Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

DESIGNING FLEXIBLE ARCHITECTURE TO HINDER FUNCTIONAL AND TECHNOLOGICAL OBSOLESCENCE

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Time, uncertainty, flexibility and resilience are the four sides of the same square around which this paper revolves. Hallmark of all complex systems is uncertainty, seen as the lack of full knowledge of current or future evolution of a system. There are various types and sources of uncertainty, but notably the incorrect knowledge of the environment in which a system operates determines the technological obsolescence and functionality of the system. Systems that have the longest life span are able to cope with the unpredictability of their contexts, while rigid and unchanging systems have a shorter lifespan. Uncertainty, traditionally seen as a negative aspect of a system, must therefore be regarded as an opportunity, an incentive to design flexible systems able to absorb changes in the environment in which they operate, in order to create added value for users. The development of "advanced" systems able to prevent that uncertainty generates diseases, commonly referred to as "risks". This is not new; the selection process of species of Darwin, or the reflections on the life of capital goods of Terborgh, have shown that there are living organisms, human artifacts or resilient complex systems that are better equipped to adapt to changing environments, compared to the rigid systems incapable of reacting to change. In other words, flexibility reduces the exposure of a project uncertainty, provides a solution to mitigate market risks, and also mitigates risks associated with technological obsolescence. Flexibility makes the system resilient, able to absorb shocks and/or disturbances without undergoing major alterations in its functional organization, structure, or identity characteristics. In this paper flexibility is seen as a fundamental property for designing a generally complex system.

Keywords: Uncertainty, Resilience, Technological flexibility, Spatial flexibility.

1 INTRODUCTION: TIME, UNCERTAINTY, FLEXIBILITY AND RESILIENCE

Time, uncertainty, flexibility and resilience are closely-related concepts. The ephemeral nature of human life has been an important topic for philosophers, theologians, poets, and others, since the dawn of history. A myriad of human behaviors and artifacts come from our relationship with time. The issue of permanence over time is a theme that characterizes human culture since prehistoric times, when man is distinguished from other animals for the characteristic to take care of their dead. The awareness of a life as finite under time opened up the challenge to immortalize life, to think of defeating or postponing death through faith and science on the one hand, and on the other the challenge to create "objects" as evidence immune to the effects of time, capable of projecting their lives in a timeless dimension (Di Sivo 2004). Of all the structures and artifacts of antiquity, only an infinitesimal small amount has remained until today, recalling the caducity of human work. In the Industrial Era, industries, infrastructure, and objects have a very ephemeral relationship with time, by relating us to the extreme transience of such artifacts.

Similar to human life cycles, a product progresses through a life cycle characterized by stages of growth, maturity and decline, then "death" (i.e., ceasing to be useful) due to functional and technological obsolescence, which happens due to the inability to manage uncertainty. At Cape Canaveral, for example, are the remains of the race to the Moon: launch pads, bunkers, and ruins of the Mercury, Gemini and Apollo missions. Similarly, outside of Tucson in the Arizona desert is the center of Aerospace Maintenance and Regeneration Center, better known as the "aircraft graveyard" where over 4,000 used and new aircraft degrade under the sun. These technologically-familiar objects constitute a clear warning that nothing is permanent. Through the physical or functional degradation or loss of economic utility, the hand of time affects negatively the know-how of human beings (Saleh et al. 2003). The uncertainty, intended as lack of complete knowledge of possible scenarios of evolution of the context of a system, is normally used in a negative sense. However, its management may be an active and proactive response to uncertainty; that is, if it allows the evolution of the system, as necessary, in order to avoid risks and exploit opportunities.

A cornerstone of the theories of the economist Stigler (1939) is the link between flexibility and uncertainty. Flexibility is needed to cope with the uncertainty, which can arise from several factors, e.g., a change in demand, variability in user preferences, technological innovations, new regulations, and resource availability (Sethi & Sethi 1990). Shi and Daniels (2003) consider the flexibility a "hedge against uncertainties, as a direct consequence of a general complexity due to technological progress and to the variability of requirements of users."

In this regard, the economist Terborgh (1949), in his Dynamic Equipment Policy, states that machinery, or systems in general, are both constantly subjected to mutations and the unpredictability of their contexts, as well as the aggressiveness of competing products. Systems that thrive longer, or have a longer service life, are the ones that cope with the unpredictability and mutations of their environment; therefore, if a system has to be designed for an extension of its service life, an ability to cope with unpredictability and change must be incorporated into the system.

The debate on capital goods brings us to another kind of struggle for life and survival of the fittest—that of biological species. Darwin (1979) says that the process of natural selection operates "every day and now", scrutinizing the minor variations, "rejecting anyone who misbehaves, preserving what is good". The species that is better-equipped to adapt to environmental changes tends to be preserved longer. Uncertainty, as "unpredictability", is a fundamental condition in which natural and man-made systems (especially all complex systems) can be compared. One way to deal with uncertainty is to incorporate flexibility in the initial design, so as to ensure the possibility of choice in the future and to be able to tackle successfully the changes that may occur during the life of these systems (Figure 1).

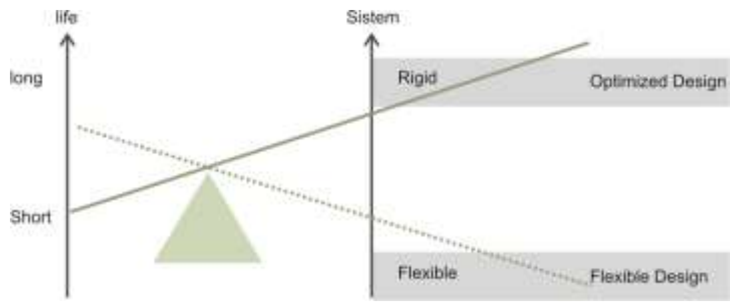

Figure 1. Relationship between the life of the system and its characteristics (rigidity flexibility).

Flexibility reduces the exposure of a project uncertainty, provides useful solutions to mitigate risks related to changes and market constraints, and reduces the risks associated with technological obsolescence. Flexibility makes the system resilient, that is, able to "absorb the shock and/or disturbance without undergoing major alterations in its functional organization, in its structure and in its identity features" (UNEP 2005). A system, in this sense, is resilient if retains the idea of its shape despite the subsequent metamorphosis, but it is not permanent, caged in an unchanging order.

2 CONSIDERATIONS FOR IMPLEMENTING FLEXIBILITY

From the previous discussion, flexibility emerges as the ability to manage change; this definition is insufficient to describe this property, which, as we have mentioned in this paper repeatedly, is essential to ensure the competitiveness in time of the system. A clear definition of flexibility must also provide the following information:

- The temporal reference associated with the occurrence of disturbance; that is, when the change takes place during the lifetime of the system;
- The characterization of what is changing, such as the environment of the system, the system itself, or the needs of the user of the system; that is, knowledge of the technological and functional obsolescence of the system.

It is clear that flexibility should be investigated during the lifetime of the system. The life cycle of a system begins with the identification of user needs and then proceeds to the definition, design, production, maintenance operations, and ultimately its decommissioning. During the positioning on the market, the ability to vary the system’s performance is incorporated within the flexible process, through the introduction of flexibility in the design of the system. After being placed on the market, there is a verification of the flexibility implemented in the environment. Thus, in engineering systems, the flexibility can be considered in two different stages of the Life Cycle Design of the good. The first focuses on the design process (i.e., process flexibility), and the second on the same design (i.e., product flexibility).

A correct definition of flexibility should, as anticipated, provide a characterization of the ever-changing uncertainty, such as the environment of the system and the system itself. There is a wide range in the types of uncertainty, so a possible simplification is to consider two types of causes of uncertainty: a) the presence of the internal or external uncertainties to the system, and b) the variability of demand or the variability of technological market—in other words, the functional obsolescence and the technological obsolescence. The coexistence or absence of external or internal uncertainties leads to the development of mitigated approaches to these sources of uncertainty, and are summarized in Table 1:

Table 1. Uncertainty vs. Vulnerability and their Mitigation.

UNCERTAINTY	VULNERABILITY	DETAILS/MITIGATION
Variability of the environment (the uncertainties concerning the social and economic context)	Functional obsolescence of the system	Versatility Convertibility Modularity
Variability of the system (the uncertainties regarding the system performance)	Technological obsolescence of the system	Maintainability Reversibility

3 DEVELOPING A METHOD FOR IMPLEMENTING FLEXIBILITY IN DESIGNING A SYSTEM

The following considerations show that flexibility is the property of a system:

- Managing immediately the uncertainty of the environment in which the system operates, allowing it to respond to changes (which occur after the system has been made operational, meaning it is functioning) of requirements of users resulting in inadequate initial objectives or requirements of the system, in terms of performance and modality, in a timely and effective way;
- Setting and targeting, in the long run, the pace of change through its ability to regroup and innovate in front of external disturbances.

To guarantee the stability of the system in the short and in the long run, flexibility affects both the shape and the technological apparatus that governs its structure, the ability to contrast both the technological and functional obsolescence is achieved through the relationship between the following requirements (see Table 2).

The results of the integrated use of these mitigations are properties of a system that the user may find valuable to increase the lifespan. The properties are in Table 3.

Spatial flexibility implies a high degree of organizational complexity, which is a fundamental attribute of resilient systems. It is evident that the multiplicity of solutions increases the resilience of the system, the possibility of evolution, of change and adaptation. The concept of technological flexibility implies the concept of simplicity of implementation, intended as the quickness and ease with which they can complete the maintenance operations and reversibility. This is undertaken to correct the gap between requirements and performance so that the system won't cease its usefulness. The concept of flexibility implies that maintainability and reversibility operations can be performed without the need to undertake other unforeseen or unpredictable collateral activities. Table 4 lists the key points of construction and control of the flexibility of the systems after developing a list of general criteria of flexibility used in reference to the design features of the system.

Table 2. The requirements of technological and functional obsolescence.

REQUIREMENTS	
Versatility	The multiple use of a system within an area with shapes and sizes that are altogether unchanged over time. We could say that a versatile system is *Universal*. This requirement affects the internal configuration of the system.
Convertibility	The system's ability to adapt to different physical configurations through a transformation that alters its internal and external configuration, in order to meet the different needs and requirements that arise after the system has been made operational. This requirement affects the system dimension.
Modularity	The organization of the system into parts which can be subtracted or added to the system according to your needs. This requirement affects the system's dimension, and its ability to expand over time.
Maintainability	The probability to repair a system at a given time when maintenance operations are implemented in accordance with the prescribed procedures and resources. The implementation of the requirement of maintainability can promote any redevelopment work which is necessary when there is an imbalance between the performance of the technical element and changing levels of need in the users. This will allow you to quickly make those adjustment operations to new levels of quality.
Reversibility	The organization of the system in sub-systems and separable components, with particular reference to the “features” and the “status” of connections. The reversibility of the system makes it possible to decrease the impact resulting from the disposal of the system, such as for large systems such as buildings; the implementation of this requirement provides the demolition through the disassembly, and consequently the separation of constituent parts and materials in order of their possible reuse or recycling.

Table 3. Properties of spatial and technological flexibility.

Spatial flexibility	The ability of a system to adapt to different uses and functions to respond to the variability of users needs. Spatial flexibility is obtained from the relationship between the requirements that affect the form of the system, the versatility, the convertibility, and the modularity of the system.
Technological flexibility	The ability to work easily on the technological apparatus that governs space. The spatial flexibility is obtained from the relationship between the requirements that act on the structure of the system, which is the maintainability and reversibility.

Table 4. List of general criteria of flexibility.

Programmatic complexity	Space solutions able to ensure easiness of modifiability over time, relative to the variability of users' needs and the satisfaction of psychological and functional needs.
Simplicity in the interface:	The choice of technical solutions capable of guaranteeing the possibility of intervening with easiness on system components, ensuring the dismantling, substitutability, and reparability of system components.
Structural simplicity	Choice of reversible construction techniques, with particular reference to the characteristics and status of the connections.
Optimization of components	Possibility of substitutability of components, through a modular organization, and their optimization for specific objectives to hinder their technological obsolescence.
Optimizing plant integration	Verification of coherence between technical-building solutions and inspection of plant equipment, ensuring the maintainability of the networks without affecting the functionality of other components or subsystems.

4 CONCLUSION

Flexibility was considered as a basis for designing a complex system, by identifying design criteria for implementation to form more technology of the system, by mitigating requirements of specific sources of uncertainty. This approach can be useful. The uncertainty of the context means that we need to reduce the risks from exposing a system to this uncertainty. The system is subject to one or more changes due to various user requirements, meaning we must mitigate the risks associated with functional obsolescence. The basic technology of the system evolves in a time shorter than its lifecycle, meaning we must mitigate risks associated with technological obsolescence.

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