Using Flexibility to Improve Value-for-Money in Hospital Infrastructure Investments[1]

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Richard de Neufville
Yun Shin Lee*
Stefan Scholtes

* Corresponding author

Authors' information

Richard de Neufville, Professor of Civil and Environmental Engineering, Engineering Systems Division, Massachusetts Institute of Technology.
Address: 77 Massachusetts Ave, Building E40-245, Cambridge, MA 02139-4307
E-mail: ardent@MIT.EDU

Yun Shin Lee, PhD candidate at Judge Business School, University of Cambridge.
Address: Queens' College, Cambridge CB3 9ET, U.K
E-mail: ysL27@cam.ac.uk

Stefan Scholtes, Professor of Management Science, Judge Business School, University of Cambridge.
Address: Judge Business School, University of Cambridge, Trumpington Street, Cambridge CB2 1AG, U.K
E-mail: s.scholtes@jbs.cam.ac.uk

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Abstract

Flexibility is a key value driver for hospital infrastructure in a highly unpredictable health care environment. This is illustrated by the example of the development of a major UK teaching hospital over the past 60 years. We then lay out some principles for the articulation of the value of flexibility to enable the designer to make an economic case for flexible infrastructure. Finally, we argue that hospital procurement under Public Private Partnership (PPP), in particular under the UK Private Finance Initiative (PFI), can be an inhibitor to the design and development of flexible infrastructure. To realise the value of flexible infrastructure systems, the PFI parties need to create a genuine long-term partnership. The private parties have to stay engaged during the lifetime of the infrastructure to help adapt it to developing circumstances and thereby minimise value risks, maximise opportunities if and when they arise, and allow the public sector to reap as much social benefit from the infrastructure as possible.

Keywords: Flexible Design, Hospital Infrastructure, Demand Uncertainty, Private Finance Initiative

1. Introduction

Hospital infrastructure is designed for a lifespan of more than 40 years. During this life, demands on the infrastructure will change significantly. Unforeseeable advances in medical technology, unpredictable national and local demographic changes in the wake of globalisation, changing epidemiological patterns driven by lifestyle changes, and rapid regulatory changes make scale and scope of the demand on any individual hospital over its lifetime highly unpredictable.

A good value-for-money hospital infrastructure therefore needs to be flexible, to allow effective adaptation to changing circumstances. The design of flexible hospital infrastructure is the focus of this paper.

Examples of flexible design features in hospital buildings include shell space where areas are built but not yet medically equipped, or suitable structural foundations of a building to allow additional floors to be added at a later time. Such flexibilities can be used to expand capacity in the future in response to increased demand, if and when this demand materialises. Another example is flexible layout of functional rooms, such as operating theatres, which would allow a change of usage in the future, e.g. to adapt to changing technology.

This paper is structured as follows: We will first illustrate the value of flexibility, using the development of a major U.K teaching hospital over the past 60 years as a case study. Then we explore some principles and processes that may help designers and their clients make an economic case for flexible infrastructures in a transparent manner. Finally, we will argue that procurement under Public Private Partnership (PPP) arrangements, in particular the current Private Finance Initiative (PFI) in the UK, can be an inhibitor to the establishment of flexible infrastructure.

2. Use of flexibility at Addenbrooke's Hospital, Cambridge

The development of the infrastructure at Addenbrooke's Hospital in Cambridge over the past 60 years provides an excellent case for successful long-term use of flexibility. The hospital is the major teaching hospital of Cambridge University, with a current capacity of 1100 beds. The hospital serves the local population as a general hospital and is also a specialist centre with an international reputation. The hospital's history goes back to the 1760ies. It was located in the centre of Cambridge until 1962, when the New Addenbrooke's site was opened at the outskirts of town. Both sites were operated in parallel, until the old site was finally closed in 1984. The following charts give an illustration of the changing demand and supply of the hospital over the past 80 years[2].

During the first half of the 80-year period the hospital had relatively stationary demand for both inpatient and outpatient service, with a marked increase during the World War II. Since the mid 70ies, demand has increased significantly.

[2] The gaps indicate missing or unreliable data in the hospital archive. The accuracy of the data could be somewhat affected by inconsistent data formats and descriptors in the various sources.

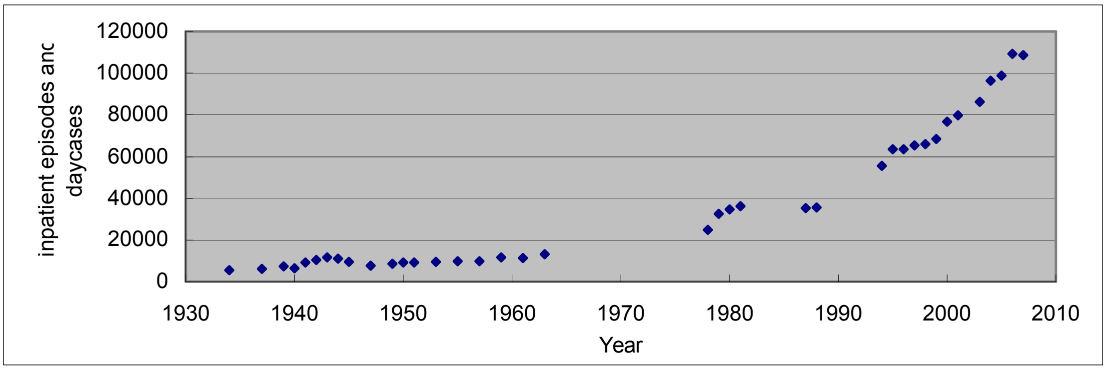

Figure 1. Inpatient Activities over the past 80 years at Addenbrooke's Hospital, Cambridge

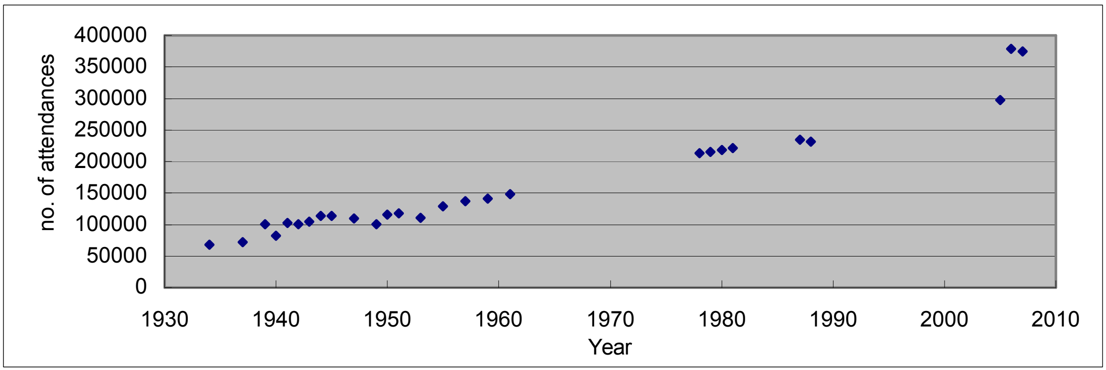

Figure 2. Outpatient Activities over the past 80 years at Addenbrooke's Hospital, Cambridge

The increase in outpatient demand is partially due to a shift of less severe cases from inpatient to outpatient treatment. In spite of the fact that this leaves the more severe cases as inpatients, the average length of stay in the hospital has been steadily declining from a figure between 15-20 days in the 1940ies to below 10 days in the 1980ies, and is now reaching the 5 days mark. This extraordinary development is largely due to significant advances in medical technology and treatment processes.

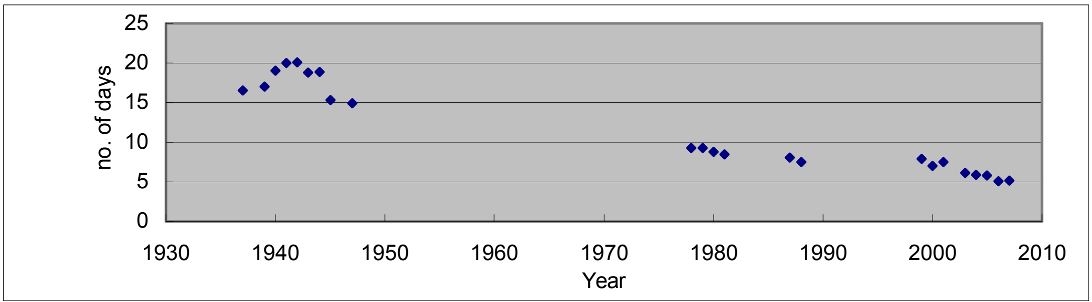

Figure 3. Average length of stay over the past 80 years at Addenbrooke's Hospital, Cambridge

Addenbrooke's Hospital has gone over a number of adaptation and expansion schemes. Following its foundation in 1766, major extensions and reconstructions of the hospital were carried out in 1824, 1834 and 1866. Further extensions in 1915 and 1930 added the top floor to the building. The important role that unforeseeable political events can play is illustrated by the distinctive rise in bed numbers and length of stay between 1940-45 during when World War II broke out. The capacity increase at the time was achieved by making use of a school and university space. In the late 1940ies, planning begun to move the hospital to a new site by acquiring a considerably larger sized land. In 1962, the new site was opened at the outskirts of town, initially with 94 beds. Over the next years, capacity was increased at the new site and reduced at the old site in the centre of town which eventually closed in 1984. A substantial increase from 400 to 800 beds occurred in the 1970ies when major developments of the new site were completed. Currently, the hospital has around 1100 beds.

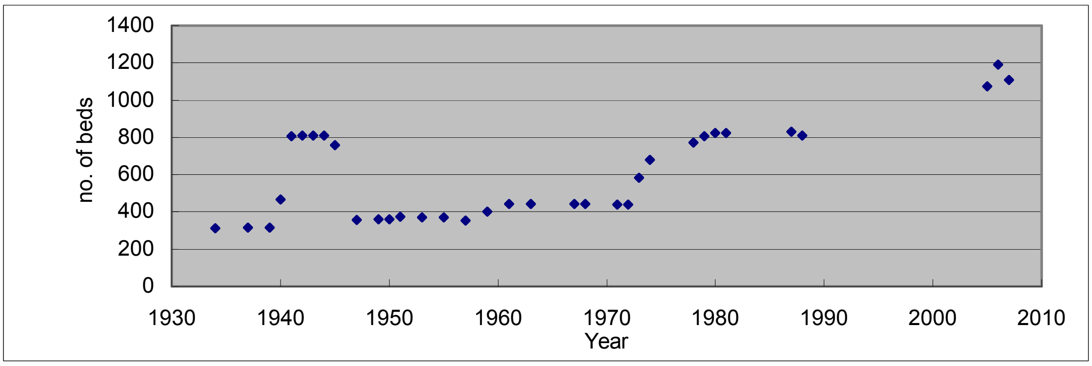

Figure 4. Number of beds over the past 80 years at Addenbrooke's Hospital, Cambridge

2.1 Forecasting capacity requirements is difficult

Forecasting required capacity, in terms of bed numbers, is a crucial input into the design of a hospital. The following figure shows the forecast bed capacity in 1981 for various planning years.

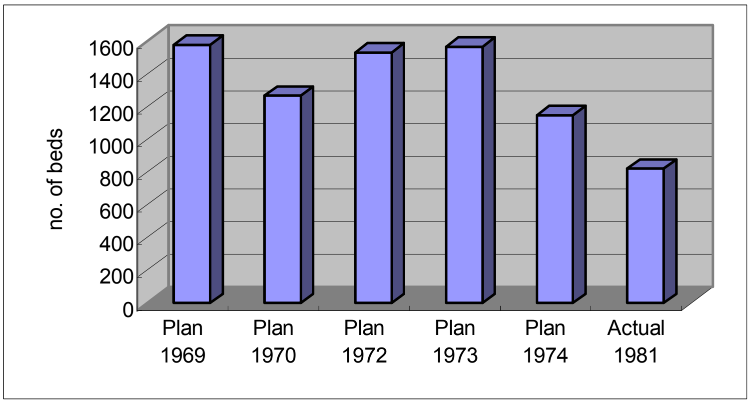

Figure 5. Forecasting bed numbers for 1981

Clearly, the plan overestimated the capacity requirements. A 1974 planning document sheds some light on the forecasting process[3]: "*The accepted method of calculating the general bed requirements of a hospital centre is to apply recognised planning 'norms' for broad categories of specialties to the population forecast for a defined catchment area. In other words, ratios of beds of various kinds to each 1000 population are used. Most of the norms are those issued by the DHSS. For general acute beds, however, a figure of 2 beds per 1000 population has been adopted by the RHB for the region as a whole, with the Department's agreement. The Department expects current*

[3] Hargreaves, A et al. (1974) *The Future Size of Addenbrooke's Hospital*. First Report of the Cambridge Study Team.

assessments generally to be related to 1981 population forecasts. The Study Team has carefully examined population forecasts and details of the catchment area, and has carried out various consultations in order to satisfy itself that the particulars which form the basis of calculations of bed requirements are likely to be generally acceptable."

The unanticipated reductions of length-of-stay and shifts from inpatient to outpatient activity are likely to be responsible for keeping the capacity of the hospital lower than planned. A second significant source of error is probably the underlying demographic forecast. Indeed, the following chart shows how far off the demographers can be at the national aggregation level. In particular the 1965-based projection was significantly higher than the eventual realisation. An analysis of projections made in Western countries indicates that the birth rate predictions made in the 1960ies, based on the assumption of a continuing baby boom, were up to 80% too high[4].

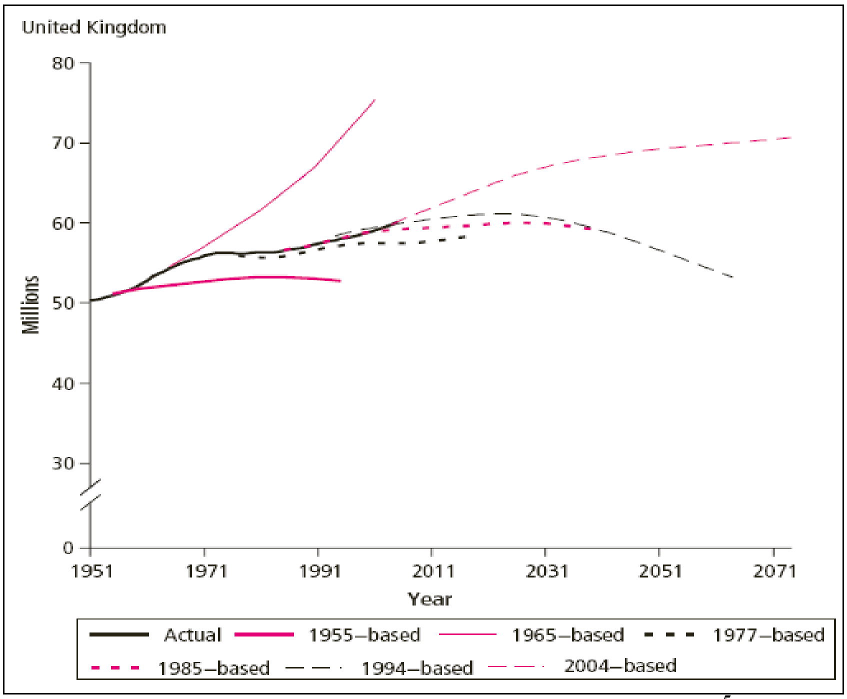

Figure 6. Actual and projected population, 1951-2074[5]

The deficiencies of long-term demographic forecasts are recognised by their immediate users. In the context of Addenbrooke's Hospital, the East Anglian Regional Strategy Team warned in 1974 "*In general terms therefore while we consider that our estimates of population growth in the Cambridge area cover most contingencies on present knowledge, we recognise that there is a great degree of uncertainty in this case. We would be dubious about the validity in these circumstances of coming to firm conclusions on a long-term programme of capital expenditure in this area for at least 3 years. Indeed, it is probable that any such programme would need a major review at that time. In the intervening period, our view would be that any commitments made should be designed to be adaptable to a*

[4] Shaw, C. (2007) Fifty years of United Kingdom national population projections: how accurate have they been?. *National Statistics*. 8-23.
[5] Shaw, C. (2007) (see footnote 4)

number of possibilities, both in the provision of services, and its relationship to transport facilities giving people access to these services."[6]

In summary, basing plans and designs on a single projection of the future is very dangerous as we saw that it is impossible to forecast hospital demand precisely. Hospital demand can be largely explained by four key factors: (i) demographic pattern (ii) medical technology advance, which is historically attributed with reduced length-of-stay and therefore a reduction of required bed capacity, (iii) epidemiological pattern, driven for example by life-style changes, which can lead to reduced demand (no-smoking policy) or increased demand (obesity), and (iv) regulation and policy, e.g. around patient choice or private practice. To help with hospital planning, we need a better understanding of the *range* of possible future hospital demands by taking account of combinational effects of these key factors.

2.2 Recognising the need for flexibility

Whether by foresight or luck, the new Addenbrooke's site was laid out for 1100 beds capacity in the 1950ies, to be developed in stages; 1100 beds is precisely its capacity today, albeit the plans have assumed this size to be achieved much earlier. On its 67 acres of dedicated land, the infrastructure could gradually develop from a 94 beds building in 1962 into an efficient modern health services campus with 1100 beds capacity and first-rate teaching and research facilities. In addition, there are ample farmlands adjacent to the current campus, allowing for further expansion. Indeed, in 1999 the Trust announced an ambitious long-term development plan, called the 2020 Vision, which will expand the hospital campus by an additional 70 acres of land, doubling the size of the existing site.

It is remarkable how much the need for flexibility has been recognised and emphasised during the planning phase for the new site in the late 1940ies and the 1950ies. Murray Euston, the appointed architect for a new site development said in 1947 *"the hospital authorities should keep in mind the need to secure a larger area than the 60 acres to allow for any eventual developments."*[7]*,* without which the 2020 Vision, initiated 50 years later, would not be realisable. The Medical Committee recommended to the Board of Governors that "*A site layout plan should be prepared and a flexible order of priority determined to allow construction of the new Hospital part by part*."[8] The 1953 annual report states that "*The construction of a large new hospital centre will have to be undertaken in stages, and work is proceeding to evolve an outline plan which will permit sections to be constructed according to a flexible order of priority.*" The 1957 annual report recognises the value of flexibility to cope with uncertain future needs explicitly: "*It is thought right to build the new hospital to meet present and foreseen needs, with some margin for probable developments, but leaving the maximum possible scope to our successors for unknown future needs, and this has been accepted as the main principle of our planning.*"

[6] Hargreaves et al. (1974) (see footnote 3)
[7] Rook, A., Carlton, M. and Cannon, W.G. (1991) *The history of Addenbrooke's hospital Cambridge*. Cambridge University Press. Cambridge.
[8] Rook et al. (1991) (see footnote 7)

These quotes demonstrate that the use of flexibility was very carefully considered at the planning and design phase for the new site of Addenbrooke's Hospital, not a remote add-on or after-thought. Indeed, the preoccupation with flexibility has carried over to the 1999 business plan for its further expansion, the 2020 Vision: "*The longer term direction of the programme requires a degree of flexibility if it is to respond to the rapidly changing agenda of the new NHS. Capability to implement rapid change is also essential if we are to benefit from the introduction of clinically relevant technological developments identified as best practice.*"

2.3 Exercising flexibility

Flexibility is only valuable if it is exercised effectively ("when the time is right") and efficiently ("at acceptable cost and disruption"). Planning and development of the new Addenbrooke's Hospital provide interesting illustrations of good practice. The ample space for expansion was only one part of the success. Setting the hospital up to exercise the expansion effectively and efficiently requires more.

The importance of proper timing of expansion plans was recognised already back in 1960, when the hospital's architect reported that "*The speed with which medical and technical changes were taking place meant that it would be to the Hospital's advantage to extend the point at which final decisions were taken on plans for new buildings to the latest moment.*" [9]

Cost-efficient exercise of flexibility requires thoughtful engineering design at the outset of the project, long before the flexibility is actually employed. Cost and disruption of service due to continuous site development were a major concern at Addenbrooke's from the initial stage of the development. The 1962 Annual Report states that "*The further development (...) will mainly be along the East-West axis of the site (...). The present buildings have been constructed with 'free ends' to permit future extensions to departments with the least possible disruption of the service of the hospital.*" A further design feature that improves efficient use of expansion flexibility is the decision to locate critical servicing at sub-ground level, thus building an expandable spine, which allows the efficient accommodation of additional servicing requirements for ward expansions. The 1967 annual report concludes that "*although the arrival on the site of the contractors with their plant and machines brings with it discomfiture (...) these have been kept to a minimum (...)*". Nevertheless, changes in the infrastructure did not go without disruption. A 1983 capacity planning report states for example that "*It permits all the geriatric wards in the F&G Block to revert to their planned usage. All surgery, except for neurosurgery of course, will now be in the C&D Block. It avoids the need for the 29 bed radiotherapy and haematology ward which was very unpopular with the nursing staff. This has been achieved by moving haematology to the 'C' end of Level 10 whilst keeping 12 infectious disease beds at the 'D' end. (...) Various essential structural alterations in this plan will cause problems. Ward will clearly have to be misused temporarily so that others can be vacated for essential alterations.*" [10]

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[9] Rook et al. (1991) (see footnote 7)

[10] Roberts, S.O.B. (1983) *The bed plan for Addenbrooke's hospital, Hills Road*. Cambridge Health Authority, Consultant Staff Council 7th March 1983.

Apart from expanding the hospital in lateral directions, hospital buildings are also extended in height. In fact, height extensions were already used for the old Addenbrooke's building. In 1915 two new operating theatres, including anaesthetics and sterilizing rooms were built on the north side of the third floor, complemented in 1930 with a new surgical ward for women with 27 beds on the other side of the third floor[11].

Improved construction technology, such as off-site construction, allows height extensions to be carried out in relatively short time and at acceptable cost. A more recent example is the building of four new modular operating theatres, to expand the Trust's operating theatre complex. The new theatres were placed on top of the Food Court at the new Addenbrooke's Hospital in 2004.

Improvement in construction technology also enabled the hospital to make efficient use of some of the gaps on the site. A new Emergency Assessment unit was opened in 2002, using the 450 sqm empty courtyard at the heart of the hospital. The new unit, which joins up the A&E department and the medical assessment unit, was assembled from 70 modular units manufactured off-site. Hillary Ritchie, the current Archivist at the hospital, commented: "*It is hard to believe the hospital underwent such a major transformation in just 6 months without huge distractions to the current hospital work.*"

So far, we have focused on expansion flexibility. This is not surprising because expansion has dominated the agenda at the new Addenbrooke's site since its opening. But what does one do when demand is lower than expected, or indeed when it disappears altogether? One possibility is to look for alternative, secondary usages. Again, and this time quite coincidentally, Addenbrooke's offers a good example. The fact that the old Addenbrooke's hospital was housed in an iconic Cambridge building in the centre of town, which was not spoilt by over-development, made it an excellent prospect for re-development. Indeed, in the early 1990ies, the site did undergo a major redevelopment to house the newly formed business school of Cambridge University. Thinking of resale and reuse value during the design phase can turn out significantly beneficial.

Whilst Addenbrooke's Hospital serves as an excellent example of the virtue of flexible planning in producing a "living infrastructure" that delivers good value-for-money in a highly volatile environment, the resulting infrastructure is not without critics. The continuous exercise of flexibilities led to a campus which, whilst very functional, has some aesthetical deficiencies, for example lack of vegetation. A 1999 capacity study comments: "*The history of the Addenbrooke's site since it was first opened in 1962, is one in which the layout of the hospital and development within the site have been borne of expediency rather than conformity to a cohesive and comprehensive Master Plan*."[12] It seems that a centralised function for flexibility exercise might have helped to produce a somewhat more aesthetically appealing infrastructure.

[11] Addenbrooke's Hospital Annual Reports 1928, 1930.

[12] Building Design Partnership (1999) *Capacity Study of the Addenbrooke's Hospital Site for the Addenbrooke's NHS Trust*.

3. Flexibility in infrastructure design

Flexibility is often described as *the right but not obligation to a specific future action.* One way of thinking about any particular type of flexibility is to regard it as a system switch which is either in "on" or in "off" (default) setting. Switching to "on" will change the way the system operates. Building the switch in costs money – and switching from "off" (default setting) to "on" will often also cost money. In some situations one can switch on or off as often as one likes, sometimes one can only use the switch once. Of course a good flexible system will typically have several switches to allow a reaction to different circumstances.

Flexible design is nothing else than contingency planning. People buy cars with spare tires because that gives them the flexibility to replace a tire quickly if they have a puncture and avoid being towed to the next garage. A very small additional investment at the design stage – adding a spare tire - can have a great payoff, if and when the need arises. The key word is "*if*" – flexibility has only value *if* a potential future scenario - a puncture - actually occurs and no value otherwise. We may well, in hindsight, have wasted our investment in flexibility but that does not mean that the investment did not make any economic sense.

Flexibility helps reduce loss in some scenarios or increase gain in others. People know that they had not built in enough flexibility in their design if they moan "Had I only done X earlier, I could now do Y and would be in a better position". This should not be confused with hindsight argumentation, i.e. "Had I known that demand was so low, I would have built a smaller hospital." Flexible design is rather to be seen as the designer's implementation of Pascal's principle that "Chance favours the prepared".

How can we become prepared? The starting point is that we explore a range of possible futures. Is this done sufficiently in the design process for infrastructure that is meant to serve for 30-50 years? Or are we all too confident to design and build infrastructure for a single projection of the future? Everyone should be aware of that forecasts, in particular long-term ones, are highly unreliable, in fact are "always wrong" in that what actually happens "never" conforms to predictions.

Therefore, the first and arguably most important step towards more flexible infrastructure is to stop asking for accurate forecasts of the future. Instead we ought to ask our forecasters for a wide range of possible futures. Given such a range, it is the designer's challenge to build an infrastructure that can cope with many of these futures. The incorporation of flexibility into the system design is then a very natural step.

A case in point: a chief technical designer of one of the satellite telephone systems used to complain that one of his major problems was to get the company forecasters to give him a precise prediction of the future capacity required for the system. In the event, the company settled on one figure, and he and his team created a design based on that figure – which turned out to be off by a factor of more than 10, and was a prime cause of the bankruptcy of the company. They would have been far wiser to recognise in advance that it was impossible to predict the capacity required with any accuracy, that they needed to anticipate many different scenarios, and to create a design that was adaptable to this range of possibilities[13].

3.1 Articulating the value of flexible design

We believe there is good evidence that the notion of flexibility was very carefully considered at Addenbrooke's planning process, inspired by the fortunate presence of enlightened individuals, and helped by the relatively low cost of land at the outskirts of Cambridge in the mid 1950ies. Today, major hospital development projects, such as the Royal Victoria Infirmary in Newcastle-upon-Tyne or indeed Addenbrooke's own 2020 Vision, are typically much more constrained. Escalating costs of land and construction and the need to prove "value-for-money" put significant pressure on hospital designers. A capital expenditure minimization mentality is often the consequence; in case of doubt about the economic value, the client will choose the lowest cost bid. Designers who build flexibility into their systems have to clearly demonstrate the economic value of flexible designs. Sometimes additional flexibility will come at an additional cost which needs to be justified. However, flexibility can also help to save on initial capital expenditure, for example by building a less costly smaller initial infrastructure with the potential for efficient scale-up later on. To date there is no standard systematic way of demonstrating the economic value of flexibility to compare projects and system designs. This section attempts to provide some guiding principles towards such a standard.

What are the principles of flexibility valuation? The overriding principle is that flexibility can, by its very nature, only show its value if the valuation process considers more than one future. Indeed, in some futures we will not use the flexibility, will not "switch it on", in others we will. If there is only one future, only one projection, then the valuation cannot reflect the use of the switch – it will either stay off or be switched on for sure and in the latter case we may just as well "hard-wire" the switching, at lower cost, and forget the switch itself.

3.2 A stylised example of economic valuation

Stylising the case of new Addenbrooke's Hospital, we will use a simplistic fictional example of a new hospital development to illustrate the process that allows the articulation and discussion of the value of flexible design. As in the case of Addenbrooke's we assume that the main reason for the new hospital is an increase in inpatient activity. A key design input is therefore the growth of annual inpatient bed days over the next 25 years. Suppose forecasts say that inpatient bed days will continue to rise, eventually requiring a large hospital with 1000 beds. However, some analysts warn that the trend could well reverse. Regulations are discussed that they could give the competing hospitals and private sectors more access to the hospital's local catchment area. Also, over the lifetime of the hospital, medical technology may drastically reduce length of stay for some diseases. The majority of analysts, however, argue against this and quote the aging population, the obesity trend amongst children,

[13] de Weck, O., de Neufville, R. and Chaize, M. (2004) Staged Deployment of Communications Satellite Constellations in Low Earth Orbit. *Journal of Aerospace Computing, Information, and Communication*. **1**(3). 119-136.

but also the increasingly successful recruitment of wealthy private patients from developing countries as drivers of further demand increase.

Before we suggest our approach we paraphrase the traditional approach to design optimisation: Take a single most likely forecast as starting point and optimise the hospital design for this demand growth projection. Let's assume that this results in a 1000 bed hospital as the best size. Then "stress-test" the design with a high and a low demand scenario, e.g. a +/- 10% variation on growth assumptions. Assume it turns out that this hospital will be economically viable even if the demand does not grow quite as rapidly as forecast and thus 1000 bed hospital is agreed to be built. But after a few years, an aggressive patient choice agenda is introduced by the government, the hospital is missing some key performance targets against its regional competitors, with broad coverage in the media. Demand under-performs dramatically and the hospital has to take drastic measures to survive, potentially impacting clinical performance.

Stress-testing on demands is a standard procedure - but one of the problems is that stress tests are typically not bold enough in their assumptions on the range of possible futures, in particular in the light of the long life-time of many hospital projects. The forecasting figures in the Addenbrooke's case provide some evidence for this (Figure 5). The figure below, which gives a sample of errors in traffic demand estimates, is a further illustration of the wide variations in infrastructure demands. Stress-testing with a +/- 10% variation on growth assumptions will not cover the real risks[14].

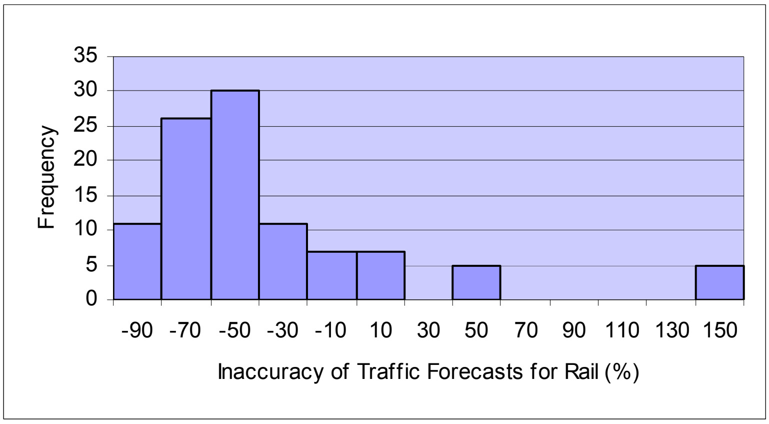

Figure 7. Inaccuracy of Traffic Forecasts for Rail

If we take a wide, more realistic range of demand scenarios for the new hospital into account, it is quite possible that there is not one particular hospital size that performs well across these scenarios. A very uncomfortable situation – but precisely the situation where flexibility can help tremendously. Why not build small, so that you can be confident that you can fill capacity, and at the same time invest in making sure that the hospital can be quickly and cost-efficiently expanded if necessary.

[14] Flyvjberg, B., Holm, M. and Buhl, S. (2005) How (in)accurate are demand forecasts in public works projects? The case of transportation. *J. American Planning Association.* 71(2). 131-146 and Flyvjberg, B., Buzelius, N. and Rothengatter, W. (2003) *Megaprojects and Risk: An Anatomy of Ambition*. Cambridge University Press. Cambridge. UK.

Suppose such a flexible design is discussed: Build 700 beds initially but invest in an option to expand up to 1200 beds in the future through the conversion of ground-level car parking space to additional hospital buildings and the building of multi-story car parks to cope with the additional traffic. How do the economics of the 700 beds + expansion option and the 1000 bed rigid stack up?

It is important to understand that staging can have economic advantages even without appealing to flexibility. In view of economies of scale, the 1000 bed hospital will be cheaper than the 700 bed hospital with future expansion in terms of costs per bed. However, this advantage is counterbalanced by the fact that the initial total expenditure is less for the 700 bed hospital and if the expansion happens late enough it is quite possible that, in discounted present value terms, the total outlay of the expanded hospital will be less than the cost of the 1000 bed hospital. In other words, traditional economics of staging balances loss of economies of scale with gains on capital cost due to postponed capital commitment.

But what if economies of scale outweigh the capital savings? Does that mean that the 1000 bed hospital is economically more valuable? Intuitively, we know that we are overlooking something important in this valuation: If demand is too low, we cannot avoid a white elephant with a rigid hospital design of 1000 bed. Also, if demand is higher than expected, a rigid design cannot amplify the gains from additional demand by quickly and efficiently reacting to grow the size of a hospital. Therefore, a flexible design of 700 beds + expansion option can create more economic values in some futures. How can we make an economic case for the value of this flexibility?

As mentioned above – the starting point for the articulation of the economic value of a flexible design must be the recognition of many possible futures. To keep things simple let us assume that we work with a range of 10 possible futures with different assumptions, call them F1, F2,..., F10.

Next we develop a contingency plan for each design. Of course if the design is rigid as in the case of the 1000 bed hospital, then there is no contingency plan. But for the 700 bed hospital a contingency plan might be of the following form: "We will decide whether to expand the hospital or not in 5 years time. If total growth in demand over these 5 years exceeds 10% then we expand to a total of 1000 beds, if growth exceeds 15% then we will increase to 1200 beds. Otherwise we do not expand." With this contingency plan we can calculate the Net Present Values[15] of the two hospital designs (or other cost-benefit metric) for each future F1,…,F10[16]. The results can be summarised in a bar-chart as follows:

[15] Present value of net cash flows. Each cash inflow/outflow is discounted back into its Present Value.
[16] In a professional analysis these scenario-by-scenario values would be calculated through a Monte Carlo Simulation.

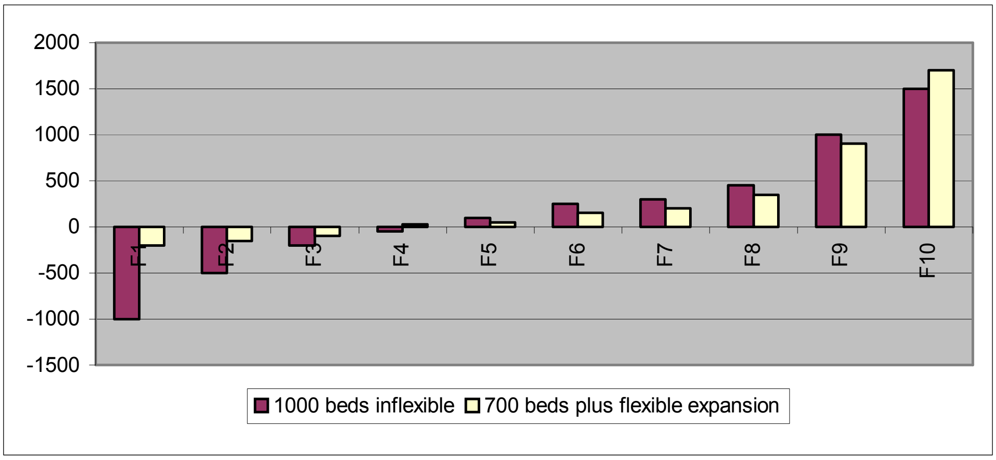

Figure 8. Net Present Value for different demand scenarios

In the low demand scenarios F1,.., F4 the flexible design performs much better because the 1000 bed hospital would be a white elephant. In the medium scenarios F5,…, F9 the flexible hospital is expanded from 700 to 1000 beds. The overall performance is worse – the saved capital costs due to delaying part of the investment were not sufficient to balance out economies of scale and the cost of operational disruption during the expansion. In the very high scenario, F10, the flexible design performs better again because the hospital can be expanded to 1200 beds to amplify gains from high realised demand.

It is not immediately clear from the bar chart which hospital design should be preferred. If one were very worried about the low demand scenarios, the flexible system looks better. But the hospital trust may have good reasons to believe that the chance of these low demand scenarios is unlikely – and be prepared to take the gamble.

This brings us to the second useful ingredient of a valuation – the relative weight assigned to any of these futures. One way of thinking about a relative weight is in terms of subjective estimates of the likelihood of occurrence of these futures. If the futures are rated equally likely, then no new information is added to the bar chart above. If, however, they are perceived to have different likelihood, then one way of incorporating this into the bar graph is to multiply every bar value with its probability of occurrence. This can result in a bar graph like this:

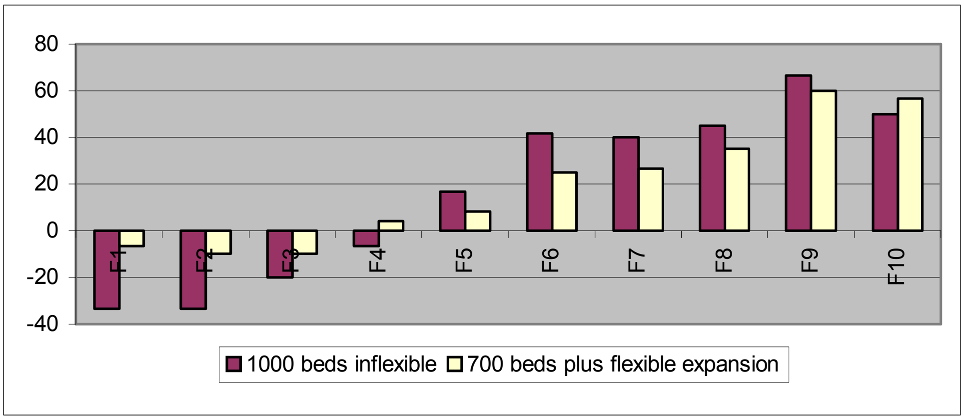

Figure 9. Likelihood-adjusted Net Present Value for different demand scenarios

This graph has a different scale because the bars have been multiplied by the estimated probability of occurrence of the respective future. But what is more interesting is that the shape of the bar chart has changed. The inflexible design now looks better in the medium demand scenarios because these were regarded to be more likely[17].

Bar charts like the above, or similar multi-future representations of economic value, can be usefully employed to illustrate where the value of flexibility lies. They do not disguise the fact that the value is uncertainty. They may well be uncomfortable for decision makers because they highlight negative value in some scenarios. However, this realisation can be used as a challenge to design additional flexibility in the system that improves the performance in some worrisome scenarios without hurting performance too much in others.

3.3 Forecasting for flexibility

Forecasting is traditionally a process of reducing the range of possible futures, resulting in a narrow projection, often even a single figure. This forecasting paradigm works in the traditional design world, where the designer needs a clear idea of the demand for which she designs the infrastructure. The design for a narrow range of future can lead to a significant underperformance of the project if different futures than what were considered materialise. This is why the infrastructure should be designed flexible. To maximise value from flexible design, however, the forecasting paradigm needs to be changed, in fact it needs to be turned upside down. Flexible design needs to consider a large range of plausible future scenarios. Only then flexibility will really show its value.

The exploration of possible futures requires a team effort. Hospital managers will bring in commercial experts, medical professionals, requisite technical experts, outside health specialists and demographers, etc. A “futures team” should be tasked to provide a diverse but still manageable range of possible demand scenarios on the infrastructure, both in scale and scope. It is important that this effort is creative, not strangled by the desire to produce one agreed forecast, or by simplistic bell-shaped thinking of producing a +/- x% variation around a single forecast. In fact, the remit of the futures team should be to ensure that no important and currently foreseeable possible future is overlooked. This is a very different set-up to a traditional forecasting team, where the end product is a single future, plus a few stress-test variations. The outcome of the “futures team” is a reasonably comprehensive *range* of possible demands on the infrastructure.

It is crucially important for the team to look at past relevant forecasts and to appreciate forecasting errors and acknowledge the range of uncertainty. Otherwise they are likely to be happy with very narrow estimates of uncertainty.

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[17] One interesting metric is the sum of the bars, which gives you the expected value of the respective system, i.e., the outcome over all considered futures weighted with your judgement of their likelihood of occurrence. Here you get an expected value of £166 for the inflexible design and of £189 for the flexible design. In this case, flexibility has added value on average. The expected values, however, do not tell you the whole story. It is important to look at the variation of values across the futures to understand the full effect of flexibility.

We do not have a tested procedure for effective brainstorming to establish sets of different health future scenarios and flexible designs, yet. This section presents working progresses to approach this. It seems sensible to start from the macro-factors that drive hospital demand, such as demographic patterns, epidemiological developments, potential technological advances, regulatory changes, etc. These macro-drivers will have impacts on micro (operational) metrics related to hospital demand, such as number of inpatients and outpatients, length of stay, or case-mix. A macro-micro matrix, highlighting the effects of the macro drivers on the micro metrics might be a useful device to help steer the discussion. Such a matrix could look like this:

MACRO-DRIVER	MICRO METRIC		
	No. of Inpatients	Length of Stay	No. of Outpatients
Immigration of middle-aged population	+	-	+
Increase in population aged 65 and over	++	++	++
Development of new treatment	+	--	+

Table 1. Macro-Micro Matrix modelling quantitative relationships between macro-drivers and their impacts on the key operational metrics

Use of plus and minus signs is a starting point to explain quantitative relationships. A plus sign means that an increase of the macro factor will lead to an increase of the micro metric, whilst a minus sign indicates a decrease of the micro metric as the macro factor increases. In reality the matrix will become more complex. For example inpatients may be segmented by disease groups.

Following from this, the team may introduce uncertainties around the quantitative relationships between macro drivers and associated micro metrics (i.e. by introducing a measure to indicate how accurate the team agrees upon the relationship they assigned). Different scenarios in each micro metric can then be found by summing up each of the micro metric columns with consideration of these uncertainties, and ultimately a range of future demand scenarios can be forecasted.

Once a range of future demand scenarios is agreed upon, the engineering design team will come in. They will work with the client towards potential designs that will produce value for money in many of these futures. The challenge is to trade off optimal designs for some futures against miserable performance in other futures. Creative use of flexibility will be a natural, in fact quite possibly the most important ingredient to the design discussion. The engineering designers will have to work actively with other professionals in the team to understand what type of flexibility might help and how it can be incorporated into the overall design at reasonable costs. Again, it is easy to drown in the myriads of possibilities and thus prioritisation is a key. A matrix structure might again help to understand the relationships between the various micro metrics and the flexibilities that might help to mitigate or exploit uncertainties around them.

FLEXIBILITY	MICRO METRIC		
	No. of Inpatients	Length of Stay	No. of Outpatients
Extension of hospital in height	+	+	+
Subletting hospital for secondary usages	-	-	-
'Shell' space	+/-	+/-	+/-

Table 2. Micro-Flexibility Matrix modelling quantitative relationships between the micro metrics and the flexibilities that might help to mitigate or exploit uncertainties around the micro metrics

A plus now indicates that the respective flexibility helps if the corresponding operational metric increases, a minus indicates that the flexibility helps if the metric decreases. Some flexibility might help in either cases or neither case. For instance shell space, originally planned for the case of high demand, could also be an attractive feature for secondary usage if demand declines. Again, this sign-based analysis is just a pre-cursor to a more quantitative analysis. Notice that the two matrices, the macro-micro matrix and the micro-flexibility matrix can be combined to understand the relationship between macro uncertainty drivers and the flexibilities in the design[18].

We are not in a position, yet, to give advice on best practical procedure to develop a flexible hospital infrastructure design. Finding the right mix of simplicity and transparency on the one hand and rigour and consistency on the other is challenging.

4. PFI and value-for-money

Our final concern in this paper is the effect of Public Private Partnership (PPP) procurement, in particular under the UK Private Finance Initiative (PFI), on flexible infrastructure design. Department of Health reported in 2007 that PFI has delivered over 550 projects in the UK since its introduction in 1997, primarily in the health, education and transportation sectors, and investments in 80 major PFI hospital projects alone exceed a total of £60 billion[19].

A chief argument for the initiative has been the perceived poor performance of traditional public procurement processes on core metrics, such as delivering projects *on time* and *on budget*. Not surprisingly, the political reflex has been to involve the private sector. Private companies are assumed to be more disciplined with capital expenditure and to have a better understanding of and better access to the expertise required to carry out large infrastructure projects. Combining this capability with competition, via a bidding process, should improve performance.

Under PFI a private consortium finances and builds the infrastructure and then rents it to the public sector client for a fixed period, typically 25-35 years, after which ownership of the infrastructure is typically transferred to the public sector. During the concession period, the public sector client makes agreed annual rental payments to the

[18] Lee, Y.S. (2007) *Flexible Design in Public Private Partnerships: A PFI Case Study in the National Health Service*. Master Thesis. Judge Business School. University of Cambridge.
[19] Department of Health (2007) *Prioritised Capital Schemes approved to go ahead since May 1997*. London.

private consortium, which in turn maintains the infrastructure to an agreed service level.

4.1 Controlling cost and time versus delivering value

PFI is a significant success with regard to delivery on time and on budget, as evidenced in a recent study by McKee et al. (2006)[20] on a sample of conventionally procured and PFI projects:

	On-Time	On-Budget
PFI projects	76%	79%
Conventionally procured projects	30%	27%

Table 3. The performance of PFI projects compared to conventionally procured projects in terms of building on-time and on-budget

On the key project management metrics, PFI seems to work well, assuming that neither budgets nor time are inflated. Competition in the bidding process should keep total budgets down and the fact that positive cash flows from government rents only start when the infrastructure becomes operational gives the private sector an incentive to keep the construction period short because they will otherwise loose part of their income stream.

Does PFI deliver value-for-money? The value proposition for any project has three main components: Construction Costs, Operational & Maintenance Costs, and Operational Benefits / Revenues. The McKee et al. study relates to construction costs and certifies the success of PFI in this respect.

How well do PFI projects do *after* construction? Might it be that the private consortia save on construction costs and time wherever possible and therefore produce infrastructure with significantly enlarged running costs, when compared to conventionally procured projects? This "moral hazard", as economists call it, was recognised early on in the design of the PFI process. The solution again is simple: PFI projects require the private consortium not only to build the infrastructure but also to maintain it during the lifetime of the contract. It is therefore in the private company's best interest to find a good balance point between spending money upfront for a robust infrastructure and spending money later on maintenance.

PFI has thus effectively transferred two key risks, the risk of excessive construction costs and time and the risk of excessive running costs, from the public to the private sector.

This leaves us to look at the third value driver: the benefits or revenues generated from PFI procured projects. Here, the record on the success of each PFI projects in terms of this third value driver is mixed. On one side, PFI projects can still be white elephants. PFI does not seem to address the issue of uncertainty in revenues or social

[20] McKee, M., Edwards, N. and Atun, R. (2006) Public private- partnerships for hospitals. *Bulletin of the World Health Organisation*. 84. 890-895.

benefits in a systematic way. Outcomes can thus differ substantially from what was originally expected. To date, to the best of our knowledge, there is no large-scale study available to substantiate or falsify the hypothesis that PFI projects do not deliver an improvement in value-for-money by enhancing the benefit or revenue stream compared to traditionally procured projects, but there is ample anecdotal evidence and there are structural arguments to help validate the hypothesis.

Balmoral High School in Belfast is a notorious example. The school was built for 500 pupils. Due to demographic changes it could only attract some 150 pupils and therefore was uneconomical and had to be closed – leaving the local education authority to honour a 20-year contract of annual payments to the private sector, a cumulative cost of £7.4M, without any future benefit[21].

Another example is Coventry University Hospital, a £400M PFI project. The local health trust could not even afford the first annual payment after the construction period, and had to be bailed out through debt, underwritten by the primary care trust. To survive, the hospital trust will have to make significant savings, which will lead to shrinking services and quite possibly a distortion of clinical performance. This is hardly a case of good value for money[22].

The first PFI development of a museum, the Royal Armouries in Leeds, is a further example. Realised visitor volume in 1999 was only 400,000 against a projection of 750,000 that formed the basis of the PFI case. This led to the financial collapse of the museum[23].

These examples point to an inherent weakness in the PFI process: its preoccupation with cost control, rather than value delivery. If we define value as a benefit-cost ratio, then PFI works on minimizing cost – but does not specifically address the maximisation of benefits**.** In summary, there is evidence that PFI helps the public sector to "build things right" but it is doubtful that PFI helps to "build the right thing" in a way to improve their income stream.

4.2 PFI can systematically inhibit good value for money

The existing PFI framework can be a significant obstacle in managing situations where the infrastructure does not create as much value as expected. The natural reaction to lower than expected demand, as in the case of Balmoral High School or Coventry University Hospital, is to change the use of the infrastructure, or even sell parts of it. Balmoral High School might be a good prospect for conversion into a cinema, gym, or other private sector facility. Within the existing PFI framework this is, however, easier said than done.

Firstly, the private consortium is naturally expected to act in the interest of its shareholders and therefore has no incentive to lower the contractually agreed rent if

[21] Education Guardian http://education.guardian.co.uk/schools/story/0,,2041507,00.html (21.03.08)
[22] BBC Radio 4 http://news.bbc.co.uk/1/shared/spl/hi/programmes/file_on_4/transcripts/pfi_120607.txt (21.03.08)
[23] National Audit Office (NAO) (2001) *The re-negotiation of the PFI-type deal for the Royal Armouries Museum in Leeds* (HC 103, 2000-2001). London: HMSO.

projected revenues do not materialise. In fact, it will have sold a significant proportion of the rental cash flows to the financial markets, e.g. to pension funds, to help finance the project in the first place. So the private consortium's base position in any negotiation is that the public partner should honour the contractually agreed payments no matter how little the realised benefits and revenues are. The negotiation space is reduced to potential savings in maintenance costs, typically a small proportion relative to the total capital expenditure.

Secondly, there is a gridlock situation with regard to the right to alter the asset. On the one hand, the public sector has a right to usage as agreed in the contract, so the private consortium cannot unilaterally change the asset. On the other hand, the private consortium owns the asset, so the public client cannot change it unilaterally to improve its value. Changes can only take place if all parties agree. To make matters worse, the membership of the private consortium may have changed, and the design and construction knowledge and expertise necessary for a creative satisfactory restructuring of the failing asset may be lacking.

Even if flexibility is recognised in the design of the hospital, the PFI contract can be a stumbling block to its efficient use. An example in point is the PFI project, Royal Victoria Infirmary in Newcastle-upon-Tyne, which includes an expansion provision for additional ward space. During the construction phase it became apparent that the Trust would rather use this space for offices, which was simpler and less costly than using the expansion space for wards. However, the potential use of the expansion space for offices was not explicitly stipulated in the contract and therefore the private consortium could not agree to the request of the Trust. The consortium argued that the change would require a potentially very costly re-rating of the bonds used to finance the PFI[24].

To summarise the challenge: Even though PFI projects may well deliver a pre-specified operational service level at low cost, they can still fail because during the contract lifetime it can turn out that the installed infrastructure and pre-specified operational service level is actually not what is needed. To make the asset valuable, it needs to be changed. PFI is currently not set up to tackle this challenge efficiently and can seriously strangle the flexibility to make changes when required.

The public sector clients of PFI projects have woken up to the need for flexibility and more and more projects are now accompanied by a flexibility strategy document. This is to be welcomed. However, a cursory sweep through several such documents indicates that what is called a flexibility strategy is often just a laundry list of flexibilities that happen to be in the chosen design, or could be added at small cost. The flexibilities are largely focused on the obvious - generic future expansion potential by 20%-30%. More importantly, the flexibility documents appear to be add-ons to the design documents, they do not form an integral part. Designs are not chosen because of their inherent flexibility and flexibilities are not linked to uncertainties. Instead, flexibility seems an after-thought in the design process.

The existing flexibility documents indicate that the mindset of the designer has not shifted from "minimal cost for the given specification" to "maximal value in an

[24] Lee, Y.S. (2007) (see footnote 18)

uncertain world". Making this shift happen is a fundamental challenge. Organisationally, this challenge is reminiscent to the challenge faced by the IT industry in expanding its role from delivering efficiency- and cost-focused back-office operation to delivering effective, revenue-focused front-office function that is of strategic significance for many service companies. Effective infrastructure design requires the engineering designer to expand her remit, too, and engage more fundamentally with the uncertainties surrounding the benefits that can be reaped from the infrastructure she designs.

4.3 Creating a genuine long-term partnership under PFI

To make the vision of flexible infrastructures work, it is important to develop a common language and set of tools, such as the ones explained in the foregoing section, to enable the partners to communicate uncertainty and flexibility effectively and to articulate the value of alternative flexible designs systematically.

However, there is an even more substantial challenge. In order to realise the value of flexible infrastructure, public private partnerships need to move from a contractor-client, "fee-for-service" relationship to a genuine partnership, where the partners engage over the life-time of the infrastructure in a genuine joint operation, sharing costs, rewards and risks in an efficient way.

The existing relationship between the private and the public sector is still essentially a contractual relationship. One might even argue that much of what PFI achieves today, in terms of improvement on traditional project management metrics, could also be achieved with suitably modified traditional procurement routes. What cannot be achieved without a genuine public private partnership is the creation and maintenance of high-value *flexible* systems, of "living infrastructures", where the operation, the reaping of value, is one part (the public sector's responsibility) and the regular adaptation of the infrastructure, the exploitation of flexibilities is the other part (the private sector's responsibility). This might be coordinated, for example, by an on-site office, jointly run by the private and public partners, with a remit to monitor unfolding circumstances, understanding their impact on the operation of the system and exercising flexibilities in the design as appropriate for the maximisation of the value reaped from the system. Such a central office could not only steer the exercise of individual flexibilities but also avoid a piecemeal exercise of flexibilities and avoid undesirable side-effects, such as the bemoaned lack of aesthetical appeal of Addenbrooke's campus. Only if the public and private sector form a genuine partnership, aligned to achieve good long-term value for the public and good value for the shareholders, can the vision of a living infrastructure become reality.

5. Conclusions

In times of significant uncertainty, be it commercial, technological, or socio-political in nature, rigid infrastructures are bound to under-perform. The challenge is to deliver high-value flexible infrastructures, “living systems”, that can cope with this uncertainty by being suitably adapted as scale and scope of future demand unfolds. Flexibility is a substantial value-driver for hospital infrastructures as starkly evidenced by the development of Addenbrooke’s Hospital in Cambridge over the past 60 years.

In a time of ever increasing concern about value-for-money in infrastructure investments, designers and their clients need to make a convincing economic case for their design and it is therefore paramount that the economic value of flexibility is articulated convincingly and transparently. This requires first and foremost a more thorough exploration of the possible futures and how flexibility can add value scenario-by-scenario basis. It is crucial that the underlying forecasting paradigm shifts from trying to give an agreed and fairly precise projection of future demand to providing a large range of possible futures.

Infrastructure investments, in particular in the health sector, are increasingly carried out within a Public Private Partnership framework. Such arrangements have been shown to be quite effective on short-term project management metrics, such as delivering a building on time and in budget. However, in order to meet the challenge to deliver high-value flexible infrastructure the private sector needs to become involved in the long-term value proposition of the project. This is not straight-forward.

Within the UK Private Finance Initiative the infrastructure asset is locked into a financial contract for a long period, typically 20-30 years, which makes its modification difficult. Any alteration that is not foreseen in the contract will be very difficult and costly to realise. This reduces a major advantage of flexible design, namely that flexibility is not only useful in the scenarios that were foreseen, but is also likely to be of use in scenarios that were not foreseen.

Nevertheless, involvement of the private sector is key to managing the crucial value uncertainty in infrastructures. Private firms have the technical expertise and employ the best engineering designers who, together with the best minds of the public sector partners, can design and deliver creative flexible infrastructures that can be adapted cost-efficiently as the future unfolds and to deliver good value in many possible future scenarios. Effective public private partnerships call for private sector partners who are bold enough to move up the value chain and fully engage in the provision of long-term value to the public. This requires genuine partnerships, not “fee for service” contracts as in the existing PFI framework. It needs visionary construction companies and governments to meet this challenge.