



Evolvable or 'Future-proof' Infrastructure Design: Integrating Modularity and Safeguards.

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EVOLVABLE OR 'FUTURE-PROOF' INFRASTRUCTURE DESIGN: INTEGRATING MODULARITY AND SAFEGUARDS

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Abstract

In the infrastructure co-development process, the project promoter or developer allows the customer organizations which will later operate the facility to participate in the design and development process. Co-development aims to align the design definition of the new facility with the customer needs. But in the years it takes to deliver a new infrastructure project, as well as throughout the operational life of the new facility, the customer needs are likely to evolve. This evolution stems from external changes in the way the customers strategically position their businesses, as well as from relevant changes in fit-out technologies, regulation, and end-user requirements. The evolvability of infrastructure is the problem at the heart of this chapter: How to best design new infrastructure so it can economically adapt to changes in the external environment over time while limiting the capital investment upfront, i.e., how to develop affordable 'future-proof' designs? Here, I build upon empirical findings on the co-development of a new airport terminal to examine how the characteristics of the design architectures affect the extent to which the infrastructure can accommodate change in customer requirements. The findings stem from observing the airport developer's strategic effort in delaying design decisions during project delivery, as well as in leaving selected options open in the design definition. The strategies aimed to make both the infrastructure design definition and the development process cope efficiently with the foreseeable evolution in the needs of the two main customer groups: the airport operator and the airline occupying the new terminal. The analysis sheds light on the value of two design approaches that complement one another in building flexibility to accommodate external change: First, modularity, i.e., the mapping of functionalities to physically decoupled elements with tested, standard interfaces. And second, safeguarding, i.e., the delivery of provisions built in the design that 1) leave open options to accommodate foreseeable change when the architectures are integral; and 2) reduce the costs of integrating functional modules when the architectures are modular. Infrastructure developers and suppliers who learn how to make good use of the two approaches will be well positioned to respond to evolution in the external world, and improve the performance of their business.

Keywords: Flexibility, Design, Modularity, Safeguards, Evolvability

Background

Industrial Context: The Infrastructure Gap

The needs for new physical infrastructure have grown dramatically around the world in the last decades. Broadly, infrastructure encompasses transportation systems (e.g., airports, roads, railways, ports), utility networks (e.g., water, gas, electricity), and social assets (e.g., hospitals, prisons, and schools). These facilities contribute to deliver services that are central to the continuance and growth of every community and state. The massive pressure for new infrastructure stems from a conflation of factors: population increase, migration flows towards cities, deterioration and obsolescence of existing assets, and the globalization of the supply chains. A report from the OECD has recently stated that infrastructure spending needs to be \$53 trillion worldwide between 2007 and 2030, if governments in developed countries are to perform the needed upgrades to utility and transport systems and emerging markets industrialize. OECD has also exhorted developed nations to invest 2.5% of their GDP a year in infrastructure (OECD 2007). For the case of the European transportation sector alone, The Van Miert Group report (2003) estimates that the investments for realizing the trans-European transport network (approved by the European Council and the Parliament in 2004) come to more than €600 billion up to 2020 for the totality of the projects of common interest, of which €235 billion for the priority projects (0.16% of GDP in annual investments). The private sector is expected to contribute up to 20% of the total cost of the transport network (ibid.). And for the case of energy, the International Energy Agency estimates in its 2006 World Energy Outlook report that \$20.7 trillion would be required today if all governments simultaneously decided to enact over 1,400 policies to secure energy supplies due to decades of underinvestment in basic energy infrastructure (IEA 2006).

To bridge this infrastructure gap, states around the world have recourse to privatization or the divestment of government-owned enterprises, as well as to private finance for developing and/or operating assets for a limited period (aka Concessions or Private Finance Initiatives/PFIs). Privatization, the first scheme, transfers the ownership rights of the assets from the public to the private sector. Concessions or PFIs involve long-term management contracts through which the government only allocates to the private enterprise the responsibility for providing infrastructure services for a limited period at an agreed level of performance. This *de facto* transformation of infrastructure into a business gained popularity in the modern age after the United Kingdom initiated a sweeping programme to privatize the utilities, airports, railways, and highways in 1979. Many countries followed suit. Two major forces triggered the trend. On one hand, the ideology that the private firm – motivated by profit-seeking – is more efficient, cost-conscious, customer-focused, and can deliver quickly than bureaucracies do. On the other hand, the pragmatic necessity to supplement constrained state budgets burdened with growing expenditures on health care and on the retired population. As a result, infrastructure has become relevant for businesses, both as the suppliers of engineering, manufacturing, and construction work, and the developers and operators of new assets.

More recently, infrastructure has become highly attractive to investment firms, pension funds, and family houses. Other investors include export-import banks of the BRIC economies and the Government of China (Orr and Kennedy 2007). Infrastructure assets supposedly can provide secure, steady inflation-proof income and market-beating returns due to their monopoly-like position. These assets are a useful source of diversification as they provide low correlation to equity markets and the economy. From 2000 to 2006, infrastructure transactions have risen from \$52 billion to about \$145 billion, and demand for new deals rose faster than supply (Saigol 2006). In 2006, there

were over 70 infrastructure funds, with targets to raise more than \$122 billion; their activities were focused primarily on US and European brownfield infrastructure, with 8 to 15 planned investments (Stodder and Orr 2006).

Problem

The problem at the heart of this chapter looks at how to balance the profit-seeking and public interests in the design of new infrastructure. Unlike most commercial products, infrastructures are built to last many decades. Bridges and airports are expected to operate 40-50 years or more, for instance, whereas parts of the water distribution and sewerage systems may be designed to last almost 100 years. During the operational lifetime of these facilities, the external environment will change: new technologies will be developed, the needs of the customers and end-users will evolve, and the government will put together new legislation and regulation. The core building systems of the new Terminal 5 (T5) at Heathrow airport, for example, are expected to operate for at least 40 years. But between the conceptualization of T5 in the mid nineties and its opening in 2008, the airline and airport activities changed dramatically in Europe, with the surge of low cost carriers, self-service and on-line check-in, stringent security procedures, and the introduction of jumbo aircrafts. Many more external changes will occur in the future, presumably. Designing affordable infrastructures that can cope with external changes over time is at the crux of the private development of new public infrastructure.

When capital was readily available, an approach to ensure that infrastructures could flex to external change over time consisted of designing in upfront provisions for foreseeable needs in the future. The London Victorian brick-built sewer network launched in 1865, for example, comprised 264 km of underground brick main sewers to intercept sewage outflows, and 1769 km of street sewers. The network still remains largely operational today due to the generous allowance which was built into its original design (Downey 2006).¹ Likewise, a major toll suspension bridge in Lisbon, Portugal, was engineered and built in the sixties with a structural allowance that left two options open for the future: first, add two more lanes to increase capacity from four to six lanes for car traffic; and second, add two railway tracks. Both options were exercised almost thirty years after the bridge opened to the public in 1964 once demand for additional car traffic and passenger railway finally materialized. The structural reinforcement involved placing a second set of main cables above the original set (Figure 1).

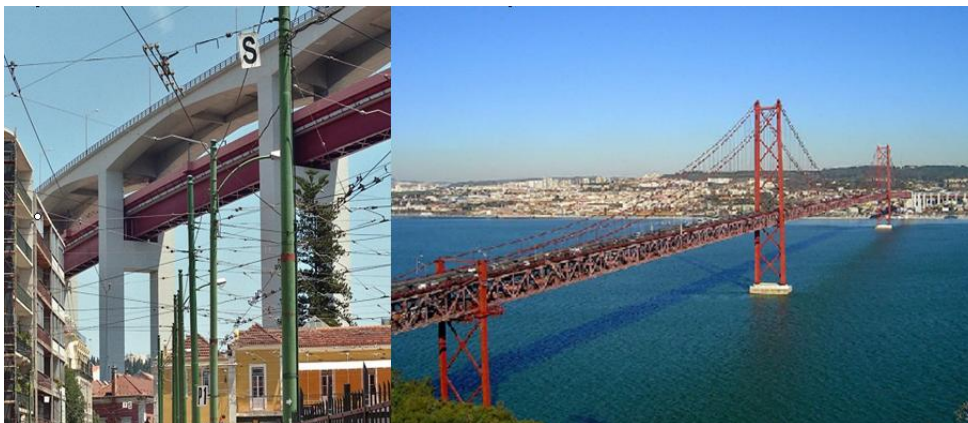


Figure 1- Bridger over the River Tagus, Lisbon (built in the sixties, upgraded in the nineties) (photos downloaded from Wikipedia)

¹ An unforeseen use for the sewer network emerged in the modern age: a quick and cost-effective location to run the London-wide optical fibre network with minimal street-work disturbance. The adaptability of infrastructure to unforeseen external changes is, however, not discussed in this chapter.

But when scarcity of capital jointly with profit-seeking interests are at the basis of design decision-making, designers have to judiciously balance provisions to make infrastructures adaptable to foreseeable evolution in the future with the capital that the infrastructure promoter can afford to spend at the present. In particular, promoters are wary of making upfront capital investments that will fail to pay off over time (or lead to unsatisfactory rates of return on investment) because the foreseeable scenarios about the future made at the project onset got it wrong. This means that designers need to find out original ways to efficiently ‘future-proof’ infrastructures, i.e., design new infrastructures that can economically adapt to change over time while requiring limited capital investment upfront. The British National Health Service (NHS) pioneered the request for future-proof designs when it commissioned new hospitals through PFI schemes. The contractualization of this notion was, however, contested by designers who felt they could not be made liable for future proofing new hospital designs (Kitching 2004).

Learning Objectives:

- Become aware for the tension between profit seeking and public interests in the design of new infrastructure
- Become aware of the importance of evolvable or future-proof infrastructure design, i.e., affordable infrastructure that can economically accommodate external change over time
- Be able to characterize the architectures of large-scale functional elements relative to the surrounding building environment as modular or integral.
- Identify the value of modularity as a strategic approach to build flexibility in infrastructure design
- Differentiate situations where modular functional elements are available ex-ante from situations where modules can be developed
- Identify the value of safeguarding as a design approach to build flexibility in infrastructure design, especially in infrastructures with integral architectures

Option-like Thinking applied to New Infrastructure Development

Key Requirements

The involvement of the profit-seeker in the development of new infrastructure creates a challenge about how to efficiently reconcile and integrate in design the concerns about affordability and evolvability. The core question is: how to design affordable infrastructure that can evolve in response to evolution in customer requirements, in technology, and in regulation over time? Stated differently, how to design and develop ‘future-proof’ infrastructure, i.e., infrastructure that can meet the constraints on capital spending upfront without undermining the capability to economically adapt to changes in the design requirements over the project delivery and the operating lifecycle?

Potential Solution: Design modularity and safeguards

The application of option-like thinking to the design of new infrastructure, or paraphrasing Wang and de Neufville (2005) the effort to build real options ‘in’

projects, offers a promising avenue for operationalizing design for future proofing. An option is “the right but not the obligation” to choose a course of action (such as expanding, acquiring, deferring, or abandoning) and obtain an associated payoff (Dixit and Pindyck 1994). The real options approach extends the financial option theory to ‘real’ assets. The aim is to incorporate the effects of private risk and foreseeable externalities into the valuation of capital investments, thereby moving beyond static methods to value capital investments based on the net present value (Trigeorgis 1996).

But unlike the advances that have been made using real options theory for valuating infrastructure investments and managing financial risk, i.e., building options ‘on’ projects, research on formally applying option-like thinking to the design of new infrastructure is still in its infancy. Gil’s (2007) study of practices in airport design suggests that designers intuitively apply option-like thinking, particularly as they search for modular designs that warrant the airport can flex to foreseeable change in requirements. Modular designs involve a one-to-one mapping between functionalities and the physical elements (Ulrich 1995). Design modularity requires physically decoupling functional elements, agreeing the rules about how the elements should interface, and establishing tests that can validate how the interfaces work (Baldwin and Clark 2000). Because functional modules are relatively easy to substitute, remove, or add, they represent options that are built in the design of a new product or system (op. cit.).

Modular principles underpin the development of trenchless technologies to lay down pipes inside conduits already buried in the ground. These technologies have allowed modern urban societies to avoid the disruption of major open-cut construction (Downey 2006). The same principles help to make sense of the award-winning design of the new Upton-upon-Severn viaduct in the UK. Flood waters inundate the Severn floodplain and rise above the road typically once in five years, rendering the route to the east of Upton upon Severn impassable for several days. The urgency to replace the deteriorated 1939 reinforced-concrete viaduct meant that there was insufficient time for a wholesale elevation of the roadway. The 170m long deck was designed both for inundation conditions, as well as to be jacked up in the future (Sreeves 2007). And the same principles also inform recent efforts to engineer ‘adaptive’ infrastructures that can move in response to outside forces, such as bridges in which the load-bearing capability might literally follow a large truck driving across.

Approaches to develop modular infrastructure echo in some ways the effort incurred by manufacturers to search for new product architectures that can ‘evolve’ in response to external change (Baldwin and Woodard 2008) Or stated differently, to search for product architectures that allow for ‘generational variety’, i.e., architectures that minimize the design effort for future products and make selected design structures common across generations (Martin and Ishii 2002). But a caveat is in order. Evolvability in commercial product design primarily involves searching for modular platform architectures that can support the efficient generation of a large number of product derivatives in response to external evolution. In contrast, evolvability in public infrastructure design demands, first, flexibility to economically change the design during project delivery to accommodate customer-driven change. And second, evolvable infrastructures also need to economically accommodate physical modifications so as to cope with change in requirements during their operating life time.

Notwithstanding the advances in the modularization of the architectures of new infrastructure, some of the large-scale functional elements of a new infrastructure can be very difficult or very costly to modularize. In these cases, the design architecture of these elements needs to remain integral to the surrounding building systems. The same happens in product design where modularity seldom comes for free (Ethiraj and

Levinthal 2004). Further, modularity can occasion penalties in product performance (Fixson and Park 2008). In effect, modularity is easier to accomplish for products based on electricity than for those based on mechanical and structural systems because of the one-dimensional flow of electrons vis-à-vis the multidimensional surfaces of the physical systems (Baldwin and Clark 2006).

Integral design architectures do not exhibit neatly decomposable systems (Simon 1962) or built-in options (Baldwin and Clark 2000) and, as a result, have low flexibility to accommodate external change. In these circumstances, infrastructure designers can future-proof by incorporating safeguards, i.e., structural provisions or allowances designed in the infrastructure that purposely leave open the capability to accommodate a foreseeable functional option in the future (Gil 2007). Safeguards manifest Simon's principle (1962) that designers should avoid designs that create irreversible commitments for future generations. Going back to the Terminal 5 illustration, the construction of an underground train tunnel and two extra platforms (unneeded at the present) has safeguarded the extension of an additional train line to the Heathrow airport in the future (Figure 2). This costly upfront investment was deemed crucial to leave open the option to increase the capacity of the airport in the future. It would be difficult otherwise for the airport owner to overcome the growing concerns of the public with the detrimental impacts of the growth of airport-related traffic to the local environment and to the welfare of the local communities.

Safeguarding can also be used to reduce the costs of integrating a new functional module in the future, or in other words, to reduce the costs of exercising a modular option. For example, investments can be made upfront in digging pits and placing temporary covers on the ground floor for a new infrastructure if the developer foresees increasing the number of lifts or escalators in the future. The pits are not a necessary condition to ensure that the option stays open. Their absence does not prohibit the developer from installing the modules at a later time. But while the spending in executing the pits is marginal relative to the overall capital investment, these safeguards can significantly reduce the costs of integrating the modular lifts in the future. If the pits are ready, the installation will be cleaner and will impact less the performance of the facility. This, in turn, can increase substantially the value of the option.

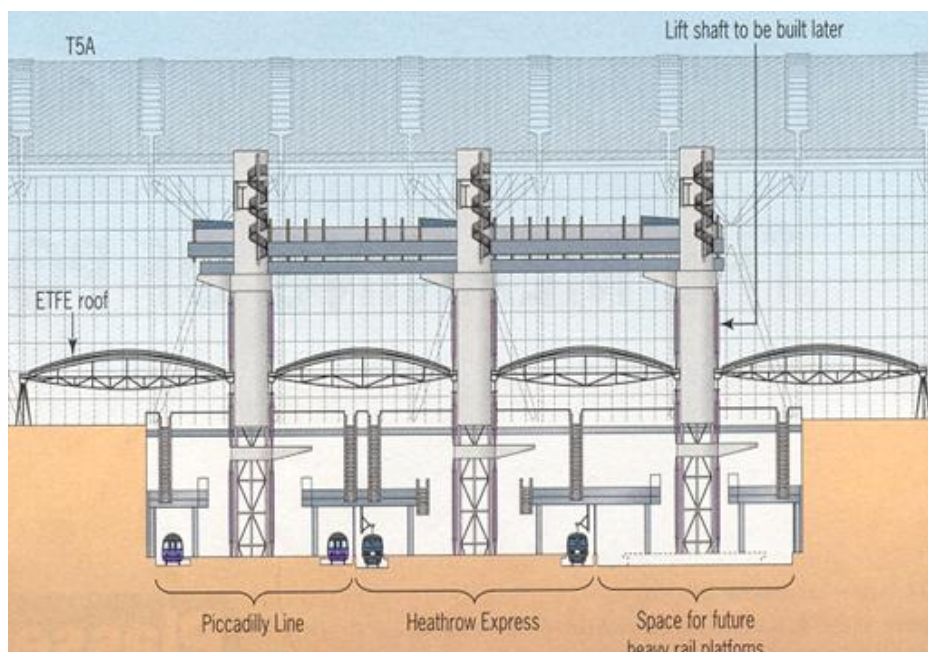


Figure 2 – Design of the Train Station for Terminal 5 showing the two unused platforms

Investments in safeguards can be passive or active. A passive safeguard consists of an instruction built in the design documents that does not need to be physically executed to ensure that the option stays open in the future. For example, an infrastructure promoter can acquire land adjacent to a new facility so as to leave open the option to further expand the facility in the future. Detailed plans about how the land will be occupied in the future can be designed into the master plan. But the infrastructure promoter can delay the physical construction of the expansion until the uncertainties resolve favourably. In contrast, active safeguards involve design instructions that need to be physically executed at a cost in the present so as to leave open the option to take an action in the future. For example, in the case of the suspended bridge that was designed in the sixties mentioned in the previous section, some of its main structural elements (foundations, towers) had to be engineered and physically built upfront to stand the design loads corresponding to the ultimate scenario.

The next section introduces the case of a new airport terminal development. It aims to illustrate how infrastructure developers can resort to modularity and safeguards to leave options open; or stated differently, to design for future-proofing or evolvability.

Leaving Options Open in Infrastructure Design: The Case of a New Airport Terminal

This case study examines design practices that were empirically observed throughout the co-development of a new airport terminal. The findings draw predominantly from two empirical studies: First, Gil et al. (2008)'s research on the implementation of design postponement. This strategy – long practiced in the world of commercial new product development (Iansiti 1995) – enables that some parts of the design definition remain unresolved while other interrelated parts progress into design detailing and physical execution during project delivery. Gil et al.'s (2007) chapter “Operationalizing the Open Building Approach in the Management of Large-scale Engineering Projects” in the first book of this series reveals the value of postponement when the infrastructure project unfolds under conditions of uncertainty and ambiguity. Specifically, postponement is useful to leave unresolved downstream design parts (fit-out systems and tooling) while moving the upstream design parts (civil engineering) into physical execution. Design modularity is a key enabler for implementing a postponement strategy. And second, Gil (2007)'s research on the value of safeguarding. This strategy aims to leave open the option to economically make adaptations to the facility after project completion provided that foreseeable uncertainties resolve favourably throughout the operational life of the facility. Strategic safeguarding is a key enabler for leaving options open when the design architectures are integral. Safeguarding can also be used to reduce the costs of integrating selected options in modular design architectures

Research Base

This research was inductive since few studies are available that theorize on how the concepts of design modularity and safeguarding can apply to the design of new large-scale infrastructure. The units of analysis were instances of design choices through which the developer and designers for the new airport terminal sought to implement a postponement or safeguarding strategies. A set of constructs from literature on modularity and option thinking applied to design were organized in empty table shells (Miles and Huberman 1994). I then induced the conceptual ideas by cycling between collecting raw data and playing theory against data through tabular and graphical cross-comparisons (Miles and Huberman 1994). The choice of the units of analysis was based

on theoretical sampling (Eisenhardt 1989), i.e., the need to build a sample representative of cases along a range of ‘polar types’. Thus, I examined instances of strategic implementation associated both to modular and integral design architectures. Some of the design choices aimed to meet the needs of the major occupier airline for leaving options open throughout the delivery of the new airport terminal project. Other design choices aimed to build flexibility in the design of the new terminal so as to accommodate the resolution of foreseeable uncertainties in the businesses of the airport owner and occupier airline during the operating lifetime of the airport. The core of the data collection process took place from May 2004 to July 2007. It involved almost 100 face-to-face, one-on-one interviews, analysis of archival documents, site observations, and numerous informal conversations.

The Use of Modularity in the Airport Terminal Design

The analysis of the characteristics of the large-scale functional elements of the airport terminal differentiates three situations from the perspective of design architecture: First, some of the functional elements that exhibited a modular interaction relative to the surrounding building systems were available from the onset of the development process; second, the physical interaction of some functional elements relative to the surrounding building systems was modularized during the development process; and third, some functional elements remained integral to the surrounding building systems because breaking apart the interdependences was technically too complex or too costly.

Functional Modules Available Ex-ante

The availability of functional elements with modular architectures at the onset of the terminal development process occurred with technologies that have little stand-alone value, yet they are valuable once integrated in the infrastructures that need them. The addition of single-function physical modules, for example, was part and parcel of installing a trolley ramp, a passenger lift, or a baggage-reclaim belt. These elements involve technologies that are associated to stable design rules. These rules specify the interfaces between the module and the surrounding building systems, as the director of the project supplier for the lifts and escalators explained:

“Our design process is different from other people. We have a product for more than 25 years. Our machines generally sit on the edge of the structure on a rubber pad. We just need to tell people the size and depth of the pit, the electrical power, and how the control panel interfaces with fire alarms.”

The limited group of firms that supply these technologies — over 80% of the world market share for lifts and escalators belongs to 7 companies (Mikkola and Gassman 2003) — may be said to form a modular cluster in the same way that clusters play host to the evolution of modular computer designs (Baldwin and Clark 2000). The modular design of these functional elements makes it relatively easy to postpone the decision about exactly how many modules should be incorporated in the design during project delivery. Design modularity also facilitates leaving open the option to incorporate more functional elements during the operational life of the facility: add more lifts to the car park, more trolley ramps to the train station; and more baggage-reclaim belts to the baggage reclaim area (Figure 3).

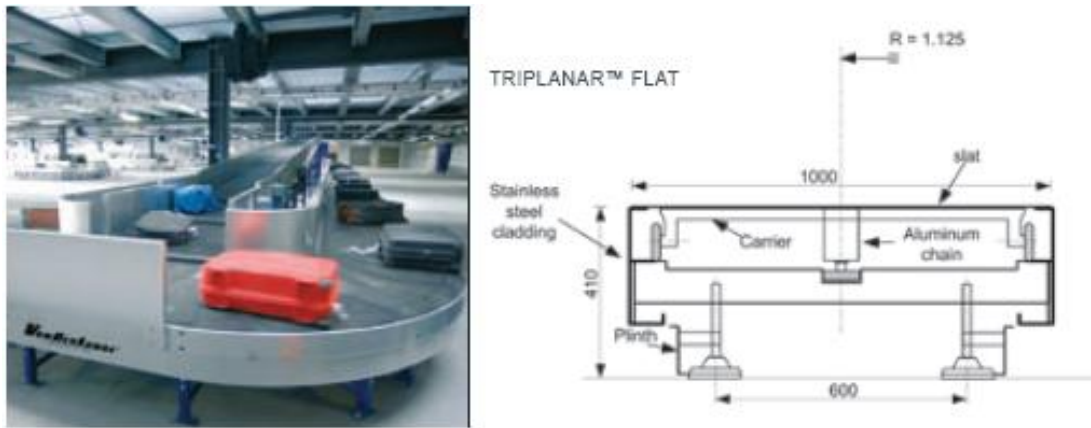


Figure 3 – Standard Baggage Carrousel (image reproduced from *Baggage Carrousel*, VanDerLande Industries)

Still, exercising these built-in options in an economic fashion – whether during project delivery or afterwards – will invariably require making functional space available for installing the modules. This space can be safeguarded in the design definition for the terminal at the project onset as discussed in the section about design safeguards.

Development of Functional Modules

In a second group of cases, the designers modularized the architecture of selected functional elements. The structure of the car park, for example, was designed to accommodate the addition of a modular steel mezzanine for parking 500 cars between the ground and the first floors. A key principle of the modular design was guaranteeing that the integration of the mezzanine will not negatively affect the aesthetic qualities of the car park in the future. Likewise, designers physically decoupled the floor plate superstructure of the main terminal building from its exterior roof and façade (Figure 4). This design solution allowed leaving an open void between the top floor and the ceiling. This void makes space available to fit a modular steel mezzanine that will expand the floor plate area. This additional area was foreseen to be needed in the future for two reasons: first, to expand the retail area of the terminal if a compelling business opportunity comes across to increase retail revenues; and second, to expand the main lounge that the airline runs for Commercially Important Passengers (CIP lounge).

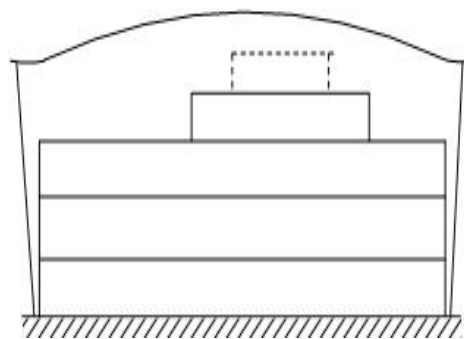


Figure 4 – Cross-section of main terminal building with room for the steel mezzanines

The Use of Safeguards in the Airport Terminal Design

In a number of cases, the designers of the new airport terminal were unable to modularize the interaction of the large-scale functional elements with the surrounding building systems. The design interdependences that were hard to break apart could be between the functional element and the building systems of the same facility, or between the functional element and the building systems belonging to other adjacent facilities. The concrete layer of the pavement of the aircraft stands (a set of layers of

granular materials topped with a thick concrete layer), for example, had to remain integral with the tunnels carrying the mechanical, electrical, fuel, and baggage systems under the aircraft stands. The service ends of the tunnels penetrate the concrete layer of the pavement in various locations on both sides of the central lane where the aircraft wheels park. The integral architecture of the aircraft stands makes it hard to economically accommodate requests to accommodate changes in the configuration of the aircraft fleet of the occupier airline in the future. This situation was particularly concerning since the airline was considering purchasing a number of jumbo aircrafts (Airbus A380) even if it could not state a date when a commitment would be made. This problem was resolved by safeguarding the option to park A380 aircrafts on four stands that could also be used to park two small aircrafts each (Figure 5)². The investment on the four Multi-Access Ramp Stand (MARS) to service one code-F aircraft with wingspan up to 80m (e.g., A380) or two small aircrafts was estimated around €1.5 million. It involved tripling a number of utility services running underground, providing three reinforced concrete lanes for receiving the loads transmitted through the wheels, as well as providing additional pier services and loading bridges.

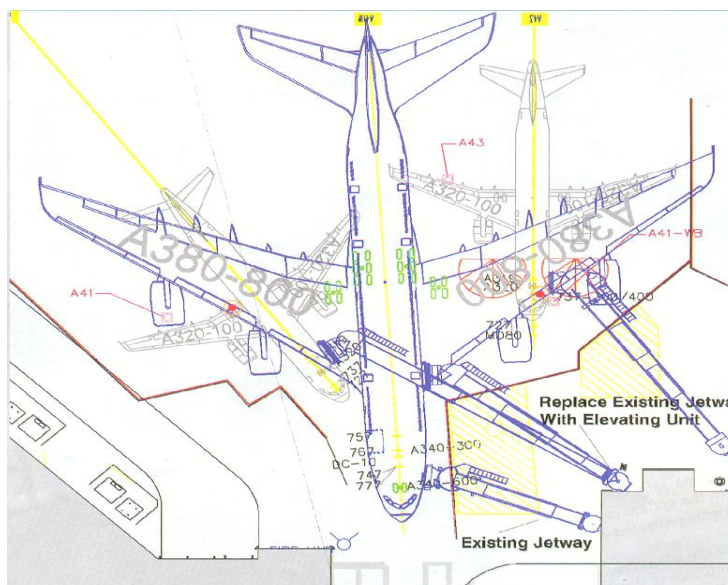


Figure 5 - Generic Representation of an Aircraft Stand with Multi-Access Ramps

In a second example, designers were interested in staging the delivery of the new airport terminal into two phases. The first phase would include two terminal buildings and a car park, whereas the second phase would include a third terminal building (Figure 6). While the airport developer publicly committed to open the first phase in 2008 from the project onset in 2001, the exact timing for moving ahead with the development of the second phase remained contingent on the growth of air traffic demand in the future. Growth projections suggested that the second phase could open sometime between 2012 and 2015. The airport developer was nonetheless cognisant that a number of capital investments on safeguards were needed upfront for leaving open the option to efficiently execute the second phase in the future. Hence, the developer decided to design and build the foundations for the third terminal building concurrently with the design and physical execution of the other two terminal buildings and ancillary facilities. The developer also decided to physically execute the design extension of the inter-terminal train and baggage handling systems to the third terminal building in the first phase.

² Real options literature would call this decision a switch option in the sense it allows for operating an aircraft stand with different sets of inputs

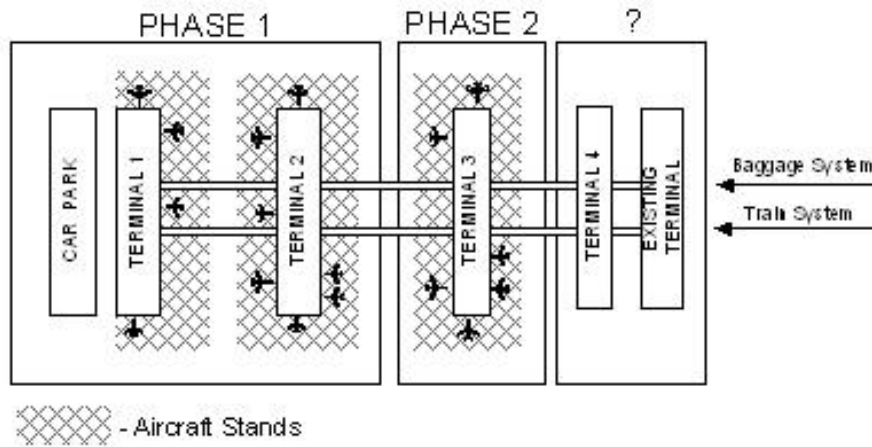


Figure 6 - Schematic Layout for the New Airport Terminal

This set of safeguards added at least €150 million to the capital investment for the first phase. But the developer reckoned that this spending was needed to efficiently leave the option open as three factors made at least six times more costly executing the extension of the two systems after the opening of the first phase. First, the construction costs in airfield conditions would be much higher due to the additional security requirements; second, the tunnels would need to be bored as the more economic cut and cover process would be too disruptive to the airfield operations; and third, the construction works would likely require putting temporarily out of service a number of aircraft stands, which would be extremely costly for airport operations.

Results and Business Impacts

Key Findings

This empirical study sheds light on the value of applying option-like strategic thinking to the new infrastructure development process. Specifically, it shows how developers and customers can use the modularity and safeguarding approaches when searching for design solutions that will be flexible to accommodate external change over time. This flexibility translates on the extent to which developers will be capable to, first, postpone design decision-making during project delivery; and second, economically accommodate external change throughout the operating life of a new facility. This capability matters to enable developers adjust to the difficulties that infrastructure customers face in freezing the design requirements at the project onset, years ahead of the date when the infrastructure opens to the public. This capability also matters to enable developers to respond efficiently to changes in customer requirements stemming from evolution in fit-out technologies, business environment, and user-needs. Of course, the findings of this research are grounded in the world of airport development. Future research should investigate how the insights induced through this study play out in other major infrastructure developments.

There can be two major hurdles in the implementation of option-like strategic thinking in infrastructure design, though. First, developers should be aware that developing reliable scenarios about how the design requirements for a new infrastructure will evolve over time is not a trivial task. It can actually be quite challenging. The application of option-like thinking calls for embedding a portfolio of options into a new infrastructure design. But even developers that undertake a meticulous application of option-like thinking in design must be prepared to incur risks that some of the options

may never be exercised over time. The point of option-like strategic thinking applied to design is not about limiting investments only to the safe options, i.e., those options for which developers are one hundred percent sure of the need to exercise them in the future. Rather, option-like thinking aims to ensure that a range of options remain open. As one developer put it, “there will always some winners and some losers in this game.” Notwithstanding this, a judicious application of option-like thinking can ensure that the value that exercising some built-in options will produce far outweighs the cost of the other built-in options which turned out unneeded in the long term.

A second issue in the application of option-like thinking to infrastructure design concerns the extent to which customers are ready to disclose their business thinking years ahead. Infrastructure customers may be reluctant to do so afraid that their plans can leak to competitors and/or suppliers, which would undermine their competitive advantage. But infrastructure developers and designers cannot search for solutions that can efficiently flex to external change unless the customers share how they anticipate their plans to impact the design requirements for the new infrastructure in the future. For example, in the case reported above, the airline was reluctant to share the plans for procuring new aircrafts. The airline was concerned that a design of the aircraft stands that revealed too much about its plans could undermine its bargaining position with the aircraft manufacturers. This stance, in turn, made the developer – understandably - reluctant to make capital investments to build options in the design of the aircraft field. In effect, the developer only decided to invest on the flexible MARS stands after communicating to the airline that it would reserve the right to park aircrafts from other airlines on the MARS stands if the airline failed to use them efficiently. It merits further research how developers and customers can share strategic plans needed to make sound design decisions without undermining the commercial interests of both of them.

Business Impacts

The findings reported here shed light on two fundamental approaches – modularity and safeguarding – that are highly relevant for infrastructure developers and suppliers interested in applying option-like strategic thinking. The use of option-like thinking can become a requirement in the case of concessions or PFI projects in the long term. Recent studies have started to develop procurement and contractual mechanisms that a government can employ to explicitly request the private enterprise to price the value of design adaptability (Lee 2007). In the case of new hospitals, for example, the hospital trust can include in the tender documents selected options that the bidders need to price in the bidding documents that they have to submit. It will be then up to the hospital trust to decide whether to buy upfront the flexibility to exercise the selected options in the future by paying the option fees. Governments appear interested in this approach due to the high costs that they often experience once they request the private enterprise to make changes in the infrastructure throughout the concession period (op. cit.).

Empirical findings also suggest that option-like strategic thinking, and its implementation in infrastructure design, can help the private owner of infrastructure assets to become more efficient. Of course some infrastructure owners face limited commercial competition because they operate natural monopolies that are difficult to contest by competitors. But other infrastructure owners face commercial competition. For instance, major European airports are facing increasing competition from airports in Dubai. Publicly listed infrastructure owners are also under pressure to increase commercial revenues year after year. Because they often have regulatory caps on the maximum fees that they can charge users, these owners need to improve the efficiency of their capital investments. This study suggests that the private enterprise will benefit commercially if it learns about how to develop evolvable or future-proof infrastructure.

Manufacturers also want to seize the business opportunities that arise from the urgency to develop future-proof designs. Innovative large-scale functional modules are one way to meet needs for combining affordability and evolvability in infrastructure design. The more modules exist ex-ante of the design process, the easier will be for infrastructure developers to, first, build options into the new infrastructure development; and second, exercise those options as uncertainties resolve favourably over time. This in turn represents increasing revenues for the suppliers.

Conclusions

The tension between the public interest and the commercial interests of the profit-seeker is an important outcome of institutional decisions to involve the private sector in the provision of public infrastructure. This tension has direct implications to infrastructure design as it calls for reconciling affordability constraints for capital cost with evolvability guarantees for operational longevity. Affordability is a function of how much capital the promoter wants/can borrow to build anew at specified rates of return on investment. Evolvability is a function of how efficient the infrastructure can accommodate external change. Option-like strategic thinking applied to design and development stands out as a way to resolve this tension. Design modularity and safeguarding are two approaches that allow building flexibility in new infrastructure development to accommodate external change over time. Their application can help infrastructure developers and suppliers efficiently build options in new infrastructure designs. These options can be exercised if uncertainties resolve favourably in the future. This in turn will prevent the premature obsolescence of new infrastructure.

Key Lessons Learned

- Large-scale functional elements with modular architectures can be available ex-ante of the development process or be developed.
- Some large-scale functional elements are very difficult, or extremely costly, to modularize
- Design safeguards are particularly useful to build options in infrastructures with integral architectures
- Design safeguards can also help to reduce the costs of exercising options in infrastructures with modular architectures
- Building options in new infrastructure development calls for the application of both modular and safeguarding approaches
- Design options are valuable to help postpone design decisions during project delivery.
- Design options are valuable to leave open options to adapt the infrastructure if foreseeable uncertainties resolve favourably in the operating life time of the infrastructure.
- Modularity and safeguarding are at the heart of efforts to design future-proof infrastructures, i.e., design affordable infrastructures that can economically adapt to change over time.
- Future-proof infrastructures are needed to prevent the premature obsolescence of capital investments

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