Durability, Resilience and Sustainability in the Building Rehabilitation Process

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Abstract. Where buildings are concerned, the term “sustainability” has been used for more than 30 years. It represents a process of designing, constructing and operating the building considering its environmental impact. A year after the major nuclear plant catastrophe from Chernobyl, the Brundtland Report defined sustainability as the actions that meet “the needs of the present without compromising the ability of future generations to meet their own needs”. A different disaster, a natural one – the Katrina hurricane – led, two decades later, to the addition of another building characteristic: “resilience”. It represents the capacity of a system to adapt after a shock. “Durability” may refer to different issues: the building materials, the building structure, its functionality of aesthetics. The more durable a building is - the more it lasts - the less it affects the environment. The more it lasts, the more resilient it is (as it withstands different types of stress). Technical durability, provided by building materials and structures, prevails over the functional durability. A good example is the case of the industrial buildings of the nineteenth century: constructed with solid masonry structures, these buildings have lost the original functions decades ago and they were subject of conversions that provided them a new life cycle. Withstanding the action of natural and anthropic agents, these buildings proved to be resilient and, by saving the natural resources, they can also be considered sustainable. Considering that in the next 30 years we will still face 70% of the current building stock, it is important how we deal with them, in order to provide, by rehabilitation, a new life cycle to the existing constructions. The paper tackles, from a critical perspective, some examples of good and bad practice in the building rehabilitation process.

1. Introduction

Thirty years from now, 70% of the existing stock of buildings will still be standing. This means that the emphasis will be placed on operating the existing buildings by updating them and providing maintenance, in order to meet the expectations and requirements of the users-to-be.

As early as 1923, Le Corbusier launched the metaphor “a machine for living in”, regarding the houses [1] but the depth of the term can be understood more today, as people are addicted to different services that provide, if not a better life, a more comfortable one undoubtedly. According to Le Corbusier’s theory, the “machine for living in” should be like a household device that can be multiplied by production of repetitive (dwelling) units.
A sustainable approach would, therefore, be to reconsider, adapt and reuse the existing buildings by either keeping the architectural function or by conversion from the original state to the new, expected one.

In both cases, design modifications and interventions are required, in the spatial configuration and envelope, as well as in the lattice of the building facilities of the construction.

While a building is designed and built to withstand centuries, the building facilities have a short(er) service life and, as the systems improve, modernize and expand, the necessary decade of “well behaviour” of the building services, usually provided by the regulations, is superseded. The relation between the versatile and growing array of services and the immovable architectural (bearing and non-bearing) components is therefore important and carefully planned.

When referring to the stock of existing buildings, the nouns “sustainability”, “resilience” and “durability” have nuanced meanings, compared to the newly designed ones.

Sustainable development, in general, was defined by the Brundtland Report, Our Common Future in 1987, as the development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” [2] and includes the ideas that the resources are limited, therefore their use should be made with social and economic responsibility.

In architecture, sustainable design implies awareness of the needs of the occupants from design to the post-use of the building, combined with a flexible concept that includes the know-how of the perennial vernacular, that uses Nature (sun, wind, waterfall, vegetation) as passive and active design parameters as well as the appropriate materials and technologies that should take into consideration the resources of the planet (in terms of building materials but also on energy resources), while providing an economic impact that leads to fairness and prosperity. Building materials should either originate from local and renewable sources or from circular economy, in the “cradle to cradle” system and should be considered from the design phase.

In this context, the concept of the new building is a holistic approach that foresees the whole lifespan of the construction, materials and technologies, the pattern of use, the disassembly and reuse of the components.

Employing local labour force is not only a social solution for working places in the territory but it represents also cultural and environmental approaches, as the migration is reduced and the sense of respect or pride for the work is accomplished. Traffic (people or products) produce greenhouse emissions, thus increasing the overall carbon footprint of the building, as a product.

In the case of existing buildings, some compromises have to be made as the construction is already there and the freedom of intervention is limited: interventions in the built space may require the demolishing of some non-bearable building components, adding new partitions or floors, changing or introducing the new generation of building services, replacing or adding new and more performant components (mainly in the building envelope area).

Compared with a new building, tackling an existing construction is more complicated, as the physical boundaries of the building are defined – the house is there already – and after removing the finishing layer, sometimes great surprises rise, as the relation with the original project (if it still exists) may be loosely. On the other hand, the impact on the environment, measured by the carbon footprint, is smaller compared to a new building.

If an existing building is subject to a rehabilitation, it must have proven to be durable and implicitly, resilient. If the new intervention is sustainable, this is another discussion.

2. Sustainability and buildings
Sustainability is a target for most of the aspects of the human activities, as they have implications at a planetary level. In fact, preoccupations regarding the capacity of the Earth to provide the necessary food resources for the increasing number of the human population have been reported for over two centuries: Thomas Robert Malthus wrote in 1798 that “the power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with
numbers will show the immensity of the first power in comparison of the second” [3]. Closer to our
days, scientists [4] state that “at our current rate of resource use we’d need 1.75 planets to support our
demand on Earth’s ecosystem”. Not only the food demands increased with the growing number of
humans but also the development of technological means and household equipment led to an
unprecedented demand of energy to power everything, from light bulbs and telephone chargers to
microwave ovens or computers. It is therefore easy to understand how, in 50 years, buildings became
responsible for more than one third of the global energy consumption and of CO2 emissions. The
numbers refer to the embodied energy (necessary for producing the devices) and not to the energy
consumed by the equipment in operation but voices [5] of the scientific world consider that the total
energy use of a computer or a mobile phone is 83% in production and 17% in operation, during a life
expectancy of 3 years. Therefore, the goal seems to change and boost the repair-recover-reuse triade
instead of continuing the consumerist attitude. Where buildings are concerned, the focus is both on the
components (production, location, installation) as well as on redefining the configuration of the space.

2.1 Durability and sustainability
Durability is the ability of a system to withstand wear and damage. Pyramids are durable. They lasted thousands of years and will probably last as much, if no cataclysm occurs. Built of large blocks of stone, they are almost as durable as the quarriers from where they come from. Durability can refer to materials and to products (and the building is a product). Stone is
durable and so are bricks

But are they also sustainable buildings? While from the environmental point of view the building
material is local and natural and therefore the stress on the planet’s resources is not important, the
social and economic aspects that cooperate to define a sustainable approach are not met: the tomb was
for the pleasure of one person or family, with the effort of unpaid slaves (at least this is what we
believe today how things happened 4000 years ago). On the other hand, the buildings are there and
their original function is lost. In the case of the ancient structures that were inherited and preserved,
the impact on the environment is null. They are functioning, not as temples or tombs but as territorial
large-scale museums.

However, it is not the building alone that should be considered but also the surrounding
environment that it influences or is influenced by. In respect with the given example: the pyramids
have fulfilled their service-life and their role, as tombs; their function changed, from eternal resting
place to a visiting place; interventions within them were minimum but still, they produce, by
influence, massive tourist migration which, in a chain reaction, leads to the development of the tertiary
sector (services): traffic and possibly new supporting constructions, thus increasing the pollution and
the carbon footprint and unbalancing the local environment.

The discussion occurs regarding “how” the (proven to be) durable building is modernized and
operated and from here on, the costs and the carbon footprints that result can be evaluated.

2.2 Resilience and sustainability
Resilience is the ability of a system to recover and adapt after a shock. The term is operating since the
early 70s, as a “measure of the persistence of systems and of their ability to absorb change and
disturbance and still maintain the same relationships between populations [of the living world A/N] or
state variables” [6]. Launched in the field of ecology, the study of resilient systems represented a
research topic for medicine, psychology, and sociology, from where it was imported to the urban scale
and to the building sector.

After the Katrina hurricane in 2005, it became clear that buildings, just as cities, persons, or other
living populations, need to withstand adapt and continue to perform fairly after a traumatic experience.
Resilience is a “stable trajectory of healthy functioning after a highly adverse event” [7] and the
statement applies perfectly in the case of the human settlements as well as in the case of the buildings
[8]. The meaning of the term is to design and operate in order to withstand the impacts of climate
change and natural disasters [9].
Resilient systems should accomplish the following attributes [10]: robustness, redundancy, resourcefulness, and a rapid response, following a disaster. In the case of the buildings, the term refers mainly to the behaviour of the building structure and less to the building as a whole, with all the array of connections between the elements that represent the Vitruvian Triade: Resistance – Utility – Aesthetics.

Densification and human migration are added stress factors to the defined natural (floods, fires, earthquakes, hurricanes) and anthropic (wars, terrorism) catastrophes that may hit settlements and the buildings that have to adapt. Obsolete industries or occupations leave the buildings empty and useless, therefore the actions that are taken to re-vitalize them may be considered as aiming to boost the building resilience. A measure of resilience is [11] “the capacity to recover”, thus being “a way to achieve a sustainability goal”. In this sense we propose resilience at the building scale, as the capacity of a building to withstand changes (functional as well as structural) throughout historic periods.

3. Building retrofitting and the Hippocratic oath

Referring to Hippocrates in the context of building retrofitting may seem bit of a stretch but there are similarities between buildings and living organisms; buildings breathe, develop pathologies, can get sick, recover or die just like humans. Interventions on existing buildings should also respect the Hippocratic oath: First Do No Harm.

Existing buildings that are worth retrofitting are in a Vitruvian balance where each part of the triade elements fulfilled its role. Therefore, an analysis should be carried out in order to establish what can be done with buildings that are structurally and functionally outdated or less energy efficient.

While in most cases, increasing the energy efficiency of existing buildings refers to the residential sector, interventions on the non-residential constructions usually preserve the existing skin and structure and change the function.

In all cases, according to the architectural programme that is proposed for an existing building, a structural analysis is mandatory, to verify and ensure that the building structure meets the required technical performances. In most cases supplementary structural elements must be provided as the interior is seldom left intact and supplementary interior spaces – floors or partitions - should be designed, in order to accommodate the new building functions.

Features that represent means of accomplishing a less resource-consuming retrofitted building, through energy saving or generation, can be added mainly as active systems, by HVAC or electric devices that use alternative energy but passive means, like vegetation envelope components or cross ventilation systems are in the hand of the designer as well.

3.1 Retrofitting the residential stock

“First Do No Harm” applies in this case, especially in the effort of improving the energy performance of the residential stock of buildings.

In countries with no seismic hazard, the preoccupations of updating the existent post-war stock of buildings aims to increase the comfort of the users while increasing in the same time the energy performance through passive and active means [12]. While research is oriented towards ways and means of acquiring the above-mentioned goals and identifying who and how will the bill of the retrofitting be paid, the activity of monitoring the refurbished buildings and the effects of the interventions on the building and the occupants does not seem to be of much interest.

During the past decade, researchers [13] draw attention on the fact that there are “differences between the calculated energy rating and the actual measured consumption” in the refurbished buildings of the residential sector, in Germany at least. Their study is based on an observation made by Walberg et al., [13] that for realistic assessments of the energy consumption, the measured and not the calculated data should be used, as houses of the same thermal rating may consume to as much as 6 times more energy, when compared. Causes behind this discrepancy range from the classic “rebound
effect” (also known as the Jevons Paradox), where the more efficient a technology is, the less expensive it is to use - so people use it more - to the financial means of each household. Based on literature reviews of other European countries, the same authors conclude that the measured consumption tends to be, on average, 30% below the expected energy performance rating, based on calculations that consider the building envelope, the heating system and the location of the building. The discrepancy was labelled as the “prebound effect” [13].

Another issue that is specific to energy retrofitting and often leads to failures - or diminishes the calculated performance – is caused by technical faults due to inappropriate detailing (at the design phase) or poor installation [14].

Appropriate detailing requires not only respecting the technical principles provided by the physics of construction and related with the thermal characteristics of the products that are proposed but also tackling all the “sensitive”, specific subassemblies: taking into consideration the on-site reality and not only the existing initial project. Even so, the same project may have been carried out with differences or adaptations, throughout the whole building, on the different storeys or facades and therefore, although the drawing is related to multiple repeating situations, many of them may be (more or less) unique. It is practically impossible to provide a detail for each architectural detail junction, according to the on-site situation. Therefore, guesses occur, as the concealed works are - until scrapped - hidden behind other layers. If the assumption was wrong and the “creativity” of the workers or the execution is poorly supervised, the on-site adaptations may lead to zones where mold develops (Figure 1).

![Figure 1. Bad quality interventions on residential multi-storey building (Photos: A-M Dabija)](image1)

In the case of thermal / energy retrofitting of mass buildings, the easy approach is to wrap the building envelope in a “thermal blanket”, preferably a thermal insulation on the exterior of the façade, to avoid solving the problem of thermal breaks. The heat transmission and the vapour diffusion may be easier managed by this solution, at least on paper, but the on-site improvising (Figure 2) lead to building defects and pathologies.

![Figure 2. Incorrect window dimension estimations ended up in installing smaller windowpanes and filling in other materials (photo: A-M Dabija)](image2)
When the aim is to retrofit a large number of (high-rise) buildings, the emphasis is on the energy efficiency resulted from calculations, even if it is proven [14] that the calculations were deforming the reality with as much as 30%, the finishing layers of the envelope seem to be less important and, as the cheapest solutions are chosen (Figure 3), the architectural expression of the building changes (and sometimes, not for the better).

**Figure 3.** After the retrofitting of some sections of a building; on the central part no interventions were made, therefore 40 years old ceramic cladding and exterior cementitious-based decorative plaster alternates with thin exterior plaster on reinforcing mesh (photo: A-M Dabija).

The durability of the finishing systems depends on the materials and technologies that were used. As presented in Figure 3, the old finishing systems proved to be more durable than the ones that were installed on the thermal blanket, as products that were used needed no maintenance throughout the 4 – 5 – 6 decades. The lack of detailing in the case of mass residential buildings also “helps” in acquiring a disastrous performance.

On the other hand, there are very good examples of retrofitting of residential buildings, even leading to Energy Plus Buildings. Such systems provide energy from panels that represent an application of ventilated façade systems and require – as in all the situations of improving building features – structural analysis that confirm that the extra load can be withstood by the building (or imply the strengthening of the structural assembly). They also represent more expensive systems that, at least now, cannot be replicated at the city scale, due to the initial costs of the intervention (although it is true that the systems are not as expensive as a decade ago).

According to the European Energy Performance of Buildings Directive (EPDB 2010), from 2020 all new buildings should be nZEB [15]; therefore, both passive and active design principles must be utilized and all the available means that technology provides. As the envelope finishing is a means and not a goal, in time the same roof and façade systems may apply to existing buildings, should the overall costs of the intervention be accepted.

The interventions aim not only to transform the building envelope in an energy generator but reconsider the inner space and functions as well.

### 3.2 Old buildings with new functions

The conversion of building represents a means to provide a new life to an existing structure. XIX-th Century industries, gas tanks, even churches abandoned their original function and began a new cycle. They represent examples of sustainability, durability and resilience, as material durability provided the building resilience, followed by a social resilience granted by the functional conversion and the overall approach is sustainable, as the impact on the planet is minor compared to demolishing and constructing other buildings or abandoning the structures that would, eventually, fall by themselves.
It is the case of the Vienna Gasometers where the gas was being stored in the end of the XIX-th and several decades of the XX-th Century: four huge cylindric telescopic structures were built to cover the need of town gas of the Austrian capital city. Eventually the gas type, the production and the storage changed; the masonry structures of the facades were preserved while the interior was totally changed, the buildings receiving mixed functions from residential to commercial, office and cultural (Figure 4).

![Figure 4. The Gasometers in Vienna: Google Earth (left) and photos by A-M Dabija (centre and right)](image)

Each building was assigned to different (great) architects: Jean Nouvel, Coop Himmelblau, Manfred Wehdorn and Wilhelm Holzbauer. Although similar outside, each gasometer has its own architectural personality (including interior gardens and playgrounds for children). (Figure 5)

![Figure 5. Gasometer A – arch. Jean Nouvel (left), photo: Abductit by (CC BY 2.0) and Gasometer D – arch. Wilhelm Holzbauer photo: Andreas Pöschek by (CC-BY-SA-2.0-at)](image)

Today, the Gasometers assembly, completed with new residential and cultural buildings, represent a pole of touristic attraction. Since 2001, when they were completed, several other such outdated structures throughout Europe were used to host new activities.

The Vienna gasometers retrofitting is only an example of the approach of huge structures that needed to find new uses; other outdated buildings led to the re-designing of the space for new functions, integrating the new technologies that aim to save or produce energy. A more recent example, Le Carreau du Temple - a former clothes market in Paris of the Hausmannian period of the XIXth Century – was transformed in a cultural center in 2014 (Figure 6). The original building was extended with two lower levels (as in the case of most of the building conversions).

The line of the envelope was preserved, as well as the slim and decorated cast-iron structure but a beautiful new skylight produces energy through the solar cells on the glass, while conferring personality and unicity to the space and building (Figure 6).
4. Comments and discussion
Building sustainable does not mean to use technologies but to design correctly, taking into consideration the interdependency between the human expectations and requirements and the natural and built environment.

Durability and resiliency are interconnected where existing buildings are concerned: the built patrimony – a cultural and historic resource – is proven to be durable (or it would not have made it, to our days). In the existing buildings resilience is not only a matter of adapting to withstand natural and anthropic disasters but also to adapt to a new function and use, according to the necessities of the society. If, in the effort of accomplishing these requirements, the resources that are used take into consideration the ”needs of the present without compromising the ability of future generations to meet their own needs”, the goal of sustainability is also achieved.

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