retail – both of which matched most other Class A space in the market at the time. Further, the rehabilitation effort has won many design awards, and is by most counts a success. However, at the bottom of the market, the development company was only able to meet debt service through a “stroke of luck,” and one wonders whether the redevelopment effort may have better succeeded as an adaptive reuse project rather than a repositioned office building.

5.1.2. THE RELIANCE BUILDING: ADAPTIVE REUSE

The Reliance Building, another Burnham and Root design in Chicago’s Loop, was the first modern skyscraper – built from riveted steel in two phases between 1890 and 1894. It was built on speculation and originally housed retail on the first floor and basement, with offices above. Over the next century, the building followed the decline of the city’s downtown, and by 1994 was in such bad shape that the city decided to buy the building by eminent domain, paying only $1.2 million. After restoring the exterior at a cost of $6.6 million, an RFP was issued.

5.1.2.1. DEVELOPMENT STRATEGY

McCaffery Interests was awarded the project, based on their proposal for redeveloping the building as a boutique hotel. The strategy behind the adaptive reuse rather than a remodeling (as at the Rookery) was to avoid competition from more efficient and better equipped office space. Rather, with a high-end hotel use, the age and form of the building could be considered a positive form of differentiation. So said the developer – in the jargon of this thesis, though, we might say that most of the existing building layers conformed less well to an office use than a hotel use, which stipulated an adaptive reuse development.

5.1.2.2. PHYSICAL ISSUES

Given the correspondence between hotel needs and the building’s site and structure, along with the city’s previous investment in restoring the building’s skin, most of the work involved in the conversion was in the services and space plan layers. While structural work was required, especially on the first floor, this was due to physical obsolescence rather than changes in the use.

Of special interest is the solution to the historic wrought-iron stairs. Installation of a smoke-removal system obviated the need to enclose the stairs with the typical 2-

144 All data regarding the redevelopment at the Reliance building is from Takesuye (2001).
hour fire wall which would typically be required, but which would also have
destroyed the architectural interest they hold as the centerpiece of each floor’s
circulation. In addition, the space plan for floors 2-6 were able to be laid out with
more efficiency than the upper 7 floors, as these lower floors had long ago been
stripped of any historic features.

5.1.2.3. ECONOMIC ISSUES

Construction took just over a year, and total costs amounted to $19.5 million,
exclusive of land and the original facade restoration. Of the hard costs, about 28%
got to structural reinforcement, 30% went to services, and the remaining 42% went
towards the space plan layer. After historic tax credits are accounted for, net
development costs (exclusive of land and furnishings) were approximately $12
million, which amounts to $151 per square foot of GBA and $178 per square foot of
NRA.145 The resulting hotel has been renamed the Hotel Burnham and has won a
few design awards. It is a truly upscale boutique hotel, capable of supporting some of
the higher nightly rates in the city.

5.1.3. 900 NORTH MICHIGAN: NEW MIXED-USE HIGH-RISE146

900 North Michigan is a 66-story mixed-use high-rise which opened in 1988 at
the north end of Chicago’s “Magnificent Mile,” the most important retail destination
in city and a significant tourist draw as well.

5.1.3.1. DEVELOPMENT STRATEGY

The high-rise at 900 North Michigan was chosen to be a mixed-use development
for economic reasons. Its location on Michigan Avenue uniquely sited for retail and
hotel uses, and the developers also hoped to capture niche markets in the office and
condominium markets for users who wanted the swanky address. Like the Hancock
building and Water Tower Place across the street (both developed in the 1970s), it
was designed as a vertically mixed-use building, with 450,000 sf of retail on the first
six floors, 550,000 sf of office space on the next 22, 343 hotel rooms on floors 30-
46, and 106 residential units topping it off.

5.1.3.2. PHYSICAL ISSUES

In a manner which is to be expected with the variety of uses, the building
floorplate sizes change with each use, as do the floor-to-floor heights. While all
floorplates extend the full width of the site, the depth reduces considerably between
the retail and office uses, forming a base for the setback high-rise which extends to
the sidewalk. The depth reduces again somewhat between the office and hotel uses,

145 All construction costs are in 1999 dollars.
146 All development data for 900 North Michigan are from Burke (1995).
though the structure for the hotel and residential uses is identical. However, the skin
does not change at all as the uses shift, with the exception of the retail section at the
base of the building, which has very few windows.

5.1.3.3. Economic Issues

Each of the use components at 900 North Michigan was financed as a separate
entity, and single source financing was obtained through TIAA. This avoided cross-
collateralization, which allows for the refinancing of some pieces without losing
others. The mixed-use nature of the project also created a diversification effect - for
example, the hotel could never have been financed on its own. Project costs for 900
North Michigan totaled $450 million, including a $60 million purchase price for the
land. This comes out to a net development cost (exclusive of land) of approximately
$145 per square foot of NRA.¹⁴⁷

5.2. Redevelopment at the Monadnock

The Monadnock building completes our Burnham and Root trifecta, since it, like
the Rookery and Reliance buildings, is yet another of Chicago’s historic landmark
skyscrapers from the firm of Burnham and Root. It is located just south of the
Federal Plaza in the heart of the Loop, between Van Buren to the south and Jackson
street to the north, with its vast length running along the west side of Dearborn.

Figure 5.1 - North Monadnock - east facade

¹⁴⁷ All figures are in 1988 dollars.
The Monadnock was built in two halves, with radical changes in construction methods and architectural style. The north half was completed in 1891 and designed by Burnham and Root. The exterior walls of this 17-story building were built entirely of load-bearing masonry – eighteen feet thick at the base – and the austere, unornamented facade constitutes a radical stylistic shift from any skyscraper that had been built before (or since). The south half was built two years later, using a steel frame construction method. This half of the building was designed by Holabird and Roche, with a facade that manages to work the stylistic flourishes common at the time into a basic form that echoes the north half.

The only major renovation to the building occurred in 1938 and was conducted by Skidmore Owings & Merrill. At this time, washrooms and other services were modernized and added, and many of the original mosaic floors were replaced with terrazzo. In 1970, the building was placed on the National Register of Historic Places, and by the late 1970s was also given Chicago Landmark designation. The building currently houses retail on the first floor and offices above, retaining the uses for which it was originally designed, though obviously rents have slowly declined, and the building would now be considered a Class B or Class C office building.

5.2.1. **EXISTING PHYSICAL CONDITIONS**

In 1978 Harry Weese & Associates published a study on several landmark buildings in Chicago’s Loop, among them the Monadnock building. Since the firm conducted an extensive survey of the building’s conditions at the time, and since no major work has occurred to the building since then, their survey is used as the basis for the Monadnock’s existing conditions. While there have, of course, probably been numerous repairs and minor upgrades over the past 25 years, especially to the retail on the bottom floor, the building is to all appearances the same as described in Harry Weese & Associates report. For the purposes of this case study, which is focused on the hypothetical opportunity of revitalizing the existing building, their report of the building provides an objective and adequate account of the major issues that will be involved in any revitalization effort.

5.2.1.1. **SITE**

The Monadnock is located in the heart of a changing CBD. As with many other downtowns across America, the trajectory of Chicago’s downtown distinctly shifted during the 1990s. No longer in decline from the trend of offices locating in the suburbs, Chicago’s downtown office market is rather on the rise. In the next twenty years, it is expected that the amount of office space in the downtown area will rise by

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30-40% from its current 107 million square feet.\textsuperscript{149} Even more dramatic, though, is the shift in downtown uses, which are becoming much more mixed than they had been in the latter half of the twentieth century. Projecting from trends of the last twenty years, the amount of residential space in downtown Chicago is expected to rise to nearly 100,000 units, around 75% more than its current base of 56,000.\textsuperscript{150} A similarly dramatic increase in retail is expected, from some 9 million square feet currently to 14-16 million in 2020 – a 55-80% increase.\textsuperscript{151} Some evidence for this growth rate and mixing of uses is already apparent in the new Lakeshore East development a few blocks to the northeast of the site, which contains a mix of office and residential buildings just north of Grant Park.

Externalities acting on the Monadnock site include Grant Park 3 blocks to the east, which houses the Art Institute of Chicago, the new Millennium outdoor amphitheater by Frank Gehry, and also hosts many cultural events. Similarly, the retail along State Street – three blocks away – is second only to Michigan Avenue and currently experiencing a rebound from its depressing days in the seventies and eighties. The Chicago Theater, Goodman Theater, Lyric Opera House and Chicago Auditorium are all within a few blocks. Offices, government services, and multiple train lines are likewise located within walking distance – all which adds up to a very vibrant, walkable, mixed-use environment.

The Monadnock lot legally consists of four contiguous parcels, totaling an area of 26,400 square feet: 66 feet east-to-west and 400 feet north-to-south. On-site amenities at the Monadnock are non-existent, which is especially important for those uses which want extensive parking. However, there are a number of garages nearby which could alleviate the problem for at least some fraction of users.

The majority of the site is zoned B7-7, which means that the site can be used for any business or residential use, including any of the uses discussed in the last chapter except for industrial (and probably only certain types of R&D space). The zoning also allows an FAR of sixteen, which the current building exceeds by one story. However, since it was built long before this zoning came into effect, the existing building would certainly be allowed to remain at its current height, no matter what interior changes were made. The most important other public issues facing the site relate to the building’s designation as a Chicago Landmark and placement on the National Register of Historic places, which would certainly restrict what forms of revitalization would be allowed.

\textsuperscript{149} City of Chicago (2003), p 11.  
\textsuperscript{150} City of Chicago (2003), p 11.  
\textsuperscript{151} City of Chicago (2003), p 11.
5.2.1.2. Structure

The northern half of the building has solid masonry exterior walls, as mentioned previously, with steel beams and cast iron columns on the interior. The southern half of the building's structure is all steel ‘Z’-bar frame. With the exception of shoring to the north foundation during the construction of the Federal Plaza, virtually nothing has been done to the Monadnock structure since its initial completion. The two aspects of physical obsolescence which will need to be dealt with in any remodeling include additional repair to the north foundation and beam deflection in the north building near the stair openings. In addition, the south building's structural member currently have inadequate fireproofing.

The building is seventeen stories tall, with a Gross Building Area per floor a little over 25,000 sf. Net Rentable Area per floor averages 20,500 sf, with 2,000 sf of the difference being used for vertical transportation and service distribution, and the rest for exterior building walls - this second claim on GBA varies floor by floor, as the load bearing masonry walls gradually get thinner as the building gets higher. The building depth is 65 feet outside wall to outside wall, and 69 feet if when the bays are included. The floors are divided into roughly equally sized bays from east to west, with north to south bay dimensions varying from 15 feet center to center in the north half, and alternating bays of 14 and 23 feet in the south half of the building. Floor-to-floor heights vary, but are approximately 13'-0" on the first three floors, and 11'-4" on floors 4 through 17.

5.2.1.3. Skin

The Monadnock exterior is in relatively good shape for a building of its age. Some cornice repair may be necessary, there is likely some preventative masonry work, and the steeply pitched roof has many protrusions creating pockets and gullies which will need to be fixed. The building provides abundant light, view and ventilation to its users. Windows are operable and very large, allowing for plentiful natural light and ventilation. However, the windows are also single-paned, making them less energy efficient than is now standard, and - like most old windows - they probably provide a little more ventilation than desired, even when shut. The image projected by both halves of the Monadnock building is definitely one of solidity - the northern half is very reminiscent of the mountains for which it is named, and the southern half does a good job of echoing and playing off of the northern half.

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age of the building further provides an image of solidity and respectability, which is also advanced by the well-known landmark status given the building by the city.

5.2.1.4. SERVICES

There are three cores in this building, each containing elevators, stairs, and vertical service distribution shafts. All three cores are elongated, and while the south building’s well-defined single core contains four elevators and two sets of fireproofed egress stairs, the north building has two “cores” connected via the same wide hallway - each core contains an open wrought-iron staircase, neither of which meet current fire safety codes, and four elevators. The northernmost elevator is used as the freight elevator, and only two of the elevators have been converted to automatic.156

Heating for the building occurs through cast iron radiators using a steam system. Two gas/oil boilers and boiler rooms exist in the basements, but the systems are interconnected, and in mild weather, only one is used.157 While the systems are currently in good condition, the age of the piping suggests the problems should be expected in the not too distant future.158 Air conditioning is a recent addition to the building, and installed on a makeshift, tenant by tenant basis - including many window units. Some of the tenants’ air conditioning systems also contain heating coils, and these receive their steam from the main system, making the forced air units capable of both heating and cooling.159

The electrical system is the “product of many years of chance development”160 and largely has no rhyme or reason. DC service, in the process of being phased out, is supplied at 230 volts. Incoming AC service is supplied to the north half of the building via two 3000 amp boards, and to the south via one 5000 amp main.161 This allows for approximately 9.6 w/sf of NRA, and is distributed through four electrical closets on each floor.162 The height of the building places it under the purview of the Chicago High Rise code for fire safety systems, which will need to be installed if the building is remodeled.163

Water for the building comes from the city main to a gravity tank above the south elevator bank, providing adequate pressure for the building.164 All interior structural columns are accompanied by plumbing risers and waste and vent stacks,
making them easy to tap.\textsuperscript{165} However, because of age, both the tank interior and concealed piping are suspect.\textsuperscript{166}

\textbf{5.2.1.5. SPACE PLAN}

Many changes the space plans over the years, and many interior finishes have been replaced. Original mosaics in the corridors have all been replaced with terrazzo, and tenant floors have usually been refinished as well. Similarly, new doors frequently replace the originals, and tenant changes over the years have removed or replaced original millwork, etc.\textsuperscript{167} On all floors, the existing north corridor is 20 feet wide, and the south corridor is 11 feet wide.

\textbf{5.2.2. REVITALIZATION POTENTIAL}

The Monadnock building currently receives class B office rents, and has vacancy rates typical downtown Chicago office buildings in its class – somewhere around 15\%. Given its class B status, the site is obviously not developed to it highest and best use, and would require some level of revitalization in order to be so.

One approach to determining appropriate revitalizations to the site is to overlay the reality of the existing building layers to the potential needs of possible users. Just such a comparison is shown in Figures 5.2 and 5.3. These figures show the same use needs/shearing layer matrix as in Figure 4.1, but with certain needs highlighted. These highlighted needs are those met by the existing characteristics of the building – in Figure 5.3, needs which match the first floor of the Monadnock are highlighted, and in Figure 5.4 the highlighted needs are those which can currently be met the upper floors of the building. Areas highlighted in the darker shade represent those needs which are currently met, and areas in the lighter shade of gray represent those areas in which only minor modifications need to be made (or where not enough information is known for certain). Areas without any highlighting are needs unmet by the current building.

A quick glance at relative areas highlighted in the two diagrams shows that the needs of the typical office user are not met very well by the existing building. Of course, some needs in the matrix are more important than others, and some are simpler to fix. In fact, a more careful reading of the two matrices reveals that the first floor best meets the needs of current retail users, while the upper floors would best be converted to residential or hotel – not surprising, given the earlier case studies.

\textsuperscript{165} Harry Weese and Associates (1978), p 90.
\textsuperscript{166} Harry Weese and Associates (1978), p 92.
\textsuperscript{167} Harry Weese and Associates (1978), p 90.
<table>
<thead>
<tr>
<th>SITE:</th>
<th>OFFICE</th>
<th>RETAIL</th>
<th>RESIDENTIAL</th>
<th>HOTEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location Drivers</td>
<td>rent, lease productivity, technology infrastructure</td>
<td>visibility, accessibility</td>
<td>proximity to work, political considerations</td>
<td>proximity to office, local attractions</td>
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<td>Positive Externalities</td>
<td>retail services, housing, central park, civic roles</td>
<td>cultural centers, parks, civic roles</td>
<td>cultural services, public education, walkable retail environment</td>
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<td>noise, industrial noise, roadway noise</td>
<td>industrial uses, air pollution</td>
<td>industrial uses, noise pollution</td>
<td>parks and recreation</td>
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<td>parking</td>
<td>business centers, healthcare, parks, landscaping</td>
<td>business centers, conference rooms, pools, healthcare, landscaping</td>
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<td>Lot Size</td>
<td>20,000 ft²</td>
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<td>suitable accommodation for 150 units</td>
<td>suitable accommodation for 150 units</td>
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<tr>
<td>Lot Shape</td>
<td>75% west to east depth</td>
<td>regularly irregular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public issues</td>
<td>F.H. height restrictions; traffic analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| STRUCTURE: | | | | |
| Loads | floor 15-30 psi live | 18,000-40,000 sf | 10,000-30,000 sf | 15,000-30,000 sf |
| Floorplate Size | 100,000 sf | 20,000 sf | 30,000 sf | 40,000 sf |
| Floorplate Shape | depth, 24-40 stories per core | depth | max 25 stories per core | max 30 stories per core |
| Clear Spans | 24-30 ft height | maximum | coordinate at core | coordinate at core |
| Vertical Transportation | | | | |
| Elevator Loads | 500 lbs per person | 500 lbs per person | 500 lbs per person | 500 lbs per person |
| Elevator Loads | 1000 lbs per person | 1000 lbs per person | 1000 lbs per person | 1000 lbs per person |
| Egress Requirements | stairwell 300 sf/level, 1000 sf/level | stairwell, 300 sf/level, 1000 sf/level | stairwell, 300 sf/level, 1000 sf/level | stairwell, 300 sf/level, 1000 sf/level |

| SKIN: | | | | |
| Light | Natural light very important | Natural light not required | Natural light critical | Natural light very important |
| View | View includes important | View critical | View critical | View critical |
| Vent | Natural vent very important | Natural vent not required | Natural vent required | Natural vent required |
| Image and Aesthetics | conservatory, health | regional, follows trends | safety important | regional as neither |

| SERVICES: | | | | |
| Core Size | 15-18% of floor area | 10% | 15% | 15% |
| Core Location | center, sub-center | center, sub-center | center, sub-center | center, sub-center |
| Mechanical | Central Plant or HVAC units | central mechanical | central mechanical | central mechanical |
| Service Loads | 0.15 cu ft/ft² | 0.25 cu ft/ft² | 0.30 cu ft/ft² | 0.30 cu ft/ft² |
| Zone Requirements | large zones for open plan | large zones for open plan | large zones for open plan | large zones for open plan |
| Locational Requirements | close to mezzanine floor | close to mezzanine floor | close to mezzanine floor | close to mezzanine floor |
| Plumbing | 60% of tenant area | 60% of tenant area | 60% of tenant area | 60% of tenant area |
| Service Loads | 10% of tenant area | 10% of tenant area | 10% of tenant area | 10% of tenant area |
| Locational Requirements | 10% of tenant area | 10% of tenant area | 10% of tenant area | 10% of tenant area |
| Vertical Transportation | elevator, glass elevators | glass elevators, glass elevators | glass elevators, glass elevators | glass elevators, glass elevators |
| Elevator Loads | 60% of tenant area | 60% of tenant area | 60% of tenant area | 60% of tenant area |
| Egress Requirements | stairwell, 300 sf/level | stairwell, 300 sf/level | stairwell, 300 sf/level | stairwell, 300 sf/level |

| SPACE PLAN: | | | | |
| Tenant Sizes | 100,000 sf/level | 10,000-150,000 sf for retail use | space for 1000 sf/level | space for 1000 sf/level |
| Tenant Shapes | regularly important | regularly important | regularly important | regularly important |
| Lease Terms | 10 years | 10 years | 10 years | 10 years |
| Parking | 1.5 spaces/1000 sf | 2.0 spaces/1000 sf | 1.5 spaces/1000 sf | 1.5 spaces/1000 sf |
| Planning Modules | 0.5 ft for tenant, 2 ft for retail | 0.5 ft for tenant, 2 ft for retail | 0.5 ft for tenant, 2 ft for retail | 0.5 ft for tenant, 2 ft for retail |

Figure 5.2 - Use Needs met by existing Monadnock building, ground floor
### SITE:

<table>
<thead>
<tr>
<th>OFFICE</th>
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<th>RESIDENTIAL</th>
<th>HOTEL</th>
</tr>
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<td>trend, client-facing technology infrastructure</td>
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<td>proximity to work, political positions</td>
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<td>Positive Externities</td>
<td>retail, service, boating</td>
<td>retail, service, pet, children</td>
<td>retail, service, retail shopping</td>
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<tr>
<td>Negative Externities</td>
<td>retail, industrial, noise</td>
<td>retail, industrial, noise</td>
<td>industrial, noise, noise generation</td>
</tr>
<tr>
<td>Important Amenities</td>
<td>parking</td>
<td>parking</td>
<td>business centers, financial districts</td>
</tr>
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<td>Lot Size</td>
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<td>40,000 sf min.</td>
<td>multi-residential to 100 units</td>
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<td>Lot Shape</td>
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<td>regularly irregular</td>
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<tr>
<td>Public Issues</td>
<td>public access, traffic analysis</td>
<td>public access, traffic analysis</td>
<td>public access, traffic analysis</td>
</tr>
</tbody>
</table>

### STRUCTURE:

<table>
<thead>
<tr>
<th>Load</th>
<th>floor 5 - 10</th>
<th>100 per ground floor / 70 per upper</th>
<th>50 per / 100 per in public areas</th>
<th>10 per / 100 per in public areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floorplate Size</td>
<td>11,000 - 40,000 sf</td>
<td>can vary</td>
<td>15,000 - 30,000 sf</td>
<td>10,000 - 30,000 sf</td>
</tr>
<tr>
<td>Floorplate Shape</td>
<td>depth, 25-40’ aspect to core</td>
<td>depth</td>
<td>max. 20’ aspect to core</td>
<td>max. 20’ aspect to core</td>
</tr>
<tr>
<td>Clear Spans</td>
<td>25’x70’ to 25’H beam</td>
<td>max. length to open space</td>
<td>max. length to open space</td>
<td>max. length to open space</td>
</tr>
<tr>
<td>Floor-to-Floor Heights</td>
<td>12’ 4” to 14’ 7” depth dependent</td>
<td>10’ 11” floor</td>
<td>10’ 11” floor</td>
<td>10’ 11” floor</td>
</tr>
<tr>
<td>Structural Systems</td>
<td>require 3” threaded rod connections</td>
<td>3” or 7” threaded rod connections</td>
<td>3” or 7” threaded rod connections</td>
<td>3” or 7” threaded rod connections</td>
</tr>
</tbody>
</table>

### SKIN:

<table>
<thead>
<tr>
<th>Light</th>
<th>Natural light very important</th>
<th>Natural light not required</th>
<th>Natural light not required</th>
<th>Natural light very important</th>
</tr>
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<tbody>
<tr>
<td>View</td>
<td>View moderately important</td>
<td>View critical</td>
<td>View critical</td>
<td>View critical</td>
</tr>
<tr>
<td>Vent</td>
<td>Natural ventilation very important</td>
<td>natural ventilation not required</td>
<td>natural ventilation not required</td>
<td>natural ventilation not required</td>
</tr>
<tr>
<td>Image and Aesthetics</td>
<td>conservative, weight</td>
<td>regional, follows trends</td>
<td>regional, follows trends</td>
<td>regional, follows trends</td>
</tr>
</tbody>
</table>

### SERVICES:

<table>
<thead>
<tr>
<th>Case Size</th>
<th>15 – 15% of floor area</th>
<th>N/A</th>
<th>Single core not suitable</th>
<th>Single core not suitable</th>
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<tbody>
<tr>
<td>Core Location</td>
<td>central core</td>
<td>N/A</td>
<td>central core, orthogonal</td>
<td>central core, orthogonal</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Central Plant/ VAV units</td>
<td>Individual Tenant units</td>
<td>VAV floor or Tenant units</td>
<td>VAV floor or Tenant units</td>
</tr>
<tr>
<td>Sanitary Loads</td>
<td>0.10 cu. ft/lf</td>
<td>about 0.20 cu. ft/lf</td>
<td>about 0.30 cu. ft/lf</td>
<td>about 0.50 cu. ft/lf</td>
</tr>
<tr>
<td>Zoning Requirements</td>
<td>large zones for open office</td>
<td>1 to more zones per unit</td>
<td>1 zone per unit</td>
<td>1 zone per unit</td>
</tr>
<tr>
<td>Electrical</td>
<td>12.11 kV + vertical transport</td>
<td>11 kV + vertical transport</td>
<td>11 kV + vertical transport</td>
<td>11 kV + vertical transport</td>
</tr>
<tr>
<td>Elevator Loads</td>
<td>50,000 lb/100 sf</td>
<td>50,000 lb/100 sf</td>
<td>50,000 lb/100 sf</td>
<td>50,000 lb/100 sf</td>
</tr>
<tr>
<td>Plumbing</td>
<td>indoor</td>
<td>high-impact residential</td>
<td>high-impact residential</td>
<td>high-impact residential</td>
</tr>
<tr>
<td>Elevator Requirements</td>
<td>5 floors + vertical transport</td>
<td>3 elevators in lobby</td>
<td>3 elevators in lobby</td>
<td>3 elevators in lobby</td>
</tr>
<tr>
<td>Vertical Transportation</td>
<td>5 floors + vertical transport</td>
<td>5 floors + vertical transport</td>
<td>5 floors + vertical transport</td>
<td>5 floors + vertical transport</td>
</tr>
<tr>
<td>Elevator Loads</td>
<td>3,000 lb</td>
<td>3,000 lb</td>
<td>3,000 lb</td>
<td>3,000 lb</td>
</tr>
<tr>
<td>Elevator Requirements</td>
<td>elevators per floor</td>
<td>elevators per floor</td>
<td>elevators per floor</td>
<td>elevators per floor</td>
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</tbody>
</table>

### SPACE PLAN:

<table>
<thead>
<tr>
<th>Tenant Sizes</th>
<th>20,000 - 100,000 sf</th>
<th>60,000 - 100,000 sf or to maximum</th>
<th>50,000 - 100,000 sf or to maximum</th>
<th>35,000 - 100,000 sf or to maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenant Shapes</td>
<td>regularly rectangular</td>
<td>depth from 15’ 1/2” minimum width</td>
<td>max. depth @ 21’ 11” “swing space”</td>
<td>max. depth @ 30’ 0”</td>
</tr>
<tr>
<td>Lease Term</td>
<td>5 - 10 years</td>
<td>5 - 10 years</td>
<td>5 - 10 years</td>
<td>5 - 10 years</td>
</tr>
<tr>
<td>Floor Plan</td>
<td>15 years</td>
<td>15 years</td>
<td>15 years</td>
<td>15 years</td>
</tr>
<tr>
<td>Parking Modules</td>
<td>1 ft to 2 ft setback</td>
<td>2 ft setback</td>
<td>2 ft setback</td>
<td>2 ft setback</td>
</tr>
</tbody>
</table>

### Figure 5.3 - Use Needs met by existing Monadnock building, upper floors
Site conditions are largely outside the control of the building owner, and for the most part cannot be changed. However, except for the lack of parking and other on-site amenities, the Monadnock’s location in downtown Chicago makes it well-suited to a variety of uses. And in such an environment, the lack of on-site amenities is less important than it would be in a more isolated area. The primary difference in the site conditions between the ground and upper floors is the increase in noise at street level, and the lack of street access and visibility on the upper floors. These key differences make the ground floor more suited to retail (and possibly office uses), and the upper floors more suited to office, residential, and hotel — speaking strictly in terms of the site.

Structural conditions at the ground floor are suited to virtually any use, although the short clear spans are somewhat of a hindrance to office and retail space. On the upper floors however, structural conditions become less suited to office and retail space. The shallower floor-to-floor heights are ill-suited to today’s office users, clear spans are not wide enough for efficient layout of office space, and there is some question as to the ability of the current beams to support office or retail loading conditions. On the other hand, none of these pose problems for residential or hotel uses. These structural issues are especially critical, because, except for floor loading, they are impossible to change without building demolition — a strict no-no given the Monadnock’s historic status (as well as this thesis’s focus on building revitalization).

The existing building skin is well suited to virtually any of the uses. The abundant light and ventilation provided by the existing bays and fenestration, and historically renowned character of the facade are assets for any of the uses. And while the exiting upper windows might need replacement, this is due to the obsolescence of single-pane windows, and not subject to any particular use.

Services in the Mondanock also are more appropriate for residential and hotel uses than for office, though repair and upgrades will need to occur with virtually any revitalization. Vertical transportation in the form of existing elevators and stair cases is probably barely adequate for office needs, but more than sufficient for residential or hotel needs. Likewise, current electrical service is insufficient for office space, but adequate for residential and hotel needs. The fact that plumbing risers and stacks are extended up every structural column means that services can be readily provided on a tenant by tenant basis, another advantage for the conversion to hotel or residential uses. Lastly, mechanical services, though inadequate for any use, will likely more easily updated for residential needs than offices. The existing radiator system, if it can be maintained, can be well-supplemented by individually controlled units on a tenant by tenant basis. More difficult, however, would be the wholesale conversion to HVAC, which would be required in an office updating.
Lastly, space plan changes will be necessitated by the need for service changes if nothing else. The need for regularity and modularity in modern offices is a disadvantage to the Monadnock building, while hotel and residential needs will be easier to fit within the existing structural conditions.

5.2.3. THE RESIDENCES AT MONADNOCK

The existing conditions of the Monadnock, along with current market conditions and tax considerations make apartments the most likely highest and best use for the site. A hotel use is not currently feasible because of the dismal conditions of the hotel market, due in part to the current stage of the economic cycle and in part to repercussions from 9-11 regarding tourism. Among the two possible residential use types, apartments and condominiums, apartments have a unique tax advantage. Historic tax credits can be applied to the construction costs for any revitalization that involves income-producing property. The credit therefore applies to apartment buildings, but not condominiums. There would therefore need to be a (roughly) 20% price premium on condominiums versus apartments before a condo use would become feasible. And, even in today’s unusual market conditions which encourage condominium development more than apartments, this premium probably does not exist. Moreover, since the current demand for condos seems driven by Federal Reserve policy than anything else, it is likely not an equilibrium condition.

Due to the historic nature of the building, and the extensive historic restoration that would accompany any revitalization which changed uses, the new apartments would almost certainly be geared to the upper end of the market. This would in turn imply significant changes to the services, windows, as befits the demands of this market segment. Air-conditioning would be required, as would new windows, extensive telecommunications, and new high-grade finishes, especially in the kitchens and baths. On the other hand, an entire bank of elevators could be removed form the building without compromising the needs of the apartments, as well as (possibly) some of the large vertical chases currently running through he floors. Furthermore, the currently very wide hallways could be reduced to less than five feet. These changes would provide more rentable area – possibly as much as 10%. Of course, such changes to services and space plan would be expected in any significant revitalization, and the fact that there would not be more changes to the other shearing layers is a testament to the innate flexibility of the building as originally designed.

A schematic plan of the residential potential in Monadnock is shown in Figure 5.4, along with the existing office layout. The drawings show typical floors, and all floors 2 through 16 could be developed in a like manner (the ground floor will
Figure 5.4 - Existing and proposed plans for the Mondanock Building, showing typical floors
remain retail). The proposed residential layout simply shows typical unit sizes for most units, but also details three units, to show the potential for one-, two-, and three-bedroom units within the building. In addition, even four-bedroom units could likely be accommodated at the ends of the buildings, where there is a higher ratio of exterior wall to area. Given the depth of the apartments, which is as much as 30 feet in some areas, and as deep as residential users would accept, a number of design principles come into play. Most important is the location of service areas, such as laundries, kitchens, baths, and large closets, towards the center of the building, with living rooms and bedrooms being given the required windows to the exterior. Further, relatively open plans are used to get light to kitchens and dining rooms when possible, and hallways are minimized so as to make the most efficient use of limited space. While these plans are not meant to necessarily represent ideal designs for the given market segment, they do show that creating a high-end residential use within the building, and subject to existing conditions, is possible.

5.3. NEW DEVELOPMENT AT BLOCK 37

Whereas the Monadnock case study centered on determining the amount of flexibility inherent in an existing building, this case study focuses on design ideas that can be used to give a new building as high a change capacity as possible. The site for this hypothetical building is the so-called “Block 37,” a site just a few blocks north of the Monadnock building, which was razed in the early 1980s for a new office development meant to revitalize the Loop’s then stagnant commercial district. However, misguided city planning and the collapse of the real estate market at the end of the 1980s stymied these plans, and the block has remained vacant ever since.

5.3.1. DESIGN APPROACH

Given some of the more recent plans for Block 37, which have all included some measure of mixed-use development, the block seems a good testing ground for an hypothetical mixed-use tower – one that is meant to be designed so as to switch flexibly between the four uses which were outlined in the last chapter. The concentration here is on creating a development process which will allow the developer to wait as long as possible before committing to any particular use. And while this will have repercussions on the long-term flexibility of the building, the long-term flexibility of the building is not the focus of the valuation model being applied to this case study in the next chapter.

The mixed-use nature of the project becomes an underlying assumption behind this case study’s proposals. Since it assumed from the outset that the building will be
mixed-use, certain parts of the structure do not need to be flexibly “switchable.” This is because each possible use requires a certain level of area in order to achieve the critical mass necessary for its operation and servicing. In the case of residential uses, for example, there needs to be at least 150 or so units in the building in order to employ on-site maintenance and service staff. Likewise for hotels. Offices, too, need to occupy a certain amount of space to justify the office lobby and its day-to-day operations. Finally, retail space needs to occupy at least the entire first floor not only because it is the most appropriate use for street level, but also in order to create a good mix of tenants.

Another reason for the mixed-use approach is that it creates a number of synergies between the uses, allowing for shared on-site amenities. Moreover, with all of these uses in the same building, the mixed-use tower is quite capable of becoming a small “city within the city,” with the ability to service all of a potential user’s needs – as evidenced by Water Tower Place and 900 North Michigan further north in Chicago’s downtown. Therefore the design proposal which follows is a building which contains both sections which are meant to be easily switched as well as fixed sections which have predetermined uses attached to them.

5.3.2. DESIGN PROPOSAL

The purpose of the design illustrations on the next two pages, and the proposal that follows is not to address the full range of issues that would encroach on any large project in an urban core. Rather, the purpose here is to illustrate how some of the principles gleaned from chapters 3 and 4 might be applied to a new project. Therefore, Figures 5.5 and 5.6 show one possible physical manifestation of a flexible mixed-use tower – but only with enough detail to orient the reader to the design strategies discussed below, and to produce basic cost estimates for the valuation model discussed in the next section.

5.3.2.1. SITE

The site is an entire city block in Chicago in the heart of the Loop. It is 400 feet square, and has the same general forces acting on it as the Monadnock. No longer in decline from the trend of offices locating in the suburbs, Chicago’s downtown office market is rather on the rise. In the next twenty years, it is expected that the amount of office space in the downtown area will rise by 30-40% from its current 107 million square feet. Even more dramatic, though, is the shift in downtown uses, which are becoming much more mixed than they had been in the latter half of the twentieth century. Projecting from trends of the

\[^{168}\text{City of Chicago (2003), p 11.}\]
Figure 5.5 – Site Plan and Elevations for Block 37 Proposal
GROUND FLOOR: RETAIL SPACE, ENTRY LOBBIES FOR OFFICE, RESIDENTIAL, HOTEL

FLOORS 9 - 18: OFFICE

FLOORS 19 - 48: OFFICE / RESIDENTIAL / HOTEL

FLOORS 49 - 60: RESIDENTIAL / HOTEL

TYPICAL FLOOR PLANS

SCALE = 1" = 100'-0"

Figure 5.6 – Typical Floor Plans for Four Sections of Block 37 Proposal
last twenty years, the amount of residential space in downtown Chicago is expected to rise to nearly 100,000 units, around 75% more than its current base of 56,000.\textsuperscript{169} A similarly dramatic increase in retail is expected, from some 9 million square feet currently to 14-16 million in 2020 - a 55-80% increase.\textsuperscript{170} Some evidence for this growth rate and mixing of uses is already apparent in the new Lakeshore East development a few blocks to the northeast of the site, which contains a mix of office and residential buildings just north of Grant Park.

The site is zoned B7-7, which means that the site can be used for any business or residential use. The zoning also allows an FAR of 16, which this proposal meets precisely. Externalities acting on the Block 37 site are much the same as for the Monadnock and include Grant Park 2 blocks to the east, which houses the Art Institute of Chicago and the new Millennium outdoor amphitheater by Frank Gehry, and also hosts many cultural events. Similarly, the retail along State Street – which runs along the east side of the site – is second only to Michigan Avenue and currently experiencing a rebound from its depressing days in the seventies and eighties. The Chicago Theater, Goodman Theater, Lyric Opera House and Chicago Auditorium are all within a few blocks. Offices, government services, and multiple train lines are likewise located within walking distance. In fact, the Daley Center, housing many of the city’s governmental offices, is just to the west, on the opposite side of Dearborn Street. All of this adds up to a very vibrant, walkable, mixed-use environment which is capable of supporting offices, retail, residential uses, and hotels.

The proposed site plan addresses the most basic issues of this urban location. The building is situated on the north half of the site, creating an open space adjacent to the Daley plaza. Entry to the office lobby occurs at the north end of this open space, centered on the south side of the building. Residential entry occurs opposite, off of Randolph Street at the north end of the site. Retail entry can occur on both State and Dearborn street, and parking entries could occur almost anywhere, possibly with multiple entries so that each use could have its own entry. Dividing up the entries in this way allows each use to have its own identity, with an appropriately sited entry: residential from the quieter Randolph Street, retail from busy State and Dearborn streets, and office from the plaza. Hotel entry could occur along any of these streets, though the lobby for the hotel will be adjacent to (or possibly in place of) the residential lobby.

\textsuperscript{169} City of Chicago (2003), p 11.
\textsuperscript{170} City of Chicago (2003), p 11.
5.3.2.2. Structure

The building's basic structure can be gleaned from the massing elevations in Figure 5.5 and the typical floor plans in 5.6. The most critical structural issues regarding flexibility are its loading capabilities, the floorplate areas and shapes, and the floor-to-floor heights. And in all three cases, designing for proper capacity is a natural approach—and usually involves over capacity.

Overcapacity is easily understandable in terms of load-bearing ability—simply design floors to meet the highest of the required live loads for each usage class. For the second and third floors, which are being designed to accept both office and retail uses, this means using 70 psf live loads for most of the structural calculations (the requirement for retail), and increasing to 100 psf nearer the centers of the structure (the requirement for public and storage areas in offices). Likewise, on floors 19 – 48, which are being designed to accept either office or residential uses, the structure will be designed to be capable of taking office loads, which are always higher than residential loads. Note that these increases in load-bearing capacity will have repercussions not only on the individual floors in which the strategy is being employed, but all the way down to the substructure and foundation. However, this sort of overcapacity is relatively inexpensive, because the primary increases are in material costs, whereas (the more expensive) labor costs remain roughly the same.

Overcapacity can also be used in designing the proper floor-to-floor heights. In the case of the second and third floors, the floor-to-floor heights will be set at 15 feet, which will make them capable of accommodating 9 to 11 foot ceiling heights throughout. In the case of the middle floors housing either residential or offices, the required floor-to-floor height is 12 1/2 feet. This allows 9 foot ceiling heights in the typical office scheme, and perhaps upwards of 10 feet for residential users. While this floor-to-floor height is a good foot or more less than is typical in the United states, that is in part because the building is less deep (see the next paragraph). The relative shallowness of these floors decreases the need for natural light to reach deeply into the building, and, more importantly, decreases the amount and size of ductwork stemming from the main trunk lines in and around the core.

Capacity is also the key to creating a floorplate which is capable of accommodating multiple uses. However, in this case the issue is less about creating overcapacity than it is about creating the proper form of capacity. Since the size and shape requirements of typical user types tends to have some overlap, floorplates can be created which accommodate more than one use. For example, floors 19 through 48 have about 27,000 square feet of gross building area, and are 60 feet deep: this amount of area is suitable for either office users or multiple residential tenants, and the depth, although at the shallow end of an office's needs, and about as deep as
possible for a residential user, is also appropriate for both. A similar situation exists for floors 2 and 3, which are perfect for large single tenant retailers or multiple smaller tenant retailers. While slightly too deep for office users, skylights or an atrium space on the third floor roof could ameliorate any problems associated with depth.

5.3.2.3. SKIN

The skin for this building, like virtually any modern high-rise, will be a curtain wall system. However, many modern high-rises have all glass curtain walls, which may be appropriate for open space office plans, but does not work well for other uses. Accordingly, the curtain wall system used here will consist of precast concrete panels with large window opening. Assuming panels which are the same height as the floor-to-floor height, and perhaps ten feet wide, the window opening should be about 7 to 8 feet wide, and about 6 to 7 feet high (the sill should be 2-3 feet high, and the head should leave just enough room for trim below the finished ceiling. Such a window maximizes the amount of natural light coming into the space and reflecting off the ceiling, but also allows the a certain amount of flexibility with the placement of interior walls and furniture.

Moreover, the window opening can be treated in a number of different ways according to the use inside. For residential space, operable windows would be best, although fixed windows are better for office uses. Thus the windows on the middle flexible floors should be divided with mullions in such a way that the same pattern can allow the insertion of a few operable windows or all fixed, depending on the use. Likewise, ground floor retail windows will be plate glass, while the floors above might have the window openings filled in with more precast concrete, as the retailers inside may or may not require the use of display windows.

Using precast concrete curtain wall panels can also allow a variety of images to be conveyed. Given the traditional massing of the building in Figures 5.5 and 5.6, a traditional aesthetic, echoing the buildings built between the turn of the century and the thirties, will provide an image appropriate for both office users (conservative) and residential (solid).

5.3.2.4. SERVICES

In addition to designing services with the same overcapacity approach used for the structure – making certain that the requirements of the most intensive uses are met – services also need to have a high level of redundancy.

Providing enough elevators to supply both the maximum number of offices and residential units is perhaps the highest cost. There are two adjacent elevator cores shown in the plans of Figure 5.6 – one for the office use, one for residential or hotel. Both cores are arranged such that additional banks of elevators can be added or
subtracted according to need. The ideal situation in terms of flexibility would be for both sets of elevators to have the maximum number shown in the plans – eight for residential/hotel, twelve for office. However, if it is optimal during the development process to fix the number of stories dedicated to residential or office use, then a lesser number of elevators would be required, saving initial costs and increasing the rentable area.

In addition, each floor would have its own variable air volume (VAV) HVAC system, located near the elevator cores. Such a system\textsuperscript{171} would provide the greatest ability to serve both office and residential users, assuming the system is designed to the more stringent needs an office users.

Lastly, electrical, plumbing, and telecommunication systems should have supply risers alongside most, if not all of the interior structural columns. This allows residential and hotel uses to tap into the services where needed for individual kitchens, baths, electrical closets, and the like. It also allows potential office users more flexibility in designing their space plans. Incoming electrical services need to be able to meet the higher demands of office users, while incoming plumbing services should be capable of service the needs of residential users.

5.3.2.5. SPACE PLAN

As explained before the space plan layer is intrinsically specific to the tenant. In the case of residential or hotel uses (and especially the more volatile latter), it would be wise to design units in such a way that they could easily be divided or combined to switch from one use to the other. However, it is basically impossible to design space plans the can switch between any other uses. The key design approaches towards the space plan layer are therefore demolition simplification and the reduction of interactions between the space plan and services.

<table>
<thead>
<tr>
<th>SITE:</th>
<th>OFFICE</th>
<th>RETAIL</th>
<th>RESIDENTIAL</th>
<th>HOTEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location Criteria</td>
<td>transit, city proximity</td>
<td>sub-div &amp; accessibility</td>
<td>proximity to office</td>
<td>transit, city proximity</td>
</tr>
<tr>
<td></td>
<td>technology infrastructure</td>
<td></td>
<td></td>
<td>fuel efficiency</td>
</tr>
<tr>
<td>Positive Externalities</td>
<td>walkability, location</td>
<td>cultural center, public, arts &amp; retail</td>
<td>cultural center, entertainment</td>
<td>walkability, location</td>
</tr>
<tr>
<td></td>
<td>walkability, location</td>
<td>cultural center, entertainment</td>
<td>walkability, retail environment</td>
<td>walkability, location</td>
</tr>
<tr>
<td>Negative Externalities</td>
<td>traffic, location</td>
<td>industrial, retail</td>
<td>industrial, retail</td>
<td>industrial, retail</td>
</tr>
<tr>
<td>Important Amenities</td>
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<td>business services</td>
<td>parking</td>
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<tr>
<td></td>
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<td>business services</td>
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<td>parking</td>
</tr>
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<td>Lot Shape</td>
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<td>access, transit, neighborhood</td>
<td>access, transit, neighborhood</td>
<td>traffic analysis</td>
</tr>
</tbody>
</table>

| STRUCTURE:            |        |        |             |        |
|                       | loads: 40% - 60% per floor | 40% | 40% per floor | 40% per floor |
|                       | 10,000 - 12,000 sf | 10,000 | 10,000 | 10,000 |
|                       | 25,000 - 30,000 sf | 25,000 | 25,000 | 25,000 |
|                       | 25,000 - 30,000 sf | 25,000 | 25,000 | 25,000 |
|                       | 19 - 21 ft | 19 - 21 ft | 19 - 21 ft | 19 - 21 ft |
|                       | 6 - 8 ft | 6 - 8 ft | 6 - 8 ft | 6 - 8 ft |
|                       | 10 - 12 ft | 10 - 12 ft | 10 - 12 ft | 10 - 12 ft |
|                       | 5.11 - 6.25 ft | 5.11 - 6.25 ft | 5.11 - 6.25 ft | 5.11 - 6.25 ft |

| SKIN:                  |        |        |             |        |
|                       | light | light | light | light |
|                       | view | view | view | view |
|                       | vent | vent | vent | vent |
|                       | Image & Aesthetics | Image & Aesthetics | Image & Aesthetics | Image & Aesthetics |

| SERVICES:              |        |        |             |        |
|                       | core size | core size | core size | core size |
|                       | electrical service loads | electrical service loads | electrical service loads | electrical service loads |
|                       | plumbing service loads | plumbing service loads | plumbing service loads | plumbing service loads |
|                       | vertical transportation | vertical transportation | vertical transportation | vertical transportation |
|                       | elevator loads | elevator loads | elevator loads | elevator loads |
|                       | Egress requirements | Egress requirements | Egress requirements | Egress requirements |

| SPACE PLAN:            |        |        |             |        |
|                       | 20% - 30% of area | 20% - 30% of area | 20% - 30% of area | 20% - 30% of area |
|                       | 3.5% - 4.0% of area | 3.5% - 4.0% of area | 3.5% - 4.0% of area | 3.5% - 4.0% of area |
|                       | 1.8% - 2.0% of area | 1.8% - 2.0% of area | 1.8% - 2.0% of area | 1.8% - 2.0% of area |

Figure 5.7 - Use Needs Met by Proposed Tower at Block 37, floors 19 - 48
6. FLEXIBLE BUILDING VALUE

6.1. FROM CASES TO MODELS

In both of the cases just presented, the most important real options are “switching options.” In both cases, the owner or developer has a choice between a number of possible uses to house in their building. At any point in time, housing a given use will have a certain value. This value can be reasonably determined through a straightforward DCF analysis of expected rents to be paid by the use, and the capital markets’ demand for that use’s expected cash flow. But of course, this value will change over time as expected rent levels and capital market demand changes.

The hypothetical owner’s charge is to optimize the value of their building as the change in value for housing different uses unfolds over time. In the new development at Block 37 the most relevant option is the option to change the building’s use mixture as new information about values appears during the development process, so that the value upon completion is maximized. In the case of the Monadnock building, the situation – and important option – is a little different. Here, the owner has a building which already exists in one mode of operation. But this owner still has the option to revitalize the existing building or redevelop the property, in essence “switching uses.”

Both option models developed in this chapter simplify the reality of the options open to the developer or owner. In both cases, the choice has been narrowed down to two uses and their values are modeled using the lattice pricing framework described in section 2.2.1. However, since these cases involve two underlying assets (potential uses), whose price movements are at least somewhat independent of each other, the binomial lattice does not suffice: these models instead use a “double binomial” framework to describe the price movements that each asset can make at each discrete point in time. In a binomial lattice world the asset can take one of two prices in any given timestep; in a double binomial lattice, however, four possible states of the world exist from one timestep to the next: both assets could go up in price, both could go down, or one could go up while the other goes down, and vice versa (see Figure 6.1, and compare it with Figure 2.13).
Figure 6.1 - A double binomial lattice: states of the world represent the up and down movements of two underlying assets.

6.1.1. THE MONADNOCK

The Monadnock case is the simpler of the two: an option to switch uses from its current suboptimal office use to a more valuable use – in this case, residential. Though the option is theoretically perpetual, the lattice modeling technique is unable to price perpetual options, and so it is modeled here as a twenty year option. As will be shown, the value of the twenty year option does approach the limit of the value of the perpetual option. Given the number of other unknowns in our model, such an approximation seems completely acceptable.

The twenty-year redevelopment option is modeled by creating a 20-step lattice and calibrating it so that one time step equals a year - thus in the model the owner can decide, once a year, and based on the state of the world he or she is currently in, whether or not to redevelop. The model is described in more detail, and laid out mathematically, in Appendix A.

In order to simplify the case so that it can valued in the double binomial lattice just described, it will be assumed that the first floor is to always remain retail, and that this retail will be kept from obsolescinc through the constant chum of retailers
and retail trends, as it has in the past. The model will therefore only calculate the redevelopment option associated with the upper 16 stories.

6.1.2. BLOCK 37

The Block 37 development is a very different model, though it is still developed within the same 20-step double binomial lattice used in the Monadnock case. (This model described in more detail and mathematically in Appendix B.) However, since there is no building in this model until the last time step, no intrinsically valuable underlying asset exists until step 20.

In this instance, the development process is modeled as a compound option, where at given timesteps a series of eight investments can be made or not. If the investment is made to pay costs for permitting the project, for example, it allows the developer to move on to the option of deciding whether or not to erect the building’s structure. But if, based on the state of the world at the time of permitting, the developer decides not to pay permitting costs, then the project is abandoned. However, since this is a mixed-use model, at each decision node the developer has one of four (not two) options: he or she can abandon the project, or go forward in one of three modes: dedicated to use 1, dedicated to use 2, or in a flexible mode that puts off the decision of which use to house. Each of these three decisions will have a different cost associated with it, with the flexible cost always being at least as high as the other two.

As with the model being applied to the Monadnock, some simplifications need to be made to the Block 37 case as described in section 5.3. In this instance, we will focus our valuation efforts on the middle section (floors 19-48), which have been designed to potentially accommodate both office and residential uses.

6.2. CALIBRATION ISSUES

The two sections following this one describe the actual application of the cases to the models. This section takes the necessary preliminary steps of explaining the reasoning behind the choice of values for each of the variables in the two models. In both cases, the models will be calibrated to reflect the state of the markets in 2002.

6.2.1. UNDERLYING ASSETS

In the world of options, the underlying asset is what one receives through the exercise of their option. With a financial option, the underlying asset is typically a share of stock. With the option to develop raw land, the underlying asset is the site’s hypothetical HBU building. With both of the cases being modeled here, the
underlying asset is basically the same as in the raw land example, though slightly more complex.

The option to redevelop the Monadnock building is fundamentally the option to receive a new underlying asset (perhaps counterintuitively, the existing building “as is” is not part of the underlying asset, but rather part of the exercise price, as will be shown in the next section). The underlying asset’s present and past underlying values can be known at any given point in time, though its future value will always be uncertain – it is modeled as one of the two stochastic variables in our lattices. The base case examined here is the option to redevelop the Monadnock as high-end luxury apartments. So the underlying asset is the hypothetical apartment building into which the Monadnock could be converted. The value of such a building can be determined one of two ways: through comparables, or through the capitalization of expected net operating income. The capitalization method suggests a potential value of between $225 and $500 per square foot for a semi-luxury apartment building in downtown Chicago. Similarly, comparable high-end apartments were trading for around $300/sf minimum in 2002, and sometimes upwards of $1000/sf. The redevelopment model therefore assumes a conservative initial value of $280/sf of gross building area (GBA) for the underlying asset.

The Block 37 development is also slightly more complex than the simple “raw land” development option. Because of the site’s zoning, the developer actually holds an option whose exercise allows him or her to claim any of a number of values by building for whichever use happens to have the highest value at the time of exercise. For the purposes of this thesis, the model has been set up so that the developer has a choice between two uses for the main part of the building – office and residential. There are thus two underlying assets involved. Initial values for the residential use are assumed to be $280/sf, just as in the Monadnock case, and office values are assumed to be $205/sf.

6.2.2. Exercise Prices

The exercise price is what one gives up in exchange for the underlying asset when exercising an option. With a financial option, the exercise price is the contractually established strike price. In a simple development option model, the strike price is the development costs, primarily consisting of the “hard” and “soft” construction costs. In the models here, things are slightly more complicated.

172 Assuming annual rents to be $30-$50/sf, annual expenses to be at most $12 / year (IREM 2002a), and cap rates to be between 7.5% and 8.0% (Korpacz 2002).
173 Linanne, interview.
174 Based on effective class A rents of $24/sf, net operating expenses to be $6.50 / sf (IREM 2002c), and a cap rate of 8.5% (Korpacz, 2002).
6.2.2.1. Monadnock

In order to redevelop the Monadnock building, the owner is giving up more than just construction costs. He or she is also giving up the current use of the building, and the value associated with it. In addition, the owner would lose potential rents during the construction process (incurring “opportunity costs”), and might have to pay tenants to relinquish their leases. Therefore the price of exercising the redevelopment option at Monadnock is the sum of all of the costs.

The construction cost for converting from offices to apartments, including all hard and soft costs will probably be around $170 per square foot of gross building area (as of 2002). The $170/sf value is slightly over the inflation-adjusted development costs paid for the adaptive reuse project at the Reliance building (excluding site acquisition, and the extensive exterior remodeling done by the city, which the Monadnock will not require). Given that the new use at the Reliance building, luxury hotel, is so similar in nature to the proposed use of the Monadnock as a high-end apartment building, using such a comparable seems reasonable, at least for the base case scenario.

In our model, it is assumed that construction will take a year (which was also the case at the Reliance building), and that one year’s rents will be forgone. It is also assumed that the costs for “buying out” tenant leases at the time of redevelopment will be equal to half a year’s rent. This is probably a lower than average ratio, but there are two reasons to believe it is a good estimate in this case. First it is assumed that all of the existing tenants, being smaller companies (none of whom take up more than half a floor), have relatively short leases without renewal options, and that a reasonably far-sighted owner can arrange such leases in the future. More importantly though, is the fact that the Monadnock was constructed in two segments which are still very distinct with regard to structure, skin, and services. An owner therefore has the possibility, if required, of conducting the reuse project in two pieces, relocating existing office tenants entirely into one building while construction occurs in the other. It is assumed that the building’s net operating income will remain at its current 9%. Therefore the rent and tenant buyout costs will always be 13.5% of the office value – which brings us to the last conversion cost.

The last cost associated with revitalization of the Monadnock is the office value that is being given up in order to convert to residential. This value, like the apartment value which will be assumed upon redevelopment, varies stochastically over time, and forms the second variable in our double binomial lattice. Also like the apartment value, the value of the office use can be determined by capitalizing

Korpacz (2002).
existing and expected rents – using the direct capitalization method, the value of the Monadnock in its current office use is between $95 and $135 per square foot of GBA. On the slightly conservative side, the base case scenario will assume a current value for the office building of $120 per square foot of GBA.

Thus the total price for exercising the redevelopment option depends on the state of the world in which exercise takes place, and is a summation of current construction costs, one year’s forgone rents, the costs of buying tenants out of their leases, and the value of the building’s use for offices.

6.2.2.2. BLOCK 37

The Block 37 development is basically a raw land development, so the exercise price is indeed just the core hard and soft development costs - however, there are two wrinkles in this model. The first is that the development process is modeled as a compound option made up of eight decisions, rather than just a simple “go/no go” decision. The second is that the developer has two potential HBUs for the site (in this case office and residential), and with each investment decision is capable of choosing to either go forward as a residential building, an office building, or as a “flexible” building which can still accommodate both uses. Thus at every decision node, the developer must decide which of three strike prices to pay (if any - abandonment always remains an option). Table 6.1 shows the base case scenario of investment layouts used for the Block 37 development model.

<table>
<thead>
<tr>
<th>timestep</th>
<th>0</th>
<th>1</th>
<th>4</th>
<th>7</th>
<th>10</th>
<th>13</th>
<th>15</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment &gt; Mode</strong></td>
<td><strong>Land</strong></td>
<td><strong>Design</strong></td>
<td><strong>Permit (1st)</strong></td>
<td><strong>Permit (2nd)</strong></td>
<td><strong>Structure</strong></td>
<td><strong>Skin</strong></td>
<td><strong>Services</strong></td>
<td><strong>Space Plan</strong></td>
</tr>
<tr>
<td>Office</td>
<td>85</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>38</td>
<td>18</td>
<td>64</td>
<td>40</td>
</tr>
<tr>
<td>Residential</td>
<td>85</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>32</td>
<td>20</td>
<td>60</td>
<td>66</td>
</tr>
<tr>
<td>Flexible</td>
<td>85</td>
<td>14</td>
<td>8</td>
<td>6</td>
<td>38</td>
<td>20</td>
<td>73</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 6.1 - Investment Diagram for Block 37

Development costs are square foot costs based on approximate calculations from R.S. Means, with adjustments to reflect actual construction costs in the past. Note that the costs associated with each outlay include all incremental costs associated

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176 Given asking rents of $18 psf, net operating costs of between $6 and $8 psf (IREM 2002c), and cap rates between 9.0% and 10.5% (Korpacz 2002). EGI per square foot assumed to be 90% of asking rent.

177 R.S. Means (2002)
with going forward with the strategy associated with the cost, even when those costs are not part of the system actually being constructed. For example, the decision to go forward with a structure able to accommodate both uses entails building a floor-to-floor height taller than would be built for residential uses alone. This in turn implies that the skin costs will be of necessity be slightly higher, if only for the simple reason that more area now needs to be covered. The $200/sf cost of producing a space plan flexible enough to be used for both uses is meant to represent the impossibility of doing so, rather than an actual cost (Although the cost may be a reasonable estimate of producing an Archigram-styled “plug-and-play” building.)

For the purposes of illustration, we are assuming that land values are the residual of the current HBU for the site - that is, the land value is the difference between the highest possible building value and all of the other development costs required to produce that building. A quick calculation reveals that this difference is currently much higher for residential ($85/sf is the residual value) than for office ($28/sf). Assuming then that the cost of the land is equal to the higher of these two, then development would proceed as residential, with an NPV of 0 (and building an office building would have an NPV of negative $57/sf). This NPV of course assumes residual land values, as well as no flexibility to stop the development process or switch uses.

6.2.3. Expiration

The expiration date of an option is the last point in time during which the option can be exercised. For our cases, the expiration date is straightforward: The model for the Monadnock building is set up such that the expiration date is 20 years away (though, as mentioned, in reality the option is perpetual). In the Block 37 model each investment stage has an expiration date, set as the timestep in which the investment decision is made (see Table 6.1). The total development time is set to 5 years as a base case, with each timestep therefore being equal to 3 months.

Unless dividends are being paid by the underlying asset, it is never optimal to exercise a call option until the expiration date (and under most circumstances, never optimal to exercise a put). In the case of the Monadnock building, dividends are being paid in the form of annual rents that could be paid by the hypothetical apartment building, and so exercise of the option (redevelopment of the building) can happen before the twenty year time horizon is over. Indeed, in a great many states of the world, such early exercise will occur. However, in the Block 37 case, there is no real, dividend-paying underlying asset until the last time step of the model. It is therefore never optimal to exercise until the timestep indicated in Table 6.1.
6.2.4. DRIFTS AND THE RISKFREE RATE

In both cases, mean asset prices are determined using standard option methodology, based on the “no arbitrage” principle: hypothetical portfolios of government bonds and the underlying asset are used to value the option at each timestep. Therefore, the short-term riskfree rate is the relevant rate of asset price “drift” and the appropriate measure to use for discounting values back. In 2002, 90-day treasury bills were yielding between 1.21 and 1.83%, and averaged 1.63%. In addition, while the yield curve was fairly steep at the start of the year, it was relatively flat by summer, suggesting that rates were not expected to rise particularly soon. Both models will therefore assume that the relevant riskfree rate is 1.60%.

In addition, however, and unlike standard option valuation, the construction costs that play into exercise prices need to be grown at inflation, which will be taken to be 1.30%, based on the historic spread between government yields and inflation.

6.2.5. VOLATILITY

The volatility for individual property prices tends to be around 20%, regardless of the type of property. This value comes from two studies which used option models to determine implied volatility given market prices. The first study, by Laura Quigg, is one of those referred to in the discussion regarding option models of land value. Given her analysis of the option premiums paid for vacant land, she was able to estimate implied annual volatilities for the underlying asset, and found a range of 18-28%, broken down as follows: business uses had volatilities in the range of 18.5-24.3%; commercial, 21.9-22.5%; and residential ranged from 21.2-26.3%. Of course, this study was restricted to Seattle prices over a short period of time. However, the second study exists, which used an option model of mortgages to determine volatility, and had access to much larger (and more diversified) pool of data. This study found the following weighted mean volatilities by property type: apartments: 17.0%; hotel: 17.0%; industrial: 17.9%; office: 16.6%; retail: 16.7%. Standard deviations for these volatilities ranged from 6.2% to 7.9%, suggesting that most individual properties have annualized volatilities in the range of 10 - 24%. Interestingly, in both studies, there was very little variation between types of uses. Given the above studies, both of the cases here use a volatility of 18% as base case scenario for both property types.

178 Quigg (1993), p 622.
6.2.6. Correlation

The last factor which affects the value of the switching options is correlation between the movements of the underlying asset prices. Since the option in both cases involves trading one asset for another, then the more the two assets move together, the less the option is worth. At the extreme, an option on the choice between two assets whose movements are perfectly correlated will have no value.¹⁸¹

A study in the mid-eighties¹⁸² found the following correlations between price time series of different uses: office and retail, 0.18; hotel and retail: 0.46; and residential and office: 0.06. Using this analysis, the relevant correlation for these models would be 0.06 – meaning that the prices for apartment buildings and office buildings move in ways that bear no relation to each other. However, since the results from this analysis were likely biased towards zero,¹⁸³ I also culled data from the NCREIF portfolio of properties, and analyzed two sets of price time series for correlation between returns (which equals correlation between prices). The first concentrated on high-rise apartments and CBD offices within the entire United States. Given NCREIF’s portfolios, which each consisted of 4 to 231 properties at any given time, quarterly correlations were 0.72 for income returns, and 0.80 for total returns between 1990 and 2002. The second series consisted of all apartments and offices in the Midwest, since the portfolios were too small to break down into the high-rise and CBD segments. In these portfolio, which consisted of 4 to 203 buildings between 1981 and 2002, correlations between offices and apartments were 0.31 for income returns and 0.56 for total returns. Of course, correlations are going to be higher for a portfolio of properties than for individual properties, and the relevant correlation for these models is individual properties.

Melding all of this information together, the models here will use 0.40 as the base case input for correlation between apartment and office prices. This is an intuitive “best guess.” The NCREIF price time series for CBD office and high-rise apartments is probably the most relevant to our cases, and the correlation of income returns probably more relevant to our models, which assume a constant annual yield, and therefore no capital appreciation/depreciation. However that number, 0.72, is based on a shifting portfolio of properties – there is therefore no way to numerically back out estimates of correlation between individual properties. But it is definitely lower, and a reduction of some 40% from 0.72 to 0.40 is not unreasonable. Tempered with the fact that the Midwest portfolio’s returns were in the range of 0.40, as well as the study referred to earlier which found virtually no correlation

¹⁸¹ Assuming that initial prices are fairly close, and that the strike price is reasonably high.
¹⁸³ David Geltner, conversation.
between apartment and office building prices over time, the 0.40 estimate seems fair enough. And, as with the rest of our variables, sensitivity analysis will be performed on the models in order to understand the effect of different assumptions.

6.3. APPLICATION: THE MONADNOCK

The Monadnock building should be viewed as an asset which has value for two reasons: because of the expected stream of future cash flows associated with the rents paid for its use as an office building, and as an opportunity for redevelopment into an apartment building. Since the Monadnock building’s current highest and best use is probably as an apartment building, the opportunity for redevelopment into that use is the most important real option associated with it.

For the purposes of this exercise, it will be assumed that the first floor is to always remain retail, and that this retail will be kept from obsolescing too greatly through the constant churn of retailers and retail trends, as it has in the past. The pertinent values we are interested in, then, are the 16 floors above. And, rather than convert the square footage values which were presented in the last section to total building areas, it will be just as illuminating to see values represented on a square foot basis.

We know from section 6.2.2.1. that direct capitalization (which is a shortcut version of the DCF methodology) values the current stream of cash flows at about $120 per square foot. And this is the value which conventional valuation procedures for commercial real estate would generate. It is possible that potential buyers might intuitively think about the redevelopment option, and that the market therefore might adjust the price upwards slightly – however, this intuitive adjustment by the market would not be part of orthodox valuation theory, and would probably not have any rigorous underpinnings. This model aims to provide just such a rigorous underpinning, and determine exactly how much extra the Monadnock building is worth due to the option to redevelop it into apartments.

6.3.1. INPUTS

Table 6.2 shows the input table used for the model, as programmed into Microsoft Excel. In this model, “Use 1” is the current office use of the building, and “Use 2” is the residential use. All of the inputs are calibrated to the values described in section 6.2.
6.3.2. OUTPUT

Table 6.3 shows the output from the model. The output includes both absolute and relative values of the option to redevelop from office to residential, as well as the (hypothetical) option value the building would have if it were currently in its apartment use, and the relevant option was to convert back to office – for reasons which should be obvious, this value is very low.

<table>
<thead>
<tr>
<th>Option Value w/ Initial Use 1:</th>
<th>25.96</th>
</tr>
</thead>
<tbody>
<tr>
<td>As Percentage of Initial Value:</td>
<td>21.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option Value w/ Initial Use 2:</th>
<th>0.47</th>
</tr>
</thead>
<tbody>
<tr>
<td>As Percentage of Initial Value:</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

Table 6.3 – Option Value and Percentage Premium over DCF Analysis

As the output shows, the option to redevelop the Monadnock adds $25.96 to the per square foot building value, which is a 21.6% premium to the total building value. This is a substantial amount, and even if some of the input assumptions are slightly wrong, the amount is clearly enough to be given serious consideration.

6.3.3. SENSITIVITY ANALYSIS

To see the effect of input assumptions on the redevelopment option value, Figures 6.2 through 6.5 show the option value as a function of initial apartment building value, construction costs, volatility of the two asset prices, and correlation. As the figures show, and just as option valuation theory predicts, the option premium increases as the potential apartment value and volatility increases, and it decreases with increases in construction cost and correlation between the uses.
Figure 6.2 takes the hypothetical new use value as high as $340/sf, which is approximately the premium required to make redevelopment a positive NPV transaction (though perhaps still not optimal, given the option model of land value discussed in chapter 2). However, at this value the redevelopment premium is over 40%, and almost certainly would be reflected in the market price of the building. Lower premiums, however, might not be perceived by the market as a whole, or even the potential seller.

The effect that construction costs and correlation between uses have on the option premium are also interesting. Construction costs can rise much higher than
the estimated costs in the base case scenario, and a significant redevelopment premium can still exist. Likewise, the same relationship would hold if tenant compensation or lost rental revenue were higher than that used in the base case scenario. The apparently anomalous situation with correlation, where a significant premium exists even when correlation is equal to 1, can be explained by the fact that the apartment use is currently so much higher in value than the use as class B office space. Even when the relative price movements of both assets are the same, the absolute difference between them is not, leading to possible situations where the absolute price differential might exceed the redevelopment costs.

Figure 6.6 – Option Premium as a Function of Time to Expiration

Figure 6.6 shows the option value as a function of its time to expiration. Since the model artificially imposes a twenty year expiration date, it is important to see if the perpetual option might have substantially more value. Likewise, if a potential buyer was intending to hold the building for some period of time less than 20 years, this graph could be used to estimate the option value associated with his or her expected holding time. Interestingly, the twenty year option value does seem to approach the theoretical limit of the perpetual option, which can be visually (or mathematically) extrapolated to some 23-24%, just a few points higher than the twenty year model suggests.

An alternate form of sensitivity analysis can also be conducted using this model. In this case the model is used to determine the relative option values for redevelopment into other uses. For example, conversion to a hotel would probably call for the inputs shown in Table 6.4.
Here the primary changes are that the hypothetical value of the new use is lower than for an apartment building, and that the correlation between offices and hotels is much higher than for apartments and offices (although expected annual yields for use 2 are also a bit higher, and tenant compensation costs are negligible). Because of these changes, the option to redevelop into a boutique hotel is less valuable than the option to convert to apartments – it is approximately $10.90 psf, or 9.1% of the current building value as determined via DCF analysis.

Similarly, it might be possible to simply remodel the existing building for office use, and reposition it to a different segment of the office market. This would probably involve slightly less construction costs and less value in the new use, as shown in Figure 6.5. Likewise, the inputs for lease buy outs and tenant compensation would probably be reduced by half, while correlation between the existing and proposed uses would be very high. This analysis uses 0.9 rather than 1 to account for the slight difference in the market segments which would be attracted to the different buildings.

Table 6.4 – Inputs for Redevelopment into Hotel use.

<table>
<thead>
<tr>
<th>Inputs:</th>
<th>Hotel Redevelopment</th>
<th>Apartment Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Value of Use 1:</td>
<td>120</td>
<td>240</td>
</tr>
<tr>
<td>Construction Cost 1&gt;2:</td>
<td>170</td>
<td>170</td>
</tr>
<tr>
<td>Buy-out costs (% of V):</td>
<td>4.50%</td>
<td>0%</td>
</tr>
<tr>
<td>Annual Yield of Use 1:</td>
<td>9.00%</td>
<td>8.00%</td>
</tr>
<tr>
<td>Volatility of Use 1:</td>
<td>18.0%</td>
<td>18.0%</td>
</tr>
<tr>
<td>Inflation Rate:</td>
<td>1.30%</td>
<td>1.60%</td>
</tr>
<tr>
<td>Riskfree Rate:</td>
<td>1.60%</td>
<td></td>
</tr>
<tr>
<td>Correlation between Uses:</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.5 – Inputs for Office Remodeling / Repositioning

<table>
<thead>
<tr>
<th>Inputs:</th>
<th>Remodeling / Repositioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Value of Use 1:</td>
<td>120</td>
</tr>
<tr>
<td>Construction Cost 1&gt;2:</td>
<td>140</td>
</tr>
<tr>
<td>Buy-out costs (% of V):</td>
<td>2.50%</td>
</tr>
<tr>
<td>Annual Yield of Use 1:</td>
<td>9.00%</td>
</tr>
<tr>
<td>Volatility of Use 1:</td>
<td>18.0%</td>
</tr>
<tr>
<td>Inflation Rate:</td>
<td>1.30%</td>
</tr>
<tr>
<td>Riskfree Rate:</td>
<td>1.60%</td>
</tr>
<tr>
<td>Correlation between Uses:</td>
<td>0.9</td>
</tr>
</tbody>
</table>
As should be expected, the option value for this sort of redevelopment is quite a bit lower than for the other two – only $3.90 psf, or a 3.3% premium. This low value is primarily because of the very high correlation between uses, and suggests that sites which are zoned to allow for multiple uses are more valuable than sites zoned for a single use.

It is important to also note that, although all three of these options (conversion to apartments, hotel, or repositioned office space) are separate from each other, their effect on building value is not simply additive. That is, one cannot simply take the three option premiums and add them together to get a total redevelopment premium. Because of correlations between all of the different uses, the options interact in far less intuitive ways. On the other hand, there is definitely some additional premium for the option to convert to hotel or offices, over and above the primary premium for the apartment conversion.

### 6.3.4. IMPLICATIONS

In addition to revealing how conventional NPV analysis can undervalue existing buildings by ignoring the ability to redevelop, the valuation of this case study also has potential implications for investment strategy. Except in cases where the redevelopment option is “in the money” or very close to it, it is quite likely that the market does not recognize the premium it entails. If true, this value could be captured by long-term investors willing to concentrate on properties in shifting urban areas.

While the exact numbers generated by this model should be taken with a grain or three of salt, the approximate numbers are probably good enough for the private real estate market, where no two assets are identical and market transactions are too few to truly determine exact values for any asset. The model does provide a good approximation of the potential value redevelopment can hold for a building, and is certainly useful for comparing alternate investments.

### 6.4. APPLICATION: BLOCK 37

The new development at Block 37, as presented in section 5.3, has two valuable options associated with it. The first is the option to abandon the project at any point in time, by simply not paying the next required investment. This option exists whether the developer is committed to one of the two uses or not, and will be exercised any time that values drop sufficiently. In fact, exercise of this option occurs regularly during the down stages of real estate market cycles, as buildings in the
planning process shrink, are put on hold for several years, or are abandoned altogether.

However, the second important option created by the design and development process outlined in the case study is relatively unique: the option to switch proposed uses. This in effect gives the developer the ability weather down markets in either one of the two uses proposed for the site, by switching the primary use of the building over to the use which is not currently experiencing trouble. This has a potentially great value, as evidenced by market changes over the past several years.

For example, a new Trump Tower was proposed for a site in Chicago’s Loop before the recession of 2001 and the sagging office market that has yet to rebound. And since this development was proposed purely as an office building, it is continually being put on hold and shrinking in size. Conversely, the market for high-rise condos is booming, with many new construction starts in downtown Chicago over the past few years. One can imagine that, if the Trump tower had been designed in a manner similar to the proposal here for Block 37, then construction could have proceeded long ago, with a very high fraction of residential units and a low fraction of office space.

There is also a third important option, though, and one which is not valued by this model. This is the option to wait. In addition to simply abandoning the project, the developer also has the option to hold off from one stage to the next, waiting for new information or for a market to improve. Because of the mathematical difficulties involved with this possibility, it has been excluded from the model. This exclusion has the effect of raising the value of the switching option relative to the option of abandoning a single use, though it should not greatly affect the value of the switching option relative to development or land costs.

Just as with the redevelopment model, a number of simplifications have also been made for ease of exposition and analysis. It is assumed that the first three floors of the building will be retail. While the option to use the second and third floors as office space exists, as described in the case, and could be valued, it will be clearer here to ignore it. Likewise, it is simply assumed that a mixed-use building will be created under any scenario of use values, and that the top 12 stories will always be residential, and that stories 9-18 will always be office. Thus, it is the middle 30 stories which are of interest here, and which are valued by the model. For further simplification, it will be assumed that the established retail, office, and residential spaces have a zero net present value after land is purchased. And, as with the Monadnock example, the analysis will be based on square foot costs and values.
6.4.1. INPUTS

Table 6.6 shows the input tab on the spreadsheet-implemented option model, along with the base scenario values whose reasoning was laid out in section 6.1. In this table, “Use 1” refers to the office use, and “Use 2” is residential.

<table>
<thead>
<tr>
<th>INPUTS:</th>
<th>Investments / Costs:</th>
<th>Use 1</th>
<th>Use 2</th>
<th>Flexible</th>
<th>Time-Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Value of Use 1:</td>
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<tr>
<td>Volatility of Use 1, annual:</td>
<td>18%</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Value of Use 2:</td>
<td>280</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatility of Use 2:</td>
<td>18%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riskfree Rate, annual:</td>
<td>1.6%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflation, annual:</td>
<td>1.3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation between Uses:</td>
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<td>Development Period, years:</td>
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</tr>
<tr>
<td>Total Development:</td>
<td>262</td>
<td>280</td>
<td>544</td>
<td>n/a</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.6 – Inputs for Block 37 model, base case scenario

6.4.2. OUTPUT

The bottom line results from the model, given the inputs of Table 6.6, are shown in Table 6.7. The output includes three values, each expressed as an absolute value in dollars per square foot, and also as percentages of the land value and initial value of the building.

<table>
<thead>
<tr>
<th>OUTPUTS:</th>
<th>Absolute</th>
<th>% of L</th>
<th>% of Vo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Development Option, Use 1:</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Value of Development Option, Use 2:</td>
<td>3.44</td>
<td>4.1%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Value of Development Option, Flexible Uses:</td>
<td>6.37</td>
<td>7.5%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

Table 6.7 – Inputs for Block 37 model, base case scenario

The first value is the value to go forward with the development of an office building, given the option to abandon the project at any time before the building is complete. In the case of the office use, since the current value is far below the cost of development, the option is worthless. The next value, for the option to abandon the apartment development, is worth $3.44/sf, or 4.1% of the land cost. Lastly, the option to go forward maintaining the ability to switch between the two uses is worth $6.37/sf, or 7.5% of the land cost. While this is not a startling sum, it is almost twice the value of the option to simply go forward at the current highest and best use –
and this doubling in the premium occurs even with the cost increases incurred by going forward with a flexible building.

However, in order to really understand these values, it is worth looking inside the proverbial black box and seeing where they come from, and under what conditions the flexibility option comes into play. As with any lattice model, the singular values described above come from probabilistic expectations about the possible future values the two uses could take. In each time step where an investment outlay is required, the possibility exists that there will be some states of the world where the option to go forward in the flexible mode, some states where it is optimal to commit to a single use, and some options where it is best to abandon the development completely.

Figure 6.7 – The 169 Possible “States of the World” at time t = 12

Figure 6.7 shows the twelfth time step in the model, under the conditions imposed by the inputs from Table 6.6. While there is no investment required at this timestep, the figure illustrates how to read each timestep in the lattice. In this figure,
each outlined cell represents a state of the world. Each state, in turn, has values for the two uses associated with it (not shown), along with three option values: office, residential, and flexible (which are shown). The black square in the middle shows the location of the initial values, and is highlighted purely for orientation.

As one moves up in the lattice, residential values are gaining in value, while residential values fall lower in the lattice. Likewise, office values move left to right, increasing in value further to the right in the lattice. Thus, movements up and to the right in the tree represent states of the world where both assets are increasing in value, movements down and to the right represent states of the world where office values are increasing and residential values are falling, and so on. Because of the correlation between uses, of course, movements up and to the right or down and to the left are more probable than movements along the other diagonal. In fact, given the inputs in Table 6.6, the probability of moving up and to the left or down and to the right is 35% each, while movements up to the left or down and to the right each have a 15% chance of occurring.

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>128.7</td>
<td>128.7</td>
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</tr>
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<td>128.7</td>
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</tr>
<tr>
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<td>128.7</td>
<td>128.7</td>
<td>128.7</td>
<td>128.7</td>
<td>128.7</td>
</tr>
</tbody>
</table>

Figure 6.8 – The 169 possible “States of the World” at time t = 12, with approximate probability topography.
When reading the diagrams that follow, it is also important to keep in mind that because of the number of links connecting to states of the world nearer the middle is much larger than the number of links connecting to the edges of the lattice, there is a much higher probability of being in a state of the world nearer the middle than nearer an edge. This is the normalized distribution effect of the lattice methodology which was described in section 2.2.1. To illustrate, Figure 6.8 shows the same lattice as figure 6.7, but with an approximate “probability topography” overlaid, showing the relative probability of states of the world occuring.

Figures 6.9 through 6.15, which follow, show the timesteps where investments are required. For illustrative purposes, states of the world in which it is advantageous to remain flexible are highlighted in gray, while states of the world in which abandonment is optimal are blacked out – the black square with white text in the center of some diagrams, however, is simply a reference to the center of the diagram. (The asterisks refer to which use is optimal at that state in the world, but can be ignored in these diagrams).

Figure 6.9 shows the possible states of the world at the first timestep, when the decision to invest in a design must be made. Under almost all conditions, it will be advantageous to go forward with a flexible design. In fact, unless residential prices continue to rise and office prices continue to fall (which, according to this model, has only a 15% chance of occurring), it will be optimal to go design a flexible building, even though the value of the building as offices is substantially worse than the value as residences, and the cost of designing the flexible building is much higher.
Figure 6.10 shows the possible states of the world at timestep 4, one year into the development process. It is here that the first outlay to pay for the permitting process must be made. Once again, there is a very high probability that having a flexible design and paying to permit the building under two scenarios is worthwhile.
Figure 6.11 – Boundary Conditions for going forward with Flexible Design in Second Round of Permitting ($t = 7$)

At timestep 7, almost two years into the process and assuming a cash outlay to complete the permitting process, it remains quite probable that the flexible strategy is beneficial. Also note that in this timestep there are two states of the world, in which asset prices for both uses have fallen almost continuously, in which the project should be completely abandoned. But the probability of these states occurring from the initial state of the world is well under 1%.
Figure 6.12 – Boundary Conditions for going forward with Flexible Structure ($t = 10$)

Figure 6.12 shows the possible states of the world at timestep 10, halfway through the development process. It is here that construction begins, and the first actual construction investment, that for the structure, must be made. As the figure shows, there is a good chance that even producing the flexible structure outlined in the case study will be optimal. Again, the possibility of stopping the development process at this point has grown considerably, mostly because this is the first really large investment that has been required. But if residential prices have fallen at all relative to office values, then it usually remains beneficial to keep open the option to switch uses.
When the decision to go forward with a skin that accommodates both uses must be made, we begin to see a more significant narrowing of the region where remaining flexible is still optimal. There is also still a small region where it might be optimal to abandon the project, even though construction has begun, and (presumably) the structure is almost finished. While unusual, abandonment of a project during construction has occurred many times in the past, especially when real estate cycles move into their downward spiral.
Figure 6.14 shows the need to make a final decision regarding the building's services, approximately halfway through the development process. Here, in part because of the significant extra costs associated with increasing the elevator cores and other services to accommodate both uses, the band of possible states of the world in which remaining flexible is the best strategy narrows considerably. But another reason for this narrowing is that, now that the development process is 3/4 complete, the amount of change which can occur in the markets before the building is complete is beginning to decrease significantly.
Figure 6.15 – Boundary Conditions for going forward with Flexible Space Plan (t = 18)

Figure 6.15 shows the expected result that paying the absurdly high costs of designing a flexible space plan does not pay off in any states of the world. But it also shows the less obvious result that, only if prices for both uses have fallen drastically during the entire development process will it be worthwhile to stop construction this late in the game. In fact, the states of the world shown in black (abandonment) in this diagram cannot occur, due to the fact the only way to reach them going forward in time is through states of the world in which abandonment would have already occurred. But, since lattices value options by moving backward in time from the future terminal state when all options expire to the present, valuation of such impossible states of the world are still required.
6.4.3. SENSITIVITY ANALYSIS

Going through sensitivity analysis with each of the five most important variables for options, as was done with the Monadnock, would show the same basic results for all three option values in this case. The values would increase with increases in volatility, the value of the underlying assets, or development times. Likewise, all three values would decrease with increases in development costs, and the value of flexibility would decrease as correlation between the two increased.

6.4.3.1. THE CASE OF SIMILAR VALUES

However, given the somewhat unusual state of the current market, in which office uses in downtown Chicago have a much lower value than residential, it might be more useful to look at a more typical scenario for which mixed-use development is more likely – one in which the values of the two uses are similar to their development costs. Table 6.8 shows the same inputs as used previously, except for one change. In this scenario, office values are set equal to their development cost. Thus, unlike in the previous analysis, a developer in this case should be indifferent to building offices or residential on the site: both are zero NPV investments, when looked at through the lens of conventional DCF analysis.

While not the current state of affairs, such a scenario is quite common – similar values to those in Table 6.8 would have been the situation all through the mid- to late-nineties, and assuming the economy recovers, will likely be the case again in another year or two.

<table>
<thead>
<tr>
<th>INPUTS:</th>
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</thead>
<tbody>
<tr>
<td>Initial Value of Use 1:</td>
<td>262</td>
</tr>
<tr>
<td>Volatility of Use 1, annual:</td>
<td>18%</td>
</tr>
<tr>
<td>Initial Value of Use 2:</td>
<td>280</td>
</tr>
<tr>
<td>Volatility of Use 2:</td>
<td>18%</td>
</tr>
<tr>
<td>Riskfree Rate, annual:</td>
<td>1.6%</td>
</tr>
<tr>
<td>Inflation, annual:</td>
<td>1.3%</td>
</tr>
<tr>
<td>Correlation between Uses:</td>
<td>0.4</td>
</tr>
<tr>
<td>Development Period, years:</td>
<td>5.0</td>
</tr>
<tr>
<td>Investments / Costs: Use 1</td>
<td></td>
</tr>
<tr>
<td>Use 2</td>
<td>Flexible</td>
</tr>
<tr>
<td>Time-Step</td>
<td></td>
</tr>
<tr>
<td>Land:</td>
<td>85</td>
</tr>
<tr>
<td>Design:</td>
<td>9</td>
</tr>
<tr>
<td>1st Permitting:</td>
<td>4</td>
</tr>
<tr>
<td>2nd Permitting:</td>
<td>4</td>
</tr>
<tr>
<td>Sitework &amp; Structural:</td>
<td>38</td>
</tr>
<tr>
<td>Skin:</td>
<td>18</td>
</tr>
<tr>
<td>Services:</td>
<td>64</td>
</tr>
<tr>
<td>Space Plan:</td>
<td>40</td>
</tr>
<tr>
<td>Total Development:</td>
<td>262</td>
</tr>
</tbody>
</table>

Table 6.8 – Inputs for Block 37 model, alternate scenario

In such a scenario, the value of flexibility increases dramatically, while the abandonment options do not increase significantly. This is shown in Table 6.9. The option to switch uses, even with the extra costs involved, is worth almost ten times
as much as the ability to abandon the project when either of the two uses are fixed. It also adds 35% to the value of the land and over 10% to the value of the proposed project. This illustrates an important (if obvious) principle: all else equal, the value of being able to hold off the decision as to the exact use for the site will be most valuable when the two uses are very close in both value and development cost. Thus, while the base case scenario shows an example of a situation where the value of flexibility is relatively low (though still significant), this case shows the maximum relative value that flexibility in the design and development process can add to the value of Block 37.

<table>
<thead>
<tr>
<th>OUTPUTS:</th>
<th>Absolute</th>
<th>% of L</th>
<th>% of Vo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Development Option, Use 1:</td>
<td>2.68</td>
<td>3.2%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Value of Development Option, Use 2:</td>
<td>3.44</td>
<td>4.1%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Value of Development Option, Flexible Uses:</td>
<td>30.50</td>
<td>35.9%</td>
<td>10.9%</td>
</tr>
</tbody>
</table>

Table 6.9 – Option Values Associated with the Inputs in Table 6.8

Figures 6.15 through 6.21 show the boundary conditions for remaining flexible at each stage in the development process, given the inputs of Table 6.8. In all stages, the probability that flexibility in design and construction is advantageous is much higher than in the previous scenario.

Figure 6.16 – Boundary Conditions for going forward with Flexible Design ($t = 1$)

Figure 6.17 – Boundary Conditions for going forward with Flexible Design in First Round of Permitting ($t = 4$)
Figure 6.18 – Boundary Conditions for going forward with Flexible Design in Second Round of Permitting ($t = 7$)

Figure 6.19 – Boundary Conditions for going forward with Flexible Structure ($t = 10$)
6.4.3.2. The Case of Land Purchase Delay

This development model can also be used to examine changes in the typical order of investment stages in the development process. For example, it is not uncommon for purchase of land to be contingent on receiving permits for a proposed project, or for land to be optioned for purchase for some time before the actual purchase is made. In a similar manner the inputs in Table 6.10 assume that the design and permitting of the Block 37 project will be complete before the land is actually purchased, with the associated option values shown in Table 6.11.

<table>
<thead>
<tr>
<th>INPUTS:</th>
<th>Investments / Costs:</th>
<th>Use 1</th>
<th>Use 2</th>
<th>Flexible</th>
<th>Time-Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Value of Use 1: 262</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Volatility of Use 1, annual: 18%</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Initial Value of Use 2: 280</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Volatility of Use 2: 18%</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riskfree Rate, annual: 1.6%</td>
<td>Sitework &amp; Structural: 38</td>
<td>32</td>
<td>38</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Inflation, annual: 1.3%</td>
<td>Skin: 18</td>
<td>20</td>
<td>20</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Correlation between Uses: 0.4</td>
<td>Services: 64</td>
<td>60</td>
<td>73</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Development Period, years: 5.0</td>
<td>Space Plan: 40</td>
<td>66</td>
<td>300</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Total Development:</td>
<td>262 280 544</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.10 – Inputs for Block 37 model, alternate scenario

<table>
<thead>
<tr>
<th>OUTPUTS:</th>
<th>Absolute</th>
<th>% of L</th>
<th>% of Vo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Development Option, Use 1:</td>
<td>18.35</td>
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<tr>
<td>Value of Development Option, Use 2:</td>
<td>20.24</td>
<td>23.8%</td>
<td>7.2%</td>
</tr>
<tr>
<td>Value of Development Option, Flexible Uses:</td>
<td>35.38</td>
<td>41.6%</td>
<td>12.6%</td>
</tr>
</tbody>
</table>

Table 6.11 – Option Values Associated with the Inputs in Table 6.10

Under this scenario all option values increase, but the most dramatic increases are for the options to abandon the project when the use for the building is fixed. While keeping the process flexible and the decision open is still quite valuable, with almost the same value as the other two options combined, it is the ability to hold off the high land investment cost for almost two years that drives the output in Table 6.11, and makes the abandonment option in single-use projects relatively more valuable.
6.4.4. IMPLICATIONS

Though this case is focused on the development process, the results also carry implications for the end product, which can be explored by combining this model with the redevelopment model set forth in the previous section.

6.4.4.1. THE FLEXIBLE PROCESS

Probably the most obvious inference that can be drawn from the valuation of the Block 37 case study is the importance of flexibility during the development process. Mixed use developments can provide a level of flexibility to the process which is not possible when developing single-use buildings, and this flexibility has a potentially great value.

But stepping through the model and examining the boundary conditions under which flexibility makes strategic sense at each investment stage allows deeper insights to be gained. It should be clear from the model that maintaining flexibility is more important early on in the process, and gradually diminishes as construction nears completion. There are two reasons for this: uncertainty and the size of the required investments. Given the length of time involved in the development of any significant project, uncertainties about future conditions are highest at the project’s inception. Likewise, it is at the beginning of a project that the investment outlays are lowest (ignoring land costs, or assuming that land has been optioned). It is in design and permitting phases where flexibility has the most value. Even if the “flexible” building is abandoned during the construction process in favor of a committed strategy, the options created early on by remaining open to the possibility of multiple uses have significant value.

6.4.4.2. THE FLEXIBLE PRODUCT

However, if, because of the way events unfold, the flexible strategy remains optimal deep into the development process, and some of the building systems are designed for multiple uses, an additional advantage is created – the ability to redevelop later with significantly reduced costs. And the value of this advantage can be approximated through the use of the redevelopment model. Though combining these two models in this way is not as technically correct or elegant as building a single model which encompasses both the initial development process as well as potential future redevelopments, the process can be illuminating and the results are not very inaccurate.

For example, suppose that Block 37 was developed with a structure, skin, and services that are capable of meeting the needs of both uses. If so, the additional cost involved was something on the order of $11 - $19 per square foot, depending
on the use commitment. Now, if this was the case, then redevelopment costs to switch from one use to the other are going to be significantly lower than they might otherwise be, since only the space plan will need major changing. Assume redevelopment costs are around twice as much as the original space plan: $80/sf to switch from residential to office, and $130/sf to make the reverse switch (this doubling of the original costs is meant to cover demolition, permitting, and interactions between the space plan and services).

Table 6.12 shows the inputs that might be plugged into the redevelopment model upon completion of the most flexible Block 37 design, and Table 6.13 shows the output.

<table>
<thead>
<tr>
<th>INPUTS:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Value of Use 1:</td>
<td>262</td>
</tr>
<tr>
<td>Construction Cost 1&gt;2:</td>
<td>130</td>
</tr>
<tr>
<td>Buy-out costs (% of V):</td>
<td>8.50%</td>
</tr>
<tr>
<td>Annual Yield of Use 1:</td>
<td>8.50%</td>
</tr>
<tr>
<td>Volatility of Use 1:</td>
<td>18.0%</td>
</tr>
<tr>
<td>Inflation Rate:</td>
<td>1.30%</td>
</tr>
<tr>
<td>Riskfree Rate:</td>
<td>1.60%</td>
</tr>
<tr>
<td>Correlation between Uses:</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Table 6.12 – Redevelopment Option Value associated with flexible Block 37 design**

<table>
<thead>
<tr>
<th>OUTPUTS:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Option Value w/ Initial Use 1:</td>
<td><strong>13.78</strong></td>
</tr>
<tr>
<td>Option Value w/ Initial Use 2:</td>
<td><strong>17.16</strong></td>
</tr>
<tr>
<td>As Percentage of Initial Value:</td>
<td><strong>5.3%</strong></td>
</tr>
<tr>
<td>As Percentage of Initial Value:</td>
<td><strong>6.1%</strong></td>
</tr>
</tbody>
</table>

**Table 6.13 – Option Value and Percentage Premium**

In such a scenario, the additional option value created is approximately the same as the additional costs incurred to make the building flexible, even though the original cost of creating the flexible product was recouped by the developer's ability to maximize profits from the initial development. Thus the potential of having a flexible product with lower future redevelopment costs will in some cases add enough value to justify the added costs, even if uncertainty during the process does not demand it. This is especially likely to be the case with the structure layer, since the additional costs incurred are relatively low, and designing it properly can allow use changes which might otherwise be impossible.
7. CONCLUSION

The research presented here has important implications for real estate strategy. In particular, this work should be of interest to three primary players in the real estate industry: investors, developers, and architects.

The results from the first model suggest that even when a building is performing moderately, and redevelopment is not optimal within the typical investment horizon of 3-5 years, the value associated with the redevelopment option can be quite high. This is especially the case when the zoning allows for multiple uses on the site and the neighborhood is changing. Given that this redevelopment option is hidden from traditional DCF analysis, and that the typical real estate investor does not explicitly consider long-term redevelopment opportunities when purchasing existing buildings, a potential strategy emerges: buy and hold those stabilized assets whose redevelopment premiums that are not reflected in the price of the asset.

The results from the second model have implications for development strategy, at least in developments that are, or can be, mixed-use. In particular, when zoning and market conditions allow, the benefits of designing and permitting multiple buildings, multiple variations of the same building, or “flexible” buildings which can switch between different types of uses will almost always outweigh the costs. Especially in markets where long delays in the permitting process are typical, and supply is in danger of increasing due to other players, the value of flexibility is keen. And while the cases herein focused on mixed-use urban buildings, the value of early flexibility — especially in the design process — can be generalized.

This is one of the reasons that architects should also have an interest in the results of the models. In addition to outlining some of the key considerations in the growing niche of building redevelopment, this thesis provides some economic justification for design work that goes beyond the traditional contract. In effect, one view of the design process is that of option creation. At least in the schematic stages, the design process is one of creating and evaluating many alternative strategies. And though architects are well versed in methods for giving such strategies physical form, the strategies also have economic value associated with them due to the options they create. Given the high degree of risk in the early stages of development, these “design options” probably have more value than architects or developers realize.

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184 Jillson, interview
185 As outlined in Baldwin & Clark (2000).
I can think of at least two direction this work could be taken: model improvement and empirical testing. Both models contain oversimplifying assumptions that could be changed to get more accurate results. The most important revision that could be made to the redevelopment model would be to change the way in which asset prices move over time. The present model assumes that real estate returns are normally distributed, even though there is some evidence that this is not the case.\footnote{Young & Graff (1995).} One way of potentially increasing the accuracy of the model would be to model asset prices such that they exhibit mean reversion and autocorrelation. Whether this would significantly affect the model output remains to be seen, but a model with these characteristics would better reflect reality.

On the other hand, mean reversion and autocorrelation in asset prices are probably less important a defect in the new development model (though they could still be added). Rather, the most important change that could be made to this model would be to allow for the option of waiting – holding off the development process for a short while – in addition to the option of abandoning the project.

Furthermore, empirical testing of these models (either the ones described in this thesis or the improved versions described above) would be very useful, especially for the redevelopment model, which is probably the more practical of the two. It would be very revealing to determine the extent to which market prices of existing assets reflect the redevelopment premium. The extent to which they do would suggest that the basic idea is correct; the extent to which they do not, however, would probably reflect inefficiencies in the real estate market more than problems with the model. This would in turn imply that the strategy I've outlined for buying and holding certain types of assets specifically for their redevelopment premium has some validity.

Despite the additional work which could be done here, however, this thesis does represent a necessary start to any architectural and economic analysis of “flexible” buildings, and important insights into architectural design, development strategy, and real estate investment can still be gained from this simple work.
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A. THE REDEVELOPMENT MODEL

This model for calculating the redevelopment option associated with a building which already contains an existing use is a double binomial lattice, using typical CRR parameters for a single binomial lattice, but with significant adjustments for the dual asset nature of the problem.

At any time \( t \), there are a finite number of states of the world, \( s \), with two underlying asset values, \( V_1(t, s) \) and \( V_2(t, s) \). Let \( V_1(t, s) \) be the value of the building in its current state of use, and let \( V_2(t, s) \) be the value of the building with the proposed redevelopment - both of these values will vary stochastically over time. Let the annual volatility of the asset prices be represented by \( \sigma_1 \) and \( \sigma_2 \), respectively, and the correlation between the two be \( \rho \). The riskfree rate will be denoted by \( r \).

Considered alone, each of the two assets have discrete up and down price movements from one timestep to the next, \( u \) and \( d \), along with probabilities, \( p \) and \( q \), of becoming either. The movements and associated probabilities are given by the following four equations, as per the typical CRR lattice:

\[
\begin{align*}
\Delta u &= \exp(\sigma) \\
\Delta d &= \exp(-\sigma) \\
p &= \frac{(\exp(\sigma) - d)}{(u-d)} \\
q &= 1 - p
\end{align*}
\]

Then at time \( (t+1) \), there can be four states of the world which derive from each state of the world at time \( t \), based on the up and down movements of the two assets: \( uu, ud, du, \) and \( dd \). There will likewise be four probabilities of moving from the state at time \( t \) to any of the above possible states at time \( (t+1) \): \( P_{uu}, P_{ud}, P_{du}, \) and \( P_{dd} \). Given a correlation between the two assets, \( \rho \), the above probabilities are set by the equations:

\[
\begin{align*}
P_{uu} &= \frac{\rho \sigma_1 \sigma_2 - p_1 u d - p_2 d u - p_1 d d + p_2 u u + p_1 u d + p_2 d u}{u u - u d u - d u + u d u} \\
P_{ud} &= p_1 - P_{uu} \\
P_{du} &= p_2 - P_{uu} \\
P_{dd} &= 1 - (P_{uu} + P_{ud} + P_{du})
\end{align*}
\]

Due to adjustments for correlation, the above four equations are only approximations for the true probabilities. For typical volatility and riskfree rate parameters, the approximation remains very precise for all correlations. However,
correlations above 0.8 begin to produce slight errors (upwards of 5%) when volatility exceeds 50% or the riskfree rate approaches 10%. For real estate problems, volatilities will usually remain around 20%, and it seems unlikely that the riskfree rate will approach anything near 10% in the foreseeable future. Moreover, given the nature of the problems for which this model is constructed, the level of innate uncertainty around “true” asset values, construction costs, volatility, and even correlation itself suggests that small errors in the calculation of probabilities is probably not of great concern.

Equations A.1 - A.4 can be used to construct a three-dimensional lattice with states of the world for both assets (see Figure A.1 for a small example), while equations A.5 - A.8 will be used (along with others) to value the option. Given a lattice which calculates possible asset prices out to a terminal time, \( T \), the value of the building with the option to redevelop, \( V_{RDV1}(T, s) \), will be given by the equation

\[
V_{RDV1}(T, s) = \max \left( V_1(T,s), V_2(T,s) - (K_c e^{iT} + y_1 V_1(T,s) + b V_1(T,s)) \right) \quad (A.9)
\]

at any given terminal node. \( K_c \) is the construction cost for switching from use 1 to use 2, which grows at an inflationary rate \( i \) during each timestep. \( y_1 \) is the annual yield (i.e., NOI) of the building in its current use, and \( b \) is the cost of buying out existing
tenants. Note that redevelopment occurs when the second side of the maximization function is larger, and that the last part of the equation, \((K_e e^T + j_1 V_1(T, s) + b_1 V_1(T, s))\), includes all of the development costs, assuming that construction causes a year of foregone rents, and that the costs of both foregone rents and tenant compensation is a constant function of the existing building’s value. (The other opportunity cost of redevelopment, loss of the building’s value in its original use, is given up by the way in which the maximization function is set up).

In addition, the model assumes that if redevelopment has occurred, and the building currently houses use 2, then the value of the building with the option to redevelop back to use 1, \(V_{RVD2}\), would be calculated using the same equation A.9, except replacing all subscripts 1 with 2, and vice versa.

In all intermediate steps \(t\) of the lattice, the value \(V_{RVD}(t, s)\) is a function of the probability of jumping to one of the four possible states of the world in time \((t+1)\). For the original use:

\[
V_{RVD1}(t, s) = \max \{j_1 V_{RVD1}(t, s) + (1-j_1) e'(e') (P_{uu} V_{RVD1}(t+1, uu) + P_{ud} V_{RVD1}(t+1, ud) + P_{du} V_{RVD1}(t+1, du) + P_{dd} V_{RVD1}(t+1, dd)) \}
\]

Note that the probabilistic value for each asset is “depreciated” by the upcoming year’s rents. When the current use is retained (in the first part of the maximization function), those rents are included in the valuation equation. However, when redevelopment occurs, those rents are lost. Thus the last part of the equation, \((K_e e^T + b_2 V_2(t, s))\), only includes the costs of construction and tenant compensation as development costs. Again, the value for \(V_{RVD2}\) (assuming the building has already been redeveloped and is currently in use 2) at intermediate timesteps would also follow equation A.10, but with subscripts 1 and 2 reversed.

Using equations A.1 - A.10, then, the current value of the building with the option to redevelop, \(V_{RVD}(0)\), can be calculated backwards from all of the terminal nodes in the lattice to the single node at initial time \(t=0\). Subtracting out the value of the building in its current use, \(V_1(0)\), the “pure” redevelopment option value, or redevelopment premium, can be obtained.

Note the model has been set up such that it values not only the option to redevelop from use 1 to use 2, but also back again. Theoretically, if redevelopment costs were low enough, situations might occur where it might be optimal to switch back and forth between the two uses several times over the twenty year time horizon.
B. THE NEW DEVELOPMENT MODEL

This model divides the development process into eight linked investments, and allows the owner/developer to decide before each investment outlay whether to go forward committed to one of two uses or whether to go forward maintaining the flexibility to choose between the two uses. Much like the redevelopment model this is a double binomial lattice, with probabilistic states of the world determined by the same eight equations.

This model also has twenty timesteps. However, the length of time represented by the timestep is a variable in this model, dependent on \( L \), which represents the total length of time for the development process. The length of time represented by a timestep is therefore given by the simple equation

\[ \delta t = \frac{L}{20} \]  

(B.1)

At any time \( t \), there are a finite number of states of the world, \( s \), with two underlying asset values, \( V_1(t, s) \) and \( V_2(t, s) \). Let \( V_1(t, s) \) be the value of the building in housing use 1, and let \( V_2(t, s) \) be the value of the building which houses use 2. Both of these values will vary stochastically over time. Let the annual volatility of the asset prices be represented by \( \sigma_1 \) and \( \sigma_2 \), respectively, and the correlation between the two be \( \rho \). The riskfree rate will be denoted by \( r \), and the rate of inflation by \( i \).

Considered alone, each of the two assets have discrete up and down price movements from one timestep to the next, \( u \) and \( d \), along with probabilities, \( p \) and \( q \), of becoming either. The movements and associated probabilities are given by the same four equations as with the redevelopment model, as per the typical CRR lattice:

\[ u = e^{\sigma_1 \sqrt{\delta t}} \]  

(B.2)

\[ d = e^{-\sigma_1 \sqrt{\delta t}} \]  

(B.3)

\[ p = \frac{(e^{\rho \sigma_1 \sigma_2} - d)}{(u - d)} \]  

(B.4)

\[ q = 1 - p \]  

(B.5)

Then at time \( (t+1) \), there can be four states of the world which derive from each state of the world at time \( t \), based on the up and down movements of the two assets: \( uu, ud, du, \) and \( dd \). There will likewise be four probabilities of moving from the state at time \( t \) to any of the above possible states at time \( (t+1) \): \( P_{uu}, P_{ud}, P_{du}, \) and \( P_{dd} \). Given a correlation between the two assets, \( \rho \), the above probabilities are set by the equations:
The same caveat regarding the correlation approximation holds here as it does in the redevelopment model: due to adjustments for correlation, the above four equations are only approximations for the true probabilities. For typical volatility and riskfree rate parameters, the approximation remains very precise for all correlations. However, correlations above 0.8 begin to produce slight errors (upwards of 5%) when volatility exceeds 50% or the riskfree rate approaches 10%. In this model, however, unlike the redevelopment model, timesteps are going to be smaller than one year—typically quarterly, and never over half a year. Thus the likelihood of the volatility or riskfree rate per timestep ever approaching 50% or 10% respectively seems highly remote.

Figure B.1 - A double binomial lattice taken from initial time $t=0$ out two steps: states of the world represent the up and down movements of two underlying assets.
Equations B.2 - B.5 can be used to construct a three-dimensional lattice with states of the world for both asset, while equations B.6 - B.9 will be used (along with others) to value the multiple options. In each state of the world at each timestep, three values need to be calculated, $V_{D1}(t, s)$, $V_{D2}(t, s)$, and $V_{F}(t, s)$, representing the value of a going forward committed to housing use 1, committed to use 2, or in a flexible mode which can choose between them.

At the terminal timestep $T$, these three values will be
\begin{align}
V_{D1}(T, s) &= V_{1}(T, s) \quad \text{(B.10)} \\
V_{D2}(T, s) &= V_{2}(T, s) \quad \text{(B.11)} \\
V_{F}(T, s) &= \max (V_{1}(T, s), V_{2}(T, s)) \quad \text{(B.12)}
\end{align}

In the intermediate timesteps, valuation of the three modes of going forward occurs in one of two ways. If no investment is required in a timestep, then the value at each state is simply the probabilistic value of the four possible states in the next timestep. That is,
\begin{align}
V_{D1}(t, s) &= e^{-\delta(t+1)} (P_{uu} V_{D1}(t+1, uu) + P_{ud} V_{D1}(t+1, ud) + P_{du} V_{D1}(t+1, du) + P_{dd} V_{D1}(t+1, dd)) \quad \text{(B.13)}
\end{align}

Likewise, the valuations of $V_{D2}(T, s)$ and $V_{F}(T, s)$ would use the same equation as B.13, except replacing all subscripts $D1$ with $D2$ and $F$, respectively.

Now, when a timestep calls for an investment decision to be made, there are always three possible investments: $K_1(t)$, $K_2(t)$, and $K_F(t)$. These correspond respectively to the investment required to go forward committed to use 1, use 2, or remaining flexible. In each of these “investment timesteps,” valuation occurs as follows:
\begin{align}
V_{D1}(t, s) &= \max (e^{-\delta(t+1)} (P_{uu} V_{D1}(t+1, uu) + P_{ud} V_{D1}(t+1, ud) + P_{du} V_{D1}(t+1, du) + P_{dd} V_{D1}(t+1, dd)) - \epsilon K_1(t), 0) \quad \text{(B.14)}
\end{align}

\begin{align}
V_{D2}(t, s) &= \max (e^{-\delta(t+1)} (P_{uu} V_{D2}(t+1, uu) + P_{ud} V_{D2}(t+1, ud) + P_{du} V_{D2}(t+1, du) + P_{dd} V_{D2}(t+1, dd)) - \epsilon K_2(t), 0) \quad \text{(B.15)}
\end{align}
\[ V_i(t, s) = \max \left( \epsilon'(P_{uu} V_{DEV1}(t+1, uu) + P_{ud} V_{DEV1}(t+1, ud) + P_{du} V_{DEV1}(t+1, du) + P_{dd} V_{DEV1}(t+1, dd) - \epsilon K_1(t), \right) \]

\[ \epsilon'(P_{uu} V_{DEV2}(t+1, uu) + P_{ud} V_{DEV2}(t+1, ud) + P_{du} V_{DEV2}(t+1, du) + P_{dd} V_{DEV2}(t+1, dd) - \epsilon K_2(t), \right) \]

\[ \epsilon'(P_{uu} V_I(t+1, uu) + P_{ud} V_I(t+1, ud) + P_{du} V_I(t+1, du) + P_{dd} V_I(t+1, dd) - \epsilon K_I(t), 0 \right) (B.16) \]

Note that equations B.14 and B.15 come into play if the development projects is currently committed to a particular use mode, while equation B.16 is used when the development project has not yet committed (i.e., is still in "flexible" mode.) This last equation allows the decision maker to choose between the staying flexible or committing to a single use.

The initial value at time \( t=0 \), can therefore be computed by stepping backward from terminal time \( T \) and applying equations B.13 through B.16 as appropriate, depending on whether or not an investment outlay needs to be made in the given timestep. The three values which will be obtained are \( V_{DEV1}(0), V_{DEV2}(0), \) and \( V_I(0) \).

The value \( V_{DEV1}(0) \) is the value of going forward committed to use 1, but with the option of abandoning the project at any time. Likewise, the value \( V_{DEV2}(0) \) is the value of going forward committed to use 2, but with the abandonment option. And \( V_I(0) \) is the value of going forward and maintaining the flexibility to choose between the two uses at a later date as well as the option to abandon the project entirely.