



The figure of Sisyphus is a metaphor for an extremely tiring activity destined to be continually repeated.
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A reckoning with the maintenance of the built environment, a Sisyphean task

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Abstract: Maintenance concerns most of the artifacts, referring simultaneously to the socio-cultural, technical and managerial spheres. Contemporary scenarios impose an overall rethinking, where key-topics such as tradition, consumerism, sustainability and digitization become pivotal in the search for suitable production models, between post-industrial and neo-craftsmanship, in order to have fresher references for the maintenance activities.

In the construction field, maintenance is not limited to the objective of prolonging the duration of quality levels that only affect direct users, but also has important implications of a social and collective nature, in the case of both public and private buildings and spaces. Despite this and other specific features, the parallelism between building maintenance and manufacturing maintenance was fundamental in the last quarter of the 20th century, when the subject made its way into the technological culture of architecture, in search of references that could replace pre-industrial habits.

In support of the theoretical rethinking of maintenance (an activity which, like the Sisyphean task, does never foresee a definitive completion), the article suggests some considerations referring in particular to the reinforced concrete: a structural material almost omnipresent in the built environment since the second half of the last century, which poses significant problems in terms of duration and not only. In conclusion, some possible developments are presented, distinguishing between newly constructed and existing reinforced concrete constructions.

Keywords: built environment; maintenance; maintainability; productive process; reinforced concrete; building quality.

1. Maintenance and production process, between tradition and contemporaneity

Maintenance consists of a set of activities which, however varied, are always characterized by a precise objective: to extend the life of a product, guaranteeing compliance with its purposes in due efficiency. Without prejudice to this fundamental objective, the approaches and operating conditions can differ considerably, in a coherent manner with different production models and operating contexts, seen from the technological, socioeconomic and cultural points of view.

The role and the consideration attributed to the maintenance activities change from time to time, reflecting the specific expression of technological practice, within the coexistence of technical, organizational, and cultural aspects and mirroring the relationships between the expert sphere and user sphere (Pacey, 1986, 71 e Tab. 5, 126).

In fact, the methods assumed by maintenance activities can be considered indicators of the implicit values that every technological practice expresses, and these activities have close ties to both spheres (Fig. 1).

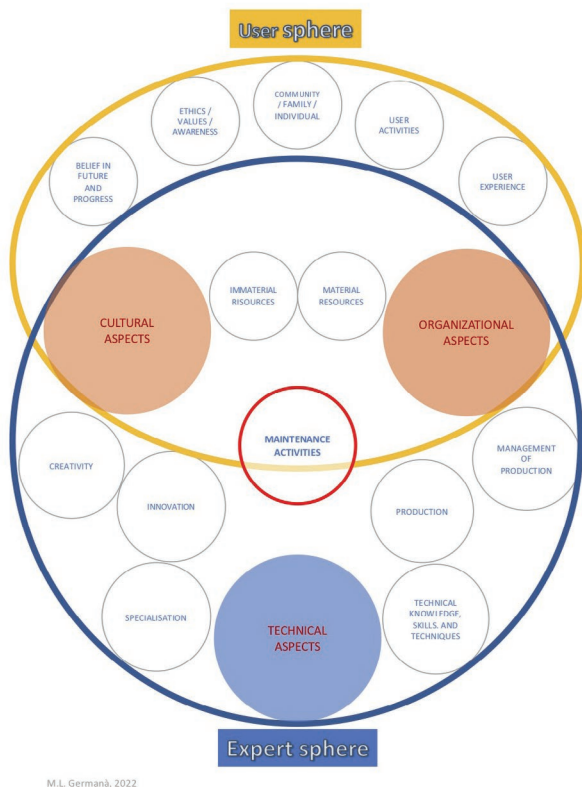


Figure 1 | Maintenance is between the user and the expert spheres, and regards cultural, organizational and technical aspects (Author's elaboration, on the basis of A. Pacey vision of technological practice; Pacey, 1983, 50).

The mutability of the role attributed to maintenance within the production processes depends, above all, on the conditioning of the socio-cultural and economic context and on the availability of resources (human and financial).

In fact, it is precisely within each specific context that the integration between tangible (materials, intervention techniques, and tools) and intangible (responsibilities, organizations, methods, and skills) aspects of the maintenance activities takes place (Fig. 2).

Therefore, the close link between maintenance and the production process is essential to fully understand how this set of activities took shape in the remote and recent past, and how it can evolve in present and future scenarios.

In the pre-industrial tradition, the maintenance of an artifact was normally an integral part of the technological processes, ascribed to the same category as the sole operator responsible for the production activities. The continuity that characterized the operating practices, in which innovation was metabolized over a long period of time, allowed for the physiological replacement of some components that might be necessary to maintain efficiency, without any problems arising, either in terms of finding materials or in terms of necessary skills and competences.

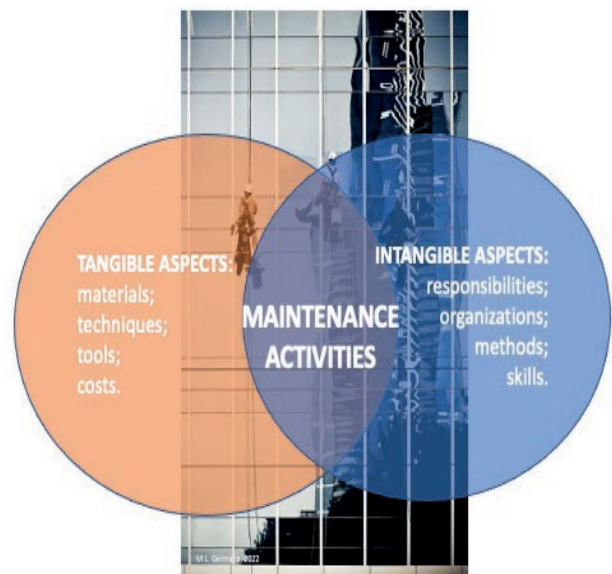


Figure 2 | Coexistence of tangible and intangible aspects in the maintenance activities (Author's elaboration).

The advent of the industrial production model, reflecting the ever-more pressing effects of technological innovation, has unhinged the previous habits, segmenting and separating the production phases with the attribution to distinct operators. For this reason, the maintenance activities have become extraneous to the production process, as they are entrusted to operators and organizations logistically and managerially detached from production. In fact, maintenance is divided into activities programmed according to precise timing and skills, acquiring a specialized (unprecedented compared to pre-industrial habits) form. Bearing in mind the entire production (raw materials, transport, energy, emissions and waste, tacit and explicit knowledge, organizations, tools, etc.), this occurs more clearly when the *technological complexity* of the product (i. e. the level and the variety of information it includes) is higher.

But above all, it should be underlined that industrial production, at the peak of its parabola reached in the 60s of the last century, almost nullified the need for maintenance itself, undermining the fundamental objective of prolonging the life of the product, with the introduction of the previously unintelligible idea of planned technological obsolescence, determined by the imbalance between product quality and the potential offered by more performing outcomes of new production processes (Mellal, 2020). In fact, the goal of extending the life of a certain product loses sense if it is foreseeable that – already in the short term – new products will be available, preferable for their better performance. Market imperatives are at the roots of planned obsolescence: durable and well-maintained products would undermine the pressure of new products that feed the capitalist economy. Unfortunately, the nullification of the duration objective and the exclusion of maintenance from the production process have contributed to the well-known, immense, pervasive, and global invasion of waste: one of the most evident tangible signs of the environmental unsustainability of industrial production and of the consumerist attitudes of the twentieth century, together with the erosion of natural resources erroneously considered inexhaustible (Butera, 2020).

During the last decades, the evolution of the production models has distanced itself from twentieth-century industrial production, gradually returning a central role to maintenance, as a consequence of the increased awareness of environmental sustainability in the last quarter of the century, with the emergence of the postindustrial society and of the technological advances of digitization, manufacturing production has progressively and radically transformed.

- 1) The general shift in trend from product to service has turned the spotlight on maintenance: among technological activities, one where the immaterial dimension seems to prevail over the tangible one.
- 2) The mending of the segmentation of the production phases (*cuncurrent engineering*) and the tension towards well-defined qualitative requirements (*continuous improvement*) (Rifkin, 1995, 166), together with the renewed role of the user in the design (*user-centered approach*) (Dai and Ómarsson, 2011) have prompted us to increasingly identify and pursue product requirements related to durability (such as cleanability, inspection, maintainability) (Sample, 2004).
- 3) The efficiency of the machines necessary for production is increasingly considered an indispensable tool for containing costs and increasing profits: maintenance, therefore, does not only concern the final product, but hinges on the entire production, applying itself to every specific logistic and operational apparatus.

By deepening this last point and looking at the most advanced manufacturing models, machinery maintenance maintains the character of a set of actions diversified by approach, intervention, intensity, and technological level, which can coexist in the same organization. *Reactive maintenance*, an eventuality that can never be categorically excluded, continues to be considered acceptable if the replacement of components is strategically convenient in terms of costs, the failure does not trigger other damages and, above all safety is not jeopardized. *Planned maintenance* consists of the replacement of components that are still-functional, according to intervals established on the basis of statistical data relating to the useful life. Understood in this way, this strategy is controversial in many ways, especially for the transformation of still functional parts into waste, and for the management of spare parts. With the maturation of the *Fourth Industrial Revolution*, digitization and connection have made practicable procedures previously outlined only on a theoretical level, allowing easy and immediate management of the detection, archiving, and monitoring of the data necessary as an information base for programmable maintenance activities and not only to be carried out after the breakdown has occurred. The use of robotic machines in manufacturing industries and the potential of Artificial Intelligence in this area have already moved maintenance from the programmatic level (already pursued with the *Second Industrial Revolution*) to the proactive and predictive one, optimizing the efficiency of production plants (Fig. 3).

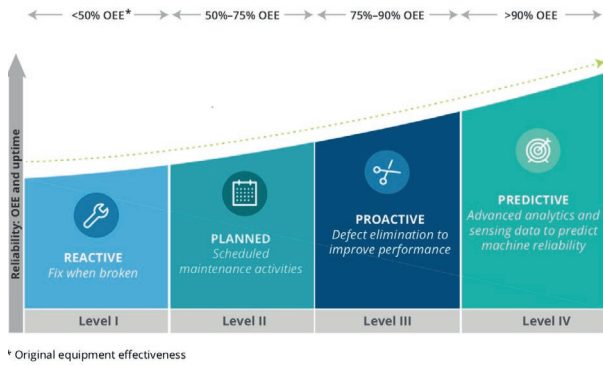


Figure 3 | Maintenance strategy continuum (Deloitte, 2017, 3).

More efficient management of information and deeper knowledge of the causes of failures in the manufacturing industry have paved the way for *proactive maintenance*, which consists in organizing interventions of a preventive nature, aimed at extending the useful life without resorting to replacements not necessary. The increase in data necessary for this type of maintenance and the diversification of the activities to be managed has made the support of digital tools (*Computerized Maintenance Management System*) essential, to be adapted to the specific production realities (Lopes *et al.*, 2016). The growing diffusion of Information Technologies has made it possible to tackle the management of maintenance of equipment, bringing out the greater amount of indirect costs, hidden and underestimated in the previous models (Fig. 4).

The availability, at affordable costs, of increasingly high-performance digital support networks has accelerated the transition to *predictive maintenance*, which allows for the organization of maintenance interventions that anticipate their need (Deloitte, 2017). The connection between different technologies based on the virtuous physical-digital-physical loop (Fig. 5) makes various and numerous data usable, also different in terms of origin (statistical information on the previous operation of the machines or data collected in real-time via sensors).

It is foreseeable that, already in the short-medium term, an increasingly close and interacting mix between the physical and digital world will find wider applications, in the production as well as in the use (and therefore also in the maintenance) of the artifacts. Just think of the possibility of having virtual models (*digital twins*) of objects, processes, products, and even people, who will communicate an inexhaustible mass of data upon request, after having collected, processed, and stored them (Kaivo-oja *et al.*, 2020).

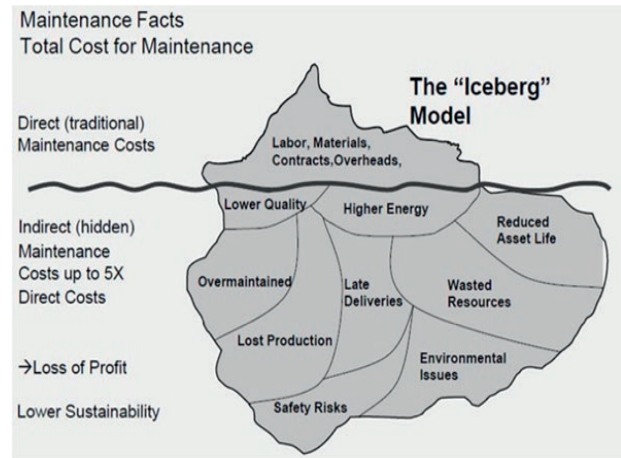


Figure 4 | Iceberg model of total costs of industrial equipment maintenance (Wienker *et al.*, 2016, 415).

The advent of digitization in the production processes, one of the prevailing factors of industrial manufacturing innovation, has also affected the development of Neo-Crafts (Neoartisan), a trend in which the pre-industrial tradition feeds on the operational potential of new tools, without losing adherence to the human factor and to the contextual relationships (Spadolini, 2013). The marked orientation towards sustainability of Neo-Crafts pushes to extend the life of the artifacts, adding to the maintenance activities the potential of a stimulating creative dimension.

2. Product and process specificities of the maintenance of the built environment

The maintenance activities applied to the built environment, compared with maintenance in the manufacturing field, are characterized by some notable specific characteristics. This imposes due distinctions, which refer to both product and process technologies, and which affect maintenance activities.

A first specificity of the product must be found in the closest relationship between the built environment and the context. As regards the anthropic context, the conditions of abandonment or use, more or less intense and wearing (Arbizzani, 1991) and the general management conditions, more or less favorable to the implementation of maintenance, depend on it. As far as the environmental context is concerned, with even greater evidence a heterogeneous set of factors determines the intensity and frequency of maintenance activities: microclimate, exposure to solar radiation, dominant air movements,

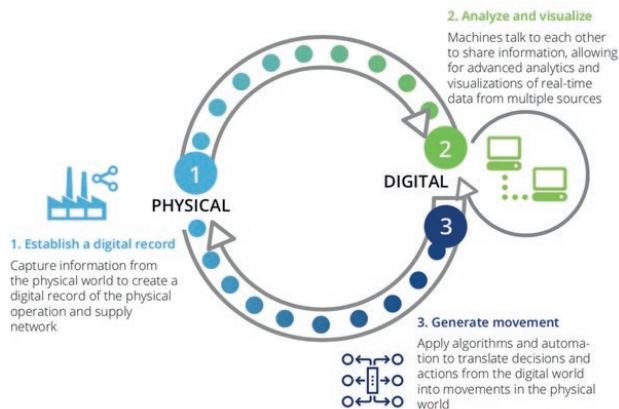


Figure 5 | The physical-to-digital-to-physical loop (Deloitte, 2017, 4).

presence of vegetation, proximity to the sea or courses of water, proximity to sources of pollution.

A second difference between manufactured products and the built environment lies in the fact that the latter gives tangible form to a set of heterogeneous factors that condition its users (often unaware) with respect to behaviours, habits, state of health and ecological footprint, with referring to both the individual and the collective sphere. In fact, the quality of a building, whether public or private, is not limited to satisfying those who use it directly, but also assumes a wider value for the community, due to the consequences it has in economic, environmental and social terms. Compared to this specificity of the product, maintenance activities on the built environment are not limited to prolonging the duration, as happens for other artifacts, but also have further positive effects (direct and indirect, tangible and intangible) on all the aspects that contribute to the users' quality of life. In fact, absent or inadequate maintenance compromises safety (both structural safety than safety in use), well-being, decorum and energy consumption.

Therefore, from this derives a further difference between the maintenance of the built environment and that applied to manufactured products, which concerns the effects of the interventions and, above all, the effects of the lack of interventions (Fig. 6). Unfortunately, in general, similar effects of maintenance activities (or of their omission) escape quantification and there is therefore a tendency to ignore or underestimate them (Lee, 1976, 3); nevertheless, there is evidence that a neglected built environment depresses the quality of life and contributes to antisocial behaviours (Kelling *et al.*, 1982; Fig. 7).

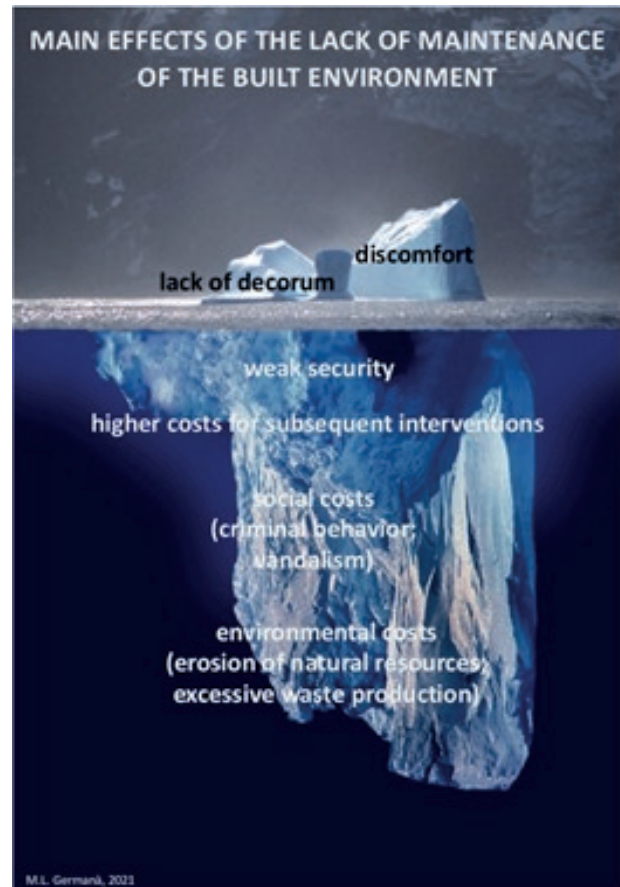


Figure 6 | The perceived and non-visible effects of the lack of maintenance in the built environment (Author's elaboration).

As far as procedural specificities are concerned, compared to a generic production process, building production is confronted with higher levels of variability and complexity, especially if one considers the growing incidence of interventions on pre-existing buildings. In most cases, it reflects a mix of different coexisting production models, in which each operator (client, designer, executor and supplier, user) can be referred to various types, each with particular criticalities.

Following the planning and design phase, in which the public or private client interfaces with different design skills, in the construction phase the adoption of numerous components made off-site by the manufacturing industry does not avoid a more or less significant share of on-site works, in which the application of the traditional rules of the art remains fundamental.

Furthermore, looking at the management phase of interventions on the built environment, compared to most other products, we are confronted with a much



Figure 7 | The *Broken Windows Theory* is based on the link between degradation of the built environment and criminal behavior [Ph. wikipedia/commons].

wider chronological extension, which is affected by a more extensive and partly random set of natural and anthropic agents.

Therefore, looking at the specificities of the process, it is evident that the maintenance of the built environment is confronted with a very wide variability of situations that can occur during the existence of a building and is applied to elements that derive from different production models, which can coexist in the same intervention and which impose different timing and modalities. Furthermore, the phenomenon of obsolescence usually affects individual categories of technical elements in a differentiated way and only rarely the entire building, in the event that it becomes inadequate in its functional aspects or its value is not proportionate to that of the area. Consequently, all the phases of the maintenance processes, and above all their planning, should be confronted with the coexistence of the physical, functional and economic aspects that affect the meanings of the duration of the built environment (Lee, 1976).

The most serious consequences of the set of characteristics that distinguish manufacturing maintenance from building maintenance can be recognized in the fact that the very idea of the process, as an organized sequence of production phases, is often excluded from common operating practice, dominated by a corrective (or reactive) maintenance, without programming, and with a cursory design. This can be explained (but not justified) by the fact that maintenance (although it can have significant transformative consequences on the pre-existing structures) tends to be considered harmless compared to other types of intervention on the built environment, and this offers the alibi for reducing maintenance activities to a sum of extemporaneous interventions (Germanà, 2010).

3. Maintenance in the evolution of the building sector in Italy

With reference to what happened for manufacturing production, also the evolutions of the construction sector (a driving sector of the economy especially where manufacturing production is less relevant, as in the South of the Mediterranean area), have marked significant changes in the role of maintenance. These changes help to better understand the current and future scenarios of this indispensable activity, which has been carried out since man began to live in permanent settlements and which will continue to be carried out, as long as this type of settlement will exist.

The built environment inherited from tradition was the result of processes characterized by a substantial continuity of knowledge, both tacit and explicit, in the field of construction techniques and materials. Thanks to this continuity, the tangible and intangible aspects of the maintenance interventions were consistent with the pre-existing structures, even when they included some replacements of parts of the building, in a way that has been defined as “physiological” (Marconi, 1984).

The interruption of this continuity, resulting from the important socio-cultural and technical transformations initiated by the advent of the industrial production model, also in the construction field has gradually ousted the maintenance practice from production, almost relegating it to oblivion. A similar phenomenon finds its deepest motivations in the dominant for most of the twentieth-century technological culture, but it was confronted with different theoretical relationships with the time variable, depending on the specific operational context.



Figure 8 | From the opening credits of the film *Le mani sulla città* [Hands over the city] by Francesco Rosi, 1963 (da <http://annyas.com/screenshots/updates/hands-over-the-city-1963-francesco-rosi/>)

For example, in Italy in the years of the “building boom” (the 60s of the last century), while immense processes of new construction absorbed a large part of the scientific, professional, and political interest (Fig. 8), the interventions on the built environment remained in the shadow (with the exception of those relating to monuments) and the maintenance activities were even more undervalued and confined to a marginal role.

However, maintenance continued to be present within the construction sites, if not in the academies and journals: in fact in 1978 under national law (L. n. 457/1978, with some minor modifications in Presidential Decree n. 380 /2001), maintenance has been codified into two categories: “ordinary”, if it concerns finishes and plant components; “extraordinary”, if it concerns interventions of much greater impact (including: structural parts; new services and systems; mergers or divisions of real estate units; changes to façades, compliant with current provisions), provided that there are no changes in the overall volume and destination of use. The distinction between ordinary and extraordinary maintenance (although for many it is a stretch) is also justified by a non-accessory difference of a financial nature: ordinary maintenance is configured as a mere management burden, extraordinary maintenance as an investment that increases the value of the asset on which it intervenes. This may have contributed to the longevity of these definitions, which have not yet been replaced by any mandatory legislation.

In fact, a redefinition of the categories of intervention would be desirable to dispel the ambiguity within which maintenance activities in Italy still today are conducted. The clear distinction proposed by Reginald Lee between maintenance interventions (aimed at

maintaining the initial quality, counteracting deterioration phenomena) and redevelopment interventions (which aim to satisfy higher quality levels deriving from a renewed framework of needs) (Lee, 1976, 18 and 49) is not always applicable to the built environment, where the initial standard is much more difficult to identify than the initial standard of a machine. The same obstacle is found in the definition of maintenance as the combination of all technical, administrative and organizational actions, including analytical activities, carried out during the useful life cycle of building organisms and their technical elements, aimed at maintaining or bringing them back to the level of the services corresponding to the initial requisites (UNI 10914-1/2001), which has the merit of highlighting that the activities necessary for maintenance involve spheres and skills of a varied nature.

In Italy the step change from a quantitative approach to one increasingly oriented towards building quality comes widely in the 1980s, also taking shape through a renewed consideration of maintenance activities and user participation (Milella, 1985; Dioguardi, 1990). In the two decades at the turn of 2000, numerous studies have examined procedural and applicative aspects of building maintenance, in most cases reflecting the cultural contamination between the building sector and the manufacturing industry, developed in the previous decades in the wake of the spread of the prefabricated building.

In the transition from pre-industrial physiological maintenance to a different kind of activity, connected to a more complex organization, the need for specific tools and methodologies has been highlighted (Molinari, 1989). Maintenance has begun to have recognized a decisive role in the quality of the built environment (Pollo, 1990; Germanà, 2007) and in the design production (Molinari, 2002; Germanà, 2004), in line with the theoretical framework of reference, increasingly shared, of the performance approach.

In the same period, other points were explored, still worthy of attention and study, such as the awareness that maintenance should not be limited to the management phase of the process and should instead be taken into consideration right from the planning and design of building interventions. In particular, the relevance of the design phase on the future conditions of use and on the duration of the built environment (Di Sivo *et al.*, 1994), has led to an emphasis on expressions such as “designing for the maintenance” and “designing the maintenance” (Molinari, 1998), thus focusing on the distinction between “maintenance within quality”, concerning procedural aspects, and “maintenance of

the quality”, referring to the outcomes of production processes (Curcio, 1999).

In parallel with the theme of maintainability in the design solutions (D’Alessandro, 1994), was developed the theme of planning the maintenance activities (Arbizzani and Di Giulio, 1995; Molinari, 2002), which, in the same years, found an important response in the renewal of the legislative framework. The inclusion of maintenance activities in some mandatory documents in the design of public works (think of the Maintenance Plan referred to the Art. 33 of Presidential Decree no. 207/2010, already introduced with Presidential Decree no. 554/1999), is a consequence of these advances. In the following years, some Italian Regions, in order to contain accidents on construction sites, for interventions involving the construction or recovery of roofs, issued the obligation to introduce devices for maintenance interventions at height (anchor points, guidelines; anti-fall systems): thus, increasing the level of maintainability, future maintenance interventions can be safer and cheaper.

These important legislative innovations, together with those that have been introduced in parallel with the standards, certainly have had the merit of spreading awareness of the need for maintenance between the Italian operators, emphasizing the importance of maintainability among project requirements. However, their real effects remain to be demonstrated. In fact, having introduced obligations, such as those mentioned, has so far not been sufficient to bring out prescriptions, neither detailed nor vague, on when maintenance activities must be carried out on public buildings and, even more so, on private ones: today only some plant components (lifts, gas-boilers) fall under the obligation of periodic reviews, carried out by specialized personnel in established times.

In the impossibility of outlining an exhaustive picture of the studies on the building maintenance in Italy, for the sake of brevity, only two other points should be highlighted here, which were outlined twenty years ago and still deserve to be explored in the national and international context. The first point is how maintenance acquires specific meanings, applying itself to particular fields of intervention, such as for example the built environment characterized by cultural meanings (Di Battista, 1999; Germanà, 2001 and 2010; Cecchi and Gasparoli, 2011). The second is the transition from a logic of “maintenance works” to a logic of “maintenance services” (UNI 10951/2001 Information System for the Management of the Maintenance of Real Estate Assets), in which the organizational and planning aspects prevail on the technical and executive

ones and in which the question of the “information system” for building maintenance adequate in terms of completeness, structuring, flexibility, and upgradability is highlighted (Maspoli, 1996; Caterina and Fiore, 2002; Talamo, 2011).

This last point is among those that have recently been providing renewed insights into the topic of building maintenance, thanks to the diffusion of digital tools in common operating practices. In particular, the contribute that Building Information Modeling (BIM) can provide is now evident, in terms of organization and efficiency of maintenance activities, finally making the integrated management of complex information feasible, thanks to a closer link between the design and management phases of the processes (Talamo, 2014) and encouraging interoperability between the subjects involved, in line with the prospects opened up by Industry 4.0 also in the construction sector (Lauria and Azzalin, 2019).

The link between the progress of maintenance activities in the manufacturing sector and the contemporary scenarios of the building sector could be confirmed and strengthened by the unstoppable trend towards “constructing” (Connors, 2020), a neologism that underlines the coexistence of different production models in the building and which can direct towards an actualization of the twentieth-century culture of prefabrication (Ciribini, 2019). This trend also legitimizes the transition from scheduled maintenance to proactive and predictive maintenance in the building sector, when the use of BIM is associated with sensor devices, capable of monitoring and transmitting any structural failure and environmental data in real-time (temperature, humidity, smoke, etc.).

The consolidated theoretical advances on maintenance and the possibilities opened up by digitization in the building sector contrast with an operational reality which in Italy has so far struggled to fully embrace innovation, mainly favouring product innovation rather than process innovation. In particular, maintenance activities continue to be carried out in the absence of long-term strategies, reflecting a general attitude well summarized by the aphorism attributed to Leo Longanesi “Alla manutenzione, l’Italia preferisce l’inaugurazione” [Italy prefers the inauguration to the maintenance]. This attitude, which can be referred to a shared trend to procrastinate and to financial limitations, is recognized both in private construction (aggravated by the fragmentation of real estate properties) and in public construction (where immobilism and inefficiency still too often prevail). The concern that arises from such a picture, increases if we consider the



Figure 9 | *Palazzo Giallo* in Cefalù (PA), designed by architects Culotta and Leone and built in the early 1970s. The facade, after about ten years after the maintenance intervention, shows again signs of degradation (Ph. M.L.G. 2022).

data: today extraordinary and ordinary maintenance interventions exceed 70% of the production value of the construction sector in Italy (Camera dei Deputati, 2021). In other words, if maintenance from Cinderella has become Queen, she risks being a sovereign without the necessary footwear to travel a long and profitable road.

4. Maintenance and reinforced concrete: what prospects for new and existing buildings

Where reinforced concrete is the most widespread structural material, as was the case in Italy for most of the twentieth century, the culture and maintenance practices have shown greater and more widespread deficiencies. Many areas (urban, peri-urban or rural) are extensively invaded by reinforced concrete buildings of all types, sizes, level of completeness, and conditions of use, which present an advanced pathological decay, unfortunately often to be considered irreversible. The

reasons for this derive from the dominant technological culture, disinclined to take into account the time variable to the point of assuming every construction as if it were invulnerable and ignoring the basic maintenance needs.

In particular, the success of the reinforced concrete, due to its very technical essence of composite material with a high level of artificiality, depends on the coexistence of a varied set of factors: quality of the base materials, correct dosage, exact sizing, and expedients in the execution phase. Durability is compromised if even just one of these factors is lacking (D'Olimpio, 2019). Furthermore, the degradation manifests itself in a treacherous way, only when the process of qualitative decay has already quite started and, in the absence of timely interventions, the deterioration worsening corresponds to an increase in costs, up to the point of no return (De Sitter, 1983; Siviero *et al.*, 1995).

For this reason, maintenance for the elements in reinforced concrete (even more than in any other

construction typology), like the punishment inflicted on Sisyphus, is an activity that can never see completion, as evidenced by the frustration shared by owners and technicians to see the deterioration that reappears a few years after onerous maintenance interventions (Fig. 9).

In the contemporary framework of a building sector increasingly focused on quality instead of quantity, awareness of the vulnerability of reinforced concrete has imposed a change in the provisions and operating methods. Therefore, it can be well hoped that in the

future constructions, reinforced concrete will be designed and built according to criteria of durability and maintainability, making effective, programmed, or even predictive maintenance processes possible (in the event that the use of special sensors is a justifiable cost/benefit ratio). On the other hand, for the huge reinforced concrete real estate stock inherited from the recent past, the variability of conditions does not allow us to outline a single destiny, but rather suggests the hope of a common diagnostic protocol, which can accompany gradual and realistic processes of disposal and renewal.

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