TRANSFORMATION PROCEDURES IN THE TYPOLOGY OF TALL BUILDINGS

Jacopo GASPARI Dr. Arch.[1]
Dario TRABUCCO Dr. Arch.[2]
Elena GIACOMELLO Ph.D[3]



Keywords: *design criteria, adaptable building, transformation, lifetime, energy savings, tall buildings, obsolescence, renovation.*

Abstract

A series of interventions aimed at facing the introduction of new requirements can be recognized during the life cycle of every existing building. In order to prevent its natural obsolescence, these interventions (which involve both technological system and physical components) are mainly related to the necessary updating tied to the evolution of environmental conditions, the changes of users' needs and the advances in technology as well.

The main factors of obsolescence can be identified in the following themes:
- change of environmental conditions
- change of the performances required
- change of technologies

The relevance of each of these factors is assessed by this paper, and some examples are used to support the methodology proposed.

Tall buildings represent a particular building typology, because of their role as a landmark and their economic relevance: that's why continuous renovations and improvements are necessary.

The main systems of a tall building that might be interested by renovations can be identified in the following hierarchical categories: building envelope, internal partitions, mechanicals. In this list the paper focuses on those parameters specifically meant to improve the sustainability of tall buildings recognizing their relevance as a tool to improve the design process.

1. The importance of supporting transformation processes

During the life cycle of every building the original concept that had originated its morphological, technological and functional layout can meet some changing factors which cause, for different reasons, an alteration in the behavior of the building and in its performances. The importance of this alteration is strictly connected to the extension and the value of the main factors that are involved in the process, but it can also be influenced by the typology, the dimension of the building and the adopted construction system. The importance of studying the potential causes of a transformation process in a building and the possible related design criteria is linked to energy and resources savings. In fact, the chance to upgrade the building configuration in order to meet new forms of requirements can be translated into an extension of the expected lifespan of the building. The idea of increasing the level of durability of a building is an important expression of sustainability which allows to spread negative impacts in a longer period of time and to maximize the use of energy and primary resources.

An archetypal expression of this concept can be identified in the transformation process of ancient buildings which have been adapted to different requirements during the centuries. From the 13th century some Roman baths have been transformed into churches, later some churches and monasteries have been converted into hospitals or prisons or, in times of war, into military districts. Each of these different functions brought different requirements that had to be faced by the features of the construction system and by the adopted technological solutions. The first important consequence of this kind of process was that the most representative, durable and complex buildings were able to survive their original conception. This approach was linked, in any case, to economic reasons and it wasn't really finalized to meet the contemporary vision of a sustainable architecture. However the benefits of this approach can be translated into modern

[1] IUAV University in Venice, Faculty of Architecture, Venice, Italy, gaspari@iuav.it
[2] IUAV University in Venice, Faculty of Architecture, Venice, Italy, trabucco@iuav.it
[3] IUAV University in Venice, Faculty of Architecture, Venice, Italy, elenag@iuav.it

parameters like, for example, materials (and embodied energy) savings.

Today there are some key-typologies in the development of the built environment which can be compared for importance to those ancient structures. Tall buildings belong to one of these strategic typologies not only for economic reasons, but especially for their role in densification process of the urban fabric. It’s quite hard to define a skyscraper a sustainable building in itself, but it is possible to insert its construction in a larger sustainable vision (which involves the transportation systems, the soil use, the strengthening of urban boundaries, the protection of green urban areas, etc.). Nevertheless sustainability of tall buildings can be improved operating an extension of their lifespan through refurbishment or renovation actions.

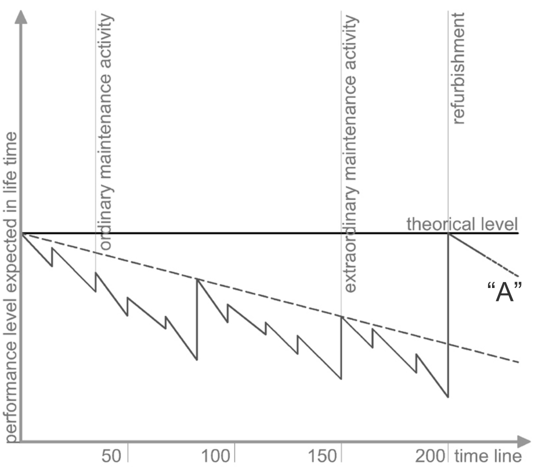
2. Obsolescence factors and their relevance

Although every building could be affected by a physiological obsolescence of its components and sub-systems (and this can be caused by a natural deterioration of materials and wrong design solutions as well), it is possible to identify some extraordinary causes for an early decrease in performance (Ciribini, 1988). These two different kinds of obsolescence are connected to different contrast actions: the one linked to ordinary and extraordinary maintenance activity and the other to deep interventions on the building as refurbishment or renovation. Both of them are expressions of a different change in the building performances: the first one aims to preserve the original features, the second one to improve them. Furthermore, they are related to different time intervals.

2.1 Physiological obsolescence analysis

The typical behaviour of a building can be represented by a graph [see figure 1] in which there is a progressive loss of performance during lifetime (Manfron, Siviero, 1998). This loss is described by a split line [“A”] in which every segment means the deterioration of the system and every vertical line corresponds to the ordinary maintenance activity. The longer vertical segment corresponds to an extraordinary maintenance action adopted to contrast larger forms of deterioration.

Each action aims to increase the technological performances of the building, but it’s unable to bring them back to the starting condition (which is represented by a constant line, expression of the theoretical level). This mainly depends on the general loss of performance of the system as a whole that can’t be effectively supplied by single interventions on the different parts of the building. Especially in extended and complex structures the behaviour and the performances of the system are greater than the simple summation of the single ones related to components and sub-systems. For this reason a level of performance comparable to the original one can only be reached by a refurbishment action. An economic analysis suggests that this kind of intervention is suitable when the building is coming to an end of the expected life cycle in order to optimize the investment. However, this approach is reasonable only if the original demand of performance is assumed as constant during the time.



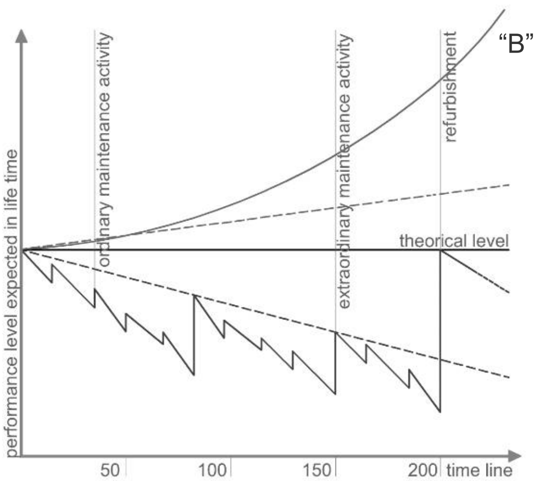


Figure 1 Trend of progressive loss of performance for physiological obsolescence in a building.

Figure 2 From linear trend to exponential trend caused by growth of requirements.

2.2 From a linear trend of demand to an exponential one

Unfortunately this represents only a theoretical condition, in fact, nowadays a progressive growth of functional or technological requirements can be recognized. This growth is linked to an evolution of demand which deeply influences the economic behaviour of the refurbishment intervention. This trend is even more relevant in the case of tall buildings in which most of the factors involved are motivated by economic reasons. Even if many other factors should be considered, the great investments necessary to develop such a huge and complex structure represent the strategic factor during the decisional process (Willis, 1995).

In addition to some typically economic factors like the improvement of net rentable area, the introduction of multifunctional spaces, media effects, etc., some other factors – not immediately connected to economic reasons – can be identified in energy reduction, adaptable spaces, environmental solutions, etc.

The growth of demand, independently from its nature, brings to the formulation of new requirements which produce an acceleration of loss of performance in comparison to the one expected by the users. So the distance (which represents the lack of performance) between the split line and the theoretical level is increased by new demands which can't be represented by a linear trend, but rather by an exponential one [see figure 2, line "B"] (Gaspari, 2008).

This element introduces some new parameters which have to be considered during the design process of new buildings (Gaspari, 2008), but also a different evaluation method in assessing the opportunity of applying a refurbishment action before the expected end of service life of a building.

In order to obtain a level of performance higher than the theoretical one, the intervention has to consider some unconventional forms of obsolescence which the new technological solutions have to give an answer.

2.3 "Other" forms of obsolescence

Some forms of obsolescence may be connected to direct or indirect anthropic factors (Molinari et al., 1992). They can be summarized in three large families: factors deriving by economic reasons (which are the most relevant in the whole process); factors deriving by a change of the performances required (a direct expression of an evolution of needs); factors deriving by a change of technology (which is linked to the availability of new materials, components, devices, etc.). Each family includes a series of sub-families of factors and sub-factors as follows.

Table 1 Factors concerning other forms of obsolescence

A	**economic reasons**		
	A1	**increased size of the building**	additional spaces can be provided
	A2	**new functional destination**	spaces can be used for new activities which require a different set of performances, etc.
	A3	**new commercial and marketing strategies**	modified commercial strategies can result in addition/modification of parts of the building
B	**change of performance required**		
	B1	**different level of comfort perceived by users**	the quality perceived can be influenced by the way of living of users and social behavior, etc.
	B2	**new requirements deriving by the introduction of new rules**	new parameters can be introduced by law for security reasons or public interests, etc.
	B3	**environmental modifications**	change in the external environment due to local modifications or global changes
C	**change of technology**		
	C1	**new components**	existing solutions can be replaced by new ones, much performing products can be used, etc.
	C2	**new electronic equipments**	information and electronic technologies have a faster development than others, etc.
	C3	**implementation of the system**	the introduction of new devices or strategies can bring to an higher level of performance of the system as a whole, etc.

All these factors can influence the expected lifespan of a building and their relevance in this process mainly depends on the typology, the extension of the building, and the construction system used, but also on the speed in technological progress and the ability of the building sector to receive these new forms of input.

These factors don't influence the building in a homogeneous way and especially as for the skyscrapers they can't be considered without having before analysed the structure of the main system with the aim to find out the most critical parts involved (which are in the meantime the ones that can play a very important role in giving to the building an adaptable character).

3. Analysis of the sub-system involved in the process

With the aim of defining a methodology to assess the opportunities of a refurbishment or a renovation action in the tall buildings typology, this paper identifies a hierarchical scheme of investigation concerning the part of the main system which might be involved by interventions. As the first aim of this kind of strategy is to save the most part of the embodied energy present in the building, interventions have to consider only those parts which are directly interested by the defined factors of obsolescence.

So the main sub-system on which it's possible to operate strategic interventions can be divided according to their position. Some smart solutions for each element can be adopted during the design stage are simplified as follows:

Table 2 Scheme of sub-system evaluation methodology

sub-systems	elements involved	smart possible solutions
building's envelope	thermal insulation	- suspended dry solutions - remove ability from inside - safety external path - implementable loading systems
	acoustic insulation	
	shading system	- internal maintenance opportunity - replace ability of components
	typology of cladding	- multilayer solutions
	windows, doors, openings	- standard dimension
	…	
internal partitions	vertical partitions	- high quality of furring joints on ceilings and floors - transformation opportunity
	horizontal partitions	- technological solutions that allow to remove a part of the floor in order to create a vertical connection - replaceable pavements and tiles - location of cables on the perimeter
	stairs	- dry construction (metal/wood) - light structures
	…	
mechanicals	water supply system and sewer system	- vertical operable ducts - sub net solutions - roof positioned HVAC machines for cooler air - introduction of electronic management system
	general electrical system	
	fire prevention system	
	elevators, lifts	
	security system	
	mechanical ventilation	
	air conditioning	
	phone and internet wires	
	…	

The envelope of the building represents the interface between the inside and the outside and it has a strength relationship with thermal behavior and energy dispersion; internal partitions are linked to the way how the spaces and the venues are used and this is strictly connected with the functional program and the human activity; mechanicals are related to plant distribution, energy efficiency and active forms of solar gaining.

Each sub-system includes a series of elements which can be involved in the transformation process. To analyze the opportunity of applying a transformation process it is important to assess the extension of each class of factors and the related embodied energy. The methodology proposed uses a scheme like table 2 (which is a simplified example) to obtain information concerning the general conditions of the different elements in order to plan interventions and maximize their efficacy.

The relevance of obsolescence factors related to sub-system features can be considered a first step to value which kind of intervention can be applied [see table 3].

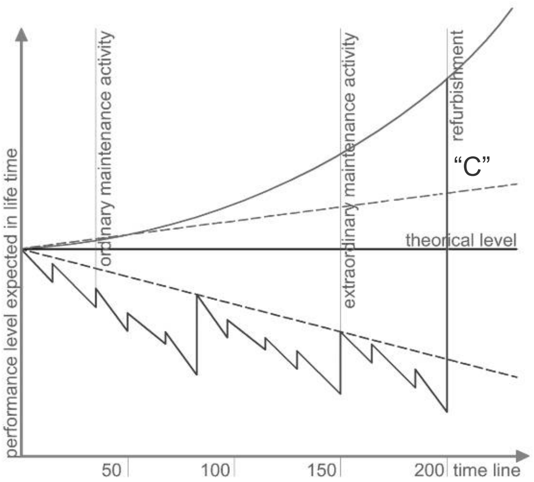
Table 3 Relevance of obsolescence factors related to sub-system. Weight of factors in transformation need of the sub-systems of the building ● low - ●● medium - ●●● high

factors	A.1	A.2	A.3	B.1	B.2	B.3	C.1	C.2	C.3
envelope	●●	●	●●●	●	●●●	●●	●	●	●●
internal partitions	●●	●●●	●●	●●●	●●●	●●	●	●●	●●
mechanicals	●●●	●●	●●	●●●	●●●	●●	●●●	●●●	●●

3.1 Updating, restoring and refurbishing a skyscraper

For the dimension of the investment and the amount of resources involved, renovating a skyscraper is a much more viable solution than demolition and reconstruction. It is particularly suitable when the building has come to an end of its life cycle. Updating a tall building means to provide a slight improvement of some of its features, specifically technological components, so as to “refresh” its mechanical elements or to improve its ICT network. A restoration takes place to bring the building back to its original status (by the change of decayed materials, out of fashion finishes, etc.) and it always implies an updating process. Unlike, a refurbishment is a much more complex kind of intervention and it requires a serious change of the building apparatus, its technical components and its appearance. The further degree of transformation, not really for the building but for the site, is demolition and reconstruction.

There are several reasons that justify an intervention on an existent tall building, though complex and costly. As it is described in figure 1, any intervention on an existent building is not able to bring it back to the original “quality”, and to match the increasing of requirements expressed by the curved line of figure 2, which can be obtained only by creating a brand new structure. Despite this it’s generally true, the case of tall buildings can be seen as the exception that proves the rule since a refurbishment can push the existent building to a point even higher than the curved line. From the developer’s point of view a refurbishment can be even more appealing than a new skyscraper.



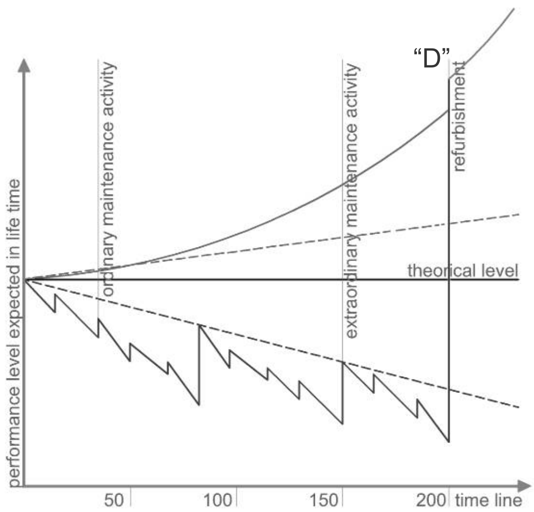


Figure 3 A refurbishment action (line “C”) should bring the building to a performance set which is higher than the theoretical one in order to match the requirements curve.

Figure 4 The introduction of new solutions in the original conception of the building should influence the trend of requirements growth, in relationship with new forms of value for the building.

In fact, a refurbishment intervention should allow to achieve a level of performance which is higher than the theoretical level of requirement of the original building conception. Figure 3 explains this kind of behavior where the line “C” connecting the split line of performance to the curved line of requirements expresses the updating process deriving form intervention. Moreover, the solutions adopted in the refurbishment action should produce a turning point in the growth of requirement introducing some forms of innovation which bring to a discontinuity point “D” in the curve as it is shown in figure 4. This means that the solutions realized by the intervention are so relevant that are able to influence the trend of requirements.

A renewed structure can provide a quick answer to the market, in a time much shorter than the delay a new building takes to be designed, approved and finally built. Additionally, a refurbishment can maintain some features of the original building (i.e. gross area, height, etc.) that a new building can’t attain due to legislative restrictions, thus bringing the refurbished building back to a greater value than a new one would have. This is the case of many old tall buildings in Manhattan, recently converted from offices to condominiums. Though demolition would have not been allowed by the city council (many Lower Manhattan buildings are preserved as national landmarks) the refurbishment quickly provided a large amount of dwellings in the heart of downtown. Many buildings which have been converted have an higher ground occupancy ratio and a built volume that newer buildings would have, thus creating a sound profit.

A refurbishment usually costs 60% the price of erecting an equivalent new skyscraper and it is much faster. Although it is usually preferred by both tenants and developers to perform a faster and easier single-stage refurbishment, it can be decided on larger projects to keep part of the tenancy in place, thus virtually eliminating the complete vacancy of the property.

3.2 Forms and causes of variability in transformation processes

The most complex kind of refurbishment is the extension of the building. This is a major intervention that requires availability of space in the surroundings, money, and favorable zoning laws. It is quite an unusual procedure and it is generally carried out through a lateral addition to the old complex, sometimes even bigger and higher than the existing building. A superposition is virtually possible, but it could be so complicate and expansive that it is usually preferred to dismantle the existing tower and to build a new skyscraper. Actually, a major upper extension is presently under way in Chicago, where the 32 storey-tall Blue Cross Building is experiencing a 25 floors addition. Despite this case in which the building was explicitly conceived for a later superposition, it is more common to add the extra space by building a new structure near the old one, then wrapping the two “twin” buildings together in order to harmonize the building envelope. This is exactly the intervention that is happening on the GAM Tower at La Defence, the Paris’ business area. The tower is being enlarged through a lateral extension that will almost double its floor area. The new part will create the structural support for an extension higher than the old building. From the upper floors, freestanding decks will be suspended over the ancient building, thus completing its silhouette as if it were a vertical extension of the original building.

A particular case of renovation of a tall building is the one following random events like fires or other major damages as a consequence of calamities. After a plane recently crushed into the Pirelli Tower in Milan, the building was completely restored bringing it back to its original ‘50 aspect and enhancing its technological equipment and its energy behavior.

Updating for user’s modified requirements in terms of performances represent the most common case of intervention, since this have a direct connection with property values and rentability. Many tall buildings of the first generation are now experiencing extended renovations. The main reason for this is what has been identified in Table 1 as “change of performance required”. Old buildings were built with outdated technologies and are thus forced to undergo updates meant to keep its commercial value on market level. The toughest technological addition a tall building can require is air conditioning. Such interventions were carried out in the last decades by the insertion of huge ducts on the floor plans. Where this was possible, an improvement of the performances of the lift service by the use of faster cabs or smart dispatching systems reduced the number of shafts used by the elevator system, thus providing the required vertical room for the ducts. Horizontal space was also required to distribute the services (cables, ducts etc) through the floor plates; despite a few cases, ancient skyscraper presented a considerable floor to floor height, thus allowing false ceilings or floating floors. Such updates are not a prerogative of very old buildings.

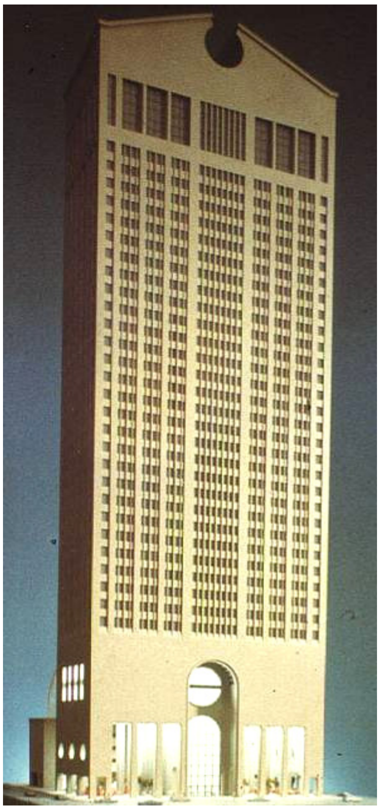


Figure 5 The Woolworth building is an example of the refurbishment process in Lower Manhattan.

Figure 6 The AT&T building has been extensively renovated to match the requirements of new tenants.

Figure 7 A 65 million dollars refurbishment has been planned for the Sears Tower of Chicago.

The 1984 AT&T building in New York was subjected to extensive renovations when the new owner, Sony corporation, moved into the building. The cooling system had to be improved to face higher heat loads deriving from an increased population and a greater use of electrical devices. The ITC network had to be improved to nowadays technologies as well.

Many relatively recent tall buildings are subject to important transformations required by mandatory legislation introduced after the building was already in use. Some requirements can’t be fulfilled for structural or relevant economic reasons (such as the addition of fire stairs and fireproof lifts), others required to be complied within a given delay. Many European skyscrapers are now facing asbestos-related problems. A prominent example is represented by the Tour Montparnasse in Paris, where asbestos was used for many purposes. The tenants and the government required a prompt decontamination of the most polluted parts of the building (mechanical floors, where maintenance staff is highly exposed) and a plan to purify the whole internal environment. The building manager decided to operate on a level by level basis during a 10 year long period instead of performing the whole task in three years by clearing out the entire tenancy of the building.

3.3 The sustainable issue

The most recent renovating impulse of the building is now provided by sustainability of the project. Old skyscrapers, especially those of the third generation (Oldfield et al., 2008) have very poor environmentally sound performances. As a consequence, building managers are encouraged to adopt new energy efficient technologies to retain old tenants and reduce the vacancy ratio. The 1974 Sears Tower of Chicago is planning a 65 million dollars makeover to reduce the energy consumption. This will feature the building with photovoltaic panels, wind turbines and an improved illuminating system that will help to reduce the energy requirement of the super tall building. Nevertheless this kind of intervention has sometime more importance for a marketing strategy intention than for the real purpose to embrace a green building concept.

Despite the utility of some environmentally sound solutions, investors often consider the economical profit deriving from acquiring a good image for the building much more than obtaining considerable energy savings advantages. For this reason it is important to identify real sustainable finalized refurbishments from maquillage solutions carried out on the building to improve its appeal.

It is also important to underline that the energy produced by some sustainable solutions (like solar collectors, wind turbines, etc.) play a very small part in the energetic balance in the extended life cycle analysis if compared to energy savings obtainable preserving the most part of an existing building during a refurbishment action.

4. Some methodological outlines

In order to value the sustainability of a refurbishment action and to assess also the degree of transformation deriving from intervention it is important to have a good set of information concerning the behavior of the building during its service life. This will allow to define the different degree of intervention necessary to match the introduction of new requirements or to face the loss of performance (D’Alessandro, 1994).

Table 4 proposes four main typologies of intervention [A], which are expression of the main cause to operate on the sub-system, and relates to them the level of intervention [B] in order to re-establish the properties and functionality state of the sub-system; the main feature [C] the sub-system should have for being renewable during the time; some suitable solution [D] to guarantee the chance of modification.

Table 4 Relationship between typology of intervention and features of sub-system

<table>
<tr><th>A</th><th>typology of intervention</th><th>B</th><th>level of intervention</th><th>C</th><th>feature of the sub-system</th><th>D</th><th>suitable solutions</th></tr>
<tr><td colspan="2">check activity</td><td colspan="2">B1. accessibility</td><td colspan="2">C1 reachable and operable</td><td colspan="2" rowspan="4">- proper and planned paths and spaces to get to the sub-systems
- expandable spaces for the lodging of the sub-system
- dry technologies for connections
- changeable positions
- decentralized plug-ins
...</td></tr>
<tr><td colspan="2">update, preservation and maintenance</td><td colspan="2">B2. partial replacement</td><td colspan="2">C1+
C2 removable</td></tr>
<tr><td colspan="2">development, expansion</td><td colspan="2">B3. addition, plug-ins</td><td colspan="2">C1+C2+
C3 improvable</td></tr>
<tr><td colspan="2">damage repair</td><td colspan="2">B4. total replacement</td><td colspan="2">C1+C2+C3+
C4 interchangeable</td></tr>
</table>

The complex nature of the tall buildings typology suggests to work on the different sub-systems separately with the aim of an easier and faster individuation of the main factors involved. Nevertheless this strategy is useful only if all the single steps of the analysis are integrated in a general evaluation procedure. One of the problems identified is to set up a methodology able to allow a comparison between parameters belonging to different sub-systems. In order to have a tool, finalized to a fast check of parameters involved, a simplified format has been set up. Table 5 associates the sub-system description and data set to the level of intervention, the cost, the time interval in which it is applied, the arrange cost spread in time interval.

Table 5 Simplified format for intervention/timing/costs relationship

sub-system description	**sub-system data set** (year of construction)	**level of intervention**	**cost**	**time interval**	**arrange costs in n-years**
		B1	x.xxx euro	n. years	cost/n. years
		B2	x.xxx euro	n. years	cost/n. years
		B3	x.xxx euro	n. years	cost/n. years
		B4	x.xxx euro	n. years	cost/n. years

The comparison between the filled format of each sub-system arranged in a macro-format allows a fast check of the different relevance of interventions which is useful to plan the maintenance and refurbishment actions to develop on the building. The chance to quickly compare the sub-system conditions puts in evidence the great differences in terms of costs and time between, for example, operating a reconfiguration of the internal spaces and transforming a single layer façade in a multilayer one. Certainly, the modification of internal partitions and of the other elements concerning the interiors requires a shorter time interval and a lower cost than working on the façade. The importance of the comparison is not directly connected to a mere cost evaluation, but rather to a cost/time interval analysis which is finalized to assess the sustainability of intervention in terms of extension of durability of the building as a whole.

This kind of analysis is a proposition too: in order to reduce the use of primary resources, to maximize the exercise life of components, to save embodied energy of the building allowing a planned refurbishment action, some new criteria should be introduced during the design phases. The idea to project a building which can be transformed during the time passes through the use of removable technological solutions, like dry and assembled constructions, but especially through a different view of the relationship between the different elements and sub-systems composing the building as a whole.

The next step of the research will be an investigation of the transformation processes realized on tall buildings in the last 10 years with the aim to check the methodology on a wide collection of case study. This will allow to have some more information about the costs of each modification class in relationship to pre-defined features. The aim of this benchmark analysis is to obtain a cost-benefits scheme of the different solution finalized to the same transformation level in order to suggest some best practice in the guidelines.

Another important element which have to be considered in the development of the research is the great impact that the transformation processes can bring on the original architectural conception of the building. For this reason the transformation classes must be arranged in relationship to technological features without considering any formal purpose.

Furthermore, if it is true that an extension of life cycle of a building obtained by a refurbishment action can be considered an expression of a sustainable approach in architecture, the relevant morphological consequences of this kind of strategy must be considered as the possible loss of architectural identity as well.

References

Ciribini, G. 1988, *Epistemologia della manutenzione progettata*, Quasco n. 7.

D'Alessandro, M. 1994, *Dalla manutenzione alla manutenibilità*, CNR Progetto Finalizzato Edilizia, Franco Angeli, Milano.

Gaspari, J. 2008, "Durability in technology design", in Türkeri N., Sengül Ö., *DBMC - Durability of Building Materials & Components 11th, Istanbul 2008*, Cenkler Matbaacilik, Istanbul, pp.1679-1686.

Gaspari, J. 2008, *L'innovazione tecnologica e la sostenibilità nelle costruzioni*, Edicom Edizioni, Monfacone.

Langdon D. 2007, Kalita N., Watts S., "Tall Buildings - Cost model". *Building*, n°17, pp. 74-80

Manfron V., Siviero E. 1998, *Manutenzione delle costruzioni: Progetto e gestione*, UTET, Torino.

Molinari C., Paganin G., Talamo C. 1992, "Tools for provision in maintainability evaluation", in *Innovations in management maintenance and modernization of building* Congress Proceedings, Rotterdam, Cong. Ed.

Oldfield P., Trabucco D., Wood A. 2008, "Five Energy Generations of Tall Buildings: A Historical Analysis of Energy Consumption in High Rise Buildings", international conference proceedings: *Tall&Green*, CTBUH World Congress 2008, Dubai, UAE 2-5 Marzo 2008, pp. 300 - 310. Chicago: CTBUH.

Willis C. 1995, *Form Follows Finance*, New York: Princeton Architectural Press.