Quantifying the Benefits of Flexible Buildings

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ABSTRACT

Three worked examples explore different ways of evaluating flexible design strategies. The first enumerates the number of different physical configurations that are allowed, but a weakness is that it does not take account of the usefulness of the configurations. The second example compares the enumeration of configurations with the enumeration of activity states; it is argued that the enumeration of activity states is more satisfactory. However, enumeration is not feasible for many real world problems. The third example suggests that the objectives of a flexible strategy can be represented by its associated lifecycle options, and shows how the value of a lifecycle option can be estimated by simulation. The lifecycle options approach to quantifying the benefits of flexiblility is widely applicable to real world problems.

THE NEED FOR EVALUATION

In design for flexiblility it is axiomatic that there will be future change in the ways that society will wish to use its buildings. If today's buildings cannot accommodate these changes they will become functionally obsolete. Therefore, flexible promotes design strategies that make it easier to change the physical fabric of buildings.

This makes sense, but there is a virtually unlimited number of ways of applying the flexible approach. How can designers evaluate flexible strategies, and decide which of many alternative strategies are the most effective? And how can they demonstrate the benefit of these strategies to clients or investors, preferably with quantification?

The quantified evaluation of benefits should add to the effectiveness and impact of design for flexibility.

COUNTING PHYSICAL CONFIGURATIONS

One method of evaluating flexible design strategies is by counting **the number of possible configurations that are allowed for**. A strategy that allows for the largest number of possible configurations would be preferred.

This method can be explored with the example of a base building with a cellular office fit-out. Suppose that the base building is designed with a module that determines the possible location of partition walls between offices. With a finer module there is a greater number of alternative locations for the partitions, increasing the number of possible fit-out configurations.

	module size (mm)	number of intermediate gridlines (n)	number of possible configurations (2^n)
A	3000	3	8
B	2000	5	32
C	1500	7	128
D	1200	9	512
E	1000	11	2 048
F	600	19	524 288

Table 1. The subdivision of a 12m length of the basic building by office partitions: the module size, the number of intermediate gridlines, and the number of

Consider a 12m zone in the base building with six alternative modules from 3000mm to 600mm. Each intermediate modular grid line can be in two states – either with a partition or without a partition. For a base building with a given module, the number of possible fit-out configurations is given by all combinations of these two states. If the number of internal gridlines is n, the number of possible configurations is 2^n.

A comparison of the six modules shows that the number of configurations rises very steeply as the module dimension is reduced (Table 1). Using this method of evaluation it appears that a fine-module design is a dramatically superior flexible strategy than a coarse-module

However, consider the useful dimensions of cellular offices. Suppose that the width of a

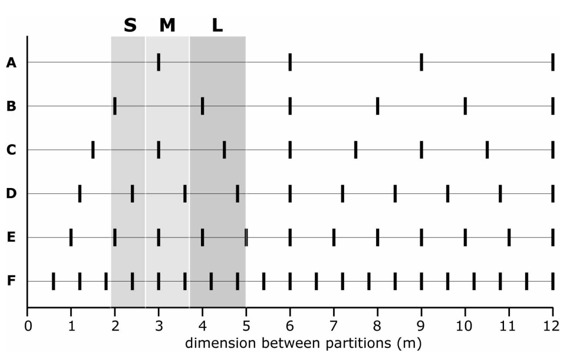

Diagram 1. The range of possible spacings between office partitions using the six modules, overlaid with the usable width of small, medium and large offices.

small office falls between 1.9m and 2.7m; for an intermediate office it falls between 2.7m and 3.5m; and for a large office between 3.5m and 5m. A dimension between partitions that is less than 1.9m or greater than 5m would never be used in a fit-out. These useful dimensions can be overlaid on a diagram showing the possible partition-spacing dimensions of the six modules (Diagram 1). The finer modules offer far more possibilities, but many of them would never be used in an office fit-out.

The three coarser modules A (3000mm), B (2000mm), and C (1500mm) offer a limited range of office sizes; whereas with the finer modules D (1200mm), E (1000mm), and F (600mm) it is possible to design fit-outs that incorporate small, medium or large offices. It is clear that finer modules do offer more fit-out opportunities than coarser modules, and are therefore more successful in flexible terms. But the difference in performance is greatly exaggerated by the number of possible configurations: it is not reasonable to say that module F is 1000 times better for office fit-outs than module D.

This example illustrates that simply counting physical configurations is not a satisfactory way of measuring the effectiveness of flexible design strategies. It is also necessary to consider how the configurations would be used.

COUNTING ACTIVITY STATES

A more radical method of evaluating flexible strategies is in terms of **the number of possible activity states that are allowed for**. A strategy that allows for the largest number of possible activity states would be preferred. This method can be applied when the number of possible activity states is precisely defined.

To explore this method, consider a base building that will be fitted out as work rooms for eight people. The number and size of the working groups is, however, unknown or may change – these working group sizes are the

	groupings	associated microstates	strategies
1	8	1	
2	7 1	8	
3	6 2	28	
4	6 1 1	28	
5	5 3	56	
6	5 2 1	168	
7	5 1 1 1	56	
8	4 4	35	
9	4 3 1	280	
10	4 2 2	210	
11	4 2 1 1	420	G
12	4 1 1 1 1	35	G
13	3 3 2	280	
14	3 3 1 1	280	
15	3 2 2 1	1680	H, J, K
16	3 2 1 1 1	560	G, J, K
17	3 1 1 1 1 1	56	G
18	2 2 2 2	105	
19	2 2 2 1 1	420	G, K
20	2 2 1 1 1 1	210	G
21	2 1 1 1 1 1 1	28	G
22	1 1 1 1 1 1 1 1	1	G
	total	4 945	

Table 2. The 22 possible groupings of 8 individuals, and the associated number of microstates for each grouping. The groupings accommodated by the four design strategies are indicated.

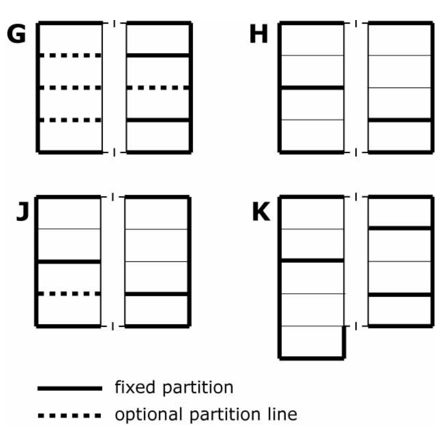

Diagram 2. The four base building strategies to accommodate eight people. The fit-outs use fixed and optional partitions.

relevant activity states for this example. A successful flexible strategy for the base building would allow for fit-outs that accommodate a wide range of working group sizes.

In this example the number of possible activity states can be enumerated – there are precisely 22 different ways that eight people can organise themselves into working groups (Table 2). These groupings are not equally likely to occur, however. Groupings with a mixture of working group sizes are likely to occur more often.[1] The expected occurrence of groupings can be weighted by the number of associated 'microstates'; there are 4945 possible microstates for eight people (Table 2).

This information can be used to evaluate the performance of four alternative flexible strategies (Figure 2). It is assumed that each person requires a floor area of at least $12m^2$,two people require at least $24m^2$, and so on. Strategy G, H and J have $96m^2$ of usable floor area (ignoring the corridor), sufficient for the eight people, and Strategy K has $108m^2$ of usable floor area. The base building is arranged in two bays, with a mixture of fixed partitions and structural bays where non-loadbearing partitions can be constructed at fit-out stage. If there are optional partition locations, the fit-out can be configured in a variety of ways depending on whether or not each optional partition is erected. As in the previous example, if there are *n* such locations, there are 2^n possible configurations.

	number of configurations	number of groupings	number of microstates
G	16	8	1730
H	1	1	1680
J	2	2	2240
K	1	3	2660

Table 3. Data for the four base building strategies: the number of possible configurations, the number of groupings that can be accommodated, and the number of microstates associated with these groupings.

For each of the four strategies it is possible to count the number of possible configurations; the number of groupings that can be accommodated, taking account of all possible configurations; and the number of microstates that can be accommodated, again taking account of all possible configurations (Table 3).

Strategy G has by far the largest number of possible fit-out configurations (16); strategies H and K have one possible configuration and strategy J has only two. Similarly, strategy G can accommodate a much larger number of groupings (8) than the other strategies (1, 2 or 3).

In terms of microstates the situation is very different. Strategy G accommodates only a slightly larger number of microstates than strategy H, and fewer than strategies J and K. Strategy K accommodates the largest number of microstates (a little over half of all possible microstates), even though the base building has no optional partitions and therefore no provision for alternative fit-out configurations. It is evident that activity change does not necessarily require physical change – this is a significant principle and may be overlooked if designers focus exclusively on physical change

If the method of evaluation for these four design strategies is based on the number of possible activity states, and the microstates are used as the relevant activity states, then strategy K performs best.

EVALUATING CONFIGURATIONS OR ACTIVITY STATES

The four designs in the second example were chosen to emphasise the divergence between strategies that maximise physical reconfiguration and those that maximise the number of activity states accommodated. In other cases the two methods of measurement may converge – but this cannot be assumed.

When comparing the two criteria for evaluation – configurations or activity states – we should recall the underlying objective of flexible, which is to accommodate change in the ways that society will use its buildings. The activity-based method of measurement connects more directly to this objective and should be preferred to the configurations-based method, which is only indirectly connected to the objective of flexible.

It may be argued that flexible strategies are valuable because of uncertainty about future activities, and it is therefore paradoxical to use future activities as the basis for evaluation. This would be a valid argument if flexible strategies were unrestricted in the activity change that they allow for, but this is not the case. It is impossible to design for universal flexibility that could accommodate the requirements of all conceivable uses. In fact, realistic flexible strategies provide for a bounded set of possibilities. For example, Kendall and Teicher's book on Open Building describes base building strategies with specific intentions, such as floor ducts that allow bathrooms to be relocated if a flat layout is changed.[2] Designers naturally explore the potential configurations achievable with a flexible strategy. Extending this to the exploration of potential uses is not fundamentally in conflict with current practice.

The two examples described above are at a small scale, where exhaustive enumeration of configurations and activity states is feasible. With increasing complexity and scale, the numbers of possible states quickly become too large to enumerate, for both configurations and activities.[3] Although reliable approximations are possible in some cases, enumeration is of limited value as a practical evaluation method.

To be useful in the real world, we need a method that can evaluate flexible strategies in terms of their activity benefits, even in large and complex situations.

EVALUATION USING LIFECYCLE OPTIONS

It is proposed that lifecycle options[4] provide the basis for the evaluation of flexible strategies. A lifecycle option is a design feature that is incorporated in the initial construction of a building, which allows for alternative courses of action to be followed in the future. In the second example above, the base building incorporates the lifecycle option to erect partitions in certain locations, giving future decision makers the choice of whether or not to exercise the option and erect the partitions. Due to future uncertainty, it is not known at the time of design when or if the lifecycle options will be exercised. Lifecycle options as described here are an instance of the more general concept of 'real options', for which there is a large body of theory and experience in other application areas.[5]

All flexible strategies can be described in terms of the lifecycle options that they create. There are three main types of lifecycle option: 1) the option to **upgrade** or expand a building to an enhanced state, where the exercise is generally assumed to be irreversible; 2) the option to **switch** between alternative states of a building, usually in a reversible way; and 3) the option to **abandon** or contract, usually irreversible.

In lifecycle option terms, the evaluation of a flexible strategy involves comparing the cost of providing a lifecycle option with the value it generates. If the value exceeds the cost, it is a good idea to incorporate the option in a design; otherwise not. When comparing flexible strategies that have alternative lifecycle options, the strategy with the greatest benefit after deducting the cost of provision is preferred.

It is usually straightforward to establish the cost of providing lifecycle options, because this is done at design stage with the rest of the building. The cost of building work involved in exercising the options can also be estimated, although the fact that it takes place in the future makes the estimate less precise.

The greater challenge is estimating the value of lifecycle options. It depends on a few critical factors:

The existence of uncertainty. In situations where there is no uncertainty (ie. the future can be predicted) there is no need for lifecycle options – nor for flexible. The existence of uncertainty about the future is a precondition for lifecycle options – and flexible.

The likelihood of exercising a lifecycle option. There is always uncertainty about whether or not lifecycle options will be exercised, but there must be a possibility of this happening. If it is inconceivable that an option could be exercised, it is valueless and should not be provided. Generally, the higher the likelihood of exercise, the higher the value of the lifecycle option.

The benefit gained by exercising a lifecycle option. The larger the benefit that would be gained when and if a lifecycle option is exercised, the higher the value attached to the option.

Methods have already been developed for estimating the value of lifecycle options.[6] A useful technique involves Monte Carlo simulation to generate many scenarios of the future; in these simulations the lifecycle options are exercised when and if it is advantageous to do so. Using the same set of scenarios, alternative designs, with and without lifecycle options, can be compared to reveal which performs best. Unlike enumeration methods, Monte Carlo simulation is feasible for large and complex situations

LIFECYCLE OPTIONS EXAMPLE

Consider the example of a new commercial building being developed on the fringe of a city centre (Fig.3; data in Table 4). A question has arisen about the use of the ground floor. At present the building's location makes it suitable for office use, like the rest of the building. However, it is possible that there might be demand for retail use of the ground floor at some time in the future, if the retail zone of the city expands to include this location. Retail is very attractive: while office rents are about €250/m^2 per year, retail rents could be three times higher.

A difficulty is that retailing requires a greater ceiling height than office use[7] – about 4.8m compared to 3.6m. If the building is constructed with a ground floor ceiling height of 3.6m it will be adequate for the current office use but unsuitable for future retail use. A flexible strategy to construct the base building with a ground floor ceiling height of 4.8m will make it suitable office use, but also allow for a future change of use from office to retail.

In lifecycle options terms we would say that the flexible strategy creates the lifecycle option to upgrade the ground floor from office to retail use. It is clearly attractive, but there is an acquisition cost due to the taller ground floor columns, walls and glazing, and also some redundancy in the mechanical and electrical and systems, fire escape routes, etc, to allow the ground floor to be operated as shops separately from the upper floors which would continue as offices. These initial costs can be estimated with confidence. The cost of exercising the option and converting from office to retail use can be also estimated, but less precisely because of the elapse of time before the exercise takes place. These acquisition and exercise costs must be compared against the value of the lifecycle option.

Figure 3. A typical new commercial building located in the fringe of a city centre. There is uncertainty about the potential for retail use of the ground floor.

The value of the option hinges on the future of the city's retail market, determining when or if the building's location becomes a retail area, and therefore whether the option to upgrade from office to retail use of the ground floor will be exercised. So long as there is any possibility of exercising it, the option it has some value. But if the probability of exercise is low, the value of the option may be less than the cost of acquiring and exercising it.

In this example we estimated the value of the option for alternative probabilities that it will be exercised during the 30 year study period. The probability varies from 0% to 100% in 5% increments. For each probability, 10,000 Monte Carlo simulations were run; in each run the simulation determined if and when the

Ground floor area (m^2)	800
Office rental (€/m^2 per year)	250
Investment value of ground floor with office rental = (250 x 800) / 0.065 (€*)	3.08m
Retail rental (€/m^2 per year)	750
Investment value of ground floor with retail rental = (750 x 800) / 0.065 (€*)	9.23m
Construction cost of ground floor for office use (3.6m ceiling height) (€/m^2)	2500
Construction cost of ground floor for office use with lifecycle option to change to retail use (4.8m ceiling height, etc) (€/m^2)	3200
Cost of exercising the lifecycle option to change from office to retail use (€/m^2)	1000
Total acquisition cost of lifecycle option = (3200 – 2500) x 800 (€)	560,000
Total exercise cost for the lifecycle option = 1000 x 800 (€)	800,000
Discount rate for present value calculations (% per year§)	10%
Study period (years)	30

* Based on a capitalisation rate from the annual rental income of 6.5%.
§ Real discount rate based on constant monetary values, ignoring inflation.

Table 4. Data for the case study of a lifecycle option to change the ground floor of a commercial building from office to retail use.

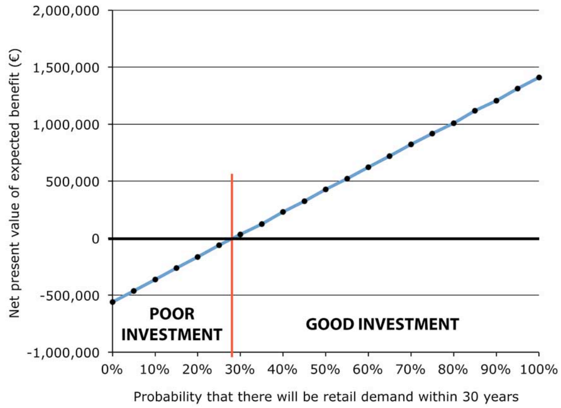

Figure 4. Results of simulation study, showing the net present value of the expected benefit of the lifecycle option, for different probabilities of upgrade from office to retail use.

option was exercised. If it was exercised, a financial benefit accrued in the year of exercise due to the increase in ground floor rental income. This benefit was discounted back to the present day to give the present value of option for that simulation run. Due to discounting, the more distant the year in which the option was exercised, the lower its present value. If the option was not exercised in a simulation run, it had zero value. The average option value from the 10,000 simulation runs was taken as the present value of the expected benefit of the option, for the given probability of exercise.

The results of this study for the different probabilities of exercise are shown in Figure 4. This shows the net present value of the option, ie. the present value of the expected benefit minus the costs of acquisition (in all cases) and exercise (when applicable).

It is evident that for a low probability of exercise it is not cost-effective to acquire the lifecycle option, as the net present value is negative. However, if the probability of exercise is about 30% or higher then it is advantageous to acquire the option.

It is important to note that even when the probability of exercise is higher than the 30% threshold and acquisition is cost-effective, there is no certainty that the option will in fact be exercised. For example, at 50% probability of exercise, there is also a 50% probability that it will not be exercised during the 30 year study period; but because the financial benefit is so high when it is exercised, the option is still a good (but risky) investment.

How would the probability of exercise be estimated? Commercial property research would look at the economic and demographic profile of the city, the planning policies, etc, to arrive at an informed view. This could be termed the present knowledge of the future prospect for retail use of the building's ground floor. It is not certain knowledge, but it is all that is available at the time when the investor must decide whether or not to acquire the option by building the taller ground floor.

Ultimately the decision will depend on the investor's belief about the future, and willingness to commit resources to a risky investment. Different investors are likely to take different views – some acquiring the option and others not. But they will all benefit from quantified evaluation of the lifecycle option's cost and benefit as input for decision making.

To summarise: it is not possible to know whether the flexible strategy of providing a taller ground floor storey height in new commercial buildings is a 'good thing' or a 'bad thing' in absolute terms; it depends on context-specific factors and the investor's attitude, and should be determined by context-specific evaluation.

CONCLUSION

The examples given in this paper are all simplified, but they illustrate the principle that flexible strategies should be evaluated with reference to their benefits in use, not just their configurational ingenuity. The first two examples involved the enumeration of configurations and activities; these are powerful techniques but not applicable to all situations. The approach in the third example, using lifecycle options and simulation, is widely applicable to real world situations; the worked example shows just one of many ways of applying simulation methods.

The adoption of more powerful evaluation techniques for flexibility would be a natural progression, complementing the extensive body of proposals for flexible technologies and geometries. It should also help to match flexible strategies with society's needs, minimising the twins risks that flexibility is either: (a) rejected in situations where it would be beneficial, or (b) used in situations where it cannot provide worthwhile benefits.

Good evaluation techniques should help to focus the efforts of flexible designers in productive directions, and increase investors' confidence in, and therefore take-up of, flexibility.

Footnotes

1. William Fawcett, "All possible and most probable activity schedules in organisations." *Environment & Planning B* 6 (1979): 123-154.

2. Stephen Kendall and Jonathan Teicher, *Residential Open Building*. (London: E & F Spon, 2000).

3. Philip Steadman, *Architectural Morphology.* (London: Pion, 1983).

4. William Fawcett, "Investing in flexibility: the lifecycle options synthesis." *Projections* 10 (2011): 13-29. http://web.mit.edu/dusp/projections/projections10web/Projections10_fawcett.pdf

5. Jonathan Mun, *Real Options Analysis* (2nd edition). (Hoboken, NJ: Wiley, 2006).

6. Ian Ellingham and William Fawcett, *New Generation Whole-life Costing: property and construction decision making under uncertainty.* (London: Taylor & Francis, 2006).

7. David Baker, "It's the Ceiling Heights, for One Thing." *SPUR* (May 2004): 8-11. http://www.dbarchitect.com/images/dynamic/articles/attachment//its_the_ceiling_heights.pdf

Note

The lifecycle options approach to the evaluation of construction projects is an area of development in the CILECCTA research project, funded by the European Community's Programme FP7/2007-2013 for Research, Technological Development and Demonstration Activities, under EC Grant Agreement no. 229061. The project duration is 2009-2013. The full project name is 'A user-oriented knowledge-based suite of Construction Industry Lifecycle Costing and Assessment software for pan-European determination and costing of sustainable projects.' (*see*: www.cileccta.eu)

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