Historic additional storeys in the cultural heritage of Palermo: critical analysis for the purpose of structural and energy improvement

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Highlights

Historic additional storeys are commonly affected by significant deficiencies, in comparison with the current requirements of structural safety and hygrothermal comfort. The lack of performances is particularly evident in the upper addition. These constructions influence substantially the seismic vulnerability and environmental quality of both historic buildings and their urban spaces. Therefore, by focusing on the additional storeys of the cultural heritage, the integration between structural reinforcement and the improvement of energy performance and indoor comfort can be explored.

Abstract

This paper analyses construction features and performances of additional storeys in historic buildings. The recurring characteristics of these historic accretions are investigated by focusing on the cultural heritage of Palermo, where the practice of extending buildings by raising new levels was widespread both in monumental and vernacular architecture, in public and private constructions. The performance deficiencies of additional storeys are examined in terms of structural safety, thermal comfort and building energy demand. On this basis, the utility of mapping these structures, their morphology and their location in the urban fabric is discussed.

Keywords

Historic architecture, Historical additional storey, Energy efficiency, Structural safety, Indoor environmental quality (IEQ)

1. INTRODUCTION

The historic development of Palermo is related to the practice of upraising additional storeys on existing buildings, in order to exploit the areas protected by the city walls. Private gardens and outdoor spaces, not rare in the Medieval town but already scarce in the XVII century, satisfied only partially the permanent demand of houses and the significant enlargements of monumental buildings. For centuries the urban development of the historic centre was characterised by union or subdivision of building units and by the gradual addition of storeys, which involved both minor and major architectures. The convent of Saint Anne in Palermo is a significant example of this building
practice. The construction of this religious complex is based on the radical transformation of a rich residence, built by a Catalan merchant in the end of the XV century and bought by the Franciscan friars in the XVII century. Several changes impacted on the indoor space, through the reorganization of partitions and floors. Furthermore, a plan of significant enlargements was carried out to make the former residence functional to the requirements of a religious community. More in detail, a monumental cloister and dormitories for the friars were erected on the large private garden, and an articulate program of additions continued until the second half of the XVIII century [1].

Due to the duration of these building transformations, to the complexity of damages and structural reinforcements, and to the disadvantaged location on the bed of an ancient stream, Saint Anne’s convent highlights the ambivalent behaviour of traditional constructions in Palermo: increasing knowledge of and persistent disregard for the structural problems related to the addition of new storeys.

Archival documents, which list the damages caused by the earthquakes occurred in 1726 and 1823, report that severe cracks and partial collapses affected the top part of several constructions [2]. In his description of the 1823-earthquake, Francesco Ferrara attributed the numerous collapses occurred in the city to the lack of bracing, the slenderness of walls and the decay of roofs. Moreover, he related the building vulnerability to construction defects on the one hand, to the decay of several fabrics on the other hand [3]. Since the town was periodically subject to seismic events, the use of tie rods and other anti-seismic reinforcements became more frequent. However, not rarely the repairs gave the opportunity to further upraise damaged constructions and numerous building transformations continued to neglect the good practice of masonry construction.

Technical awareness of the deficiencies of additional storeys emerged after the XVIII-century earthquakes and was enriched with a new point of view during the XIX century. Frequent epidemics, caused by the high population density in the urban centres and by the constant demographic growth, showed the negative effects of additional storeys on town hygienic conditions. Consequently, during the second half of the century, the planning of urban fabric and building volumes attached increasing importance to sunshine, lighting and ventilation of indoor and outdoor spaces [4].

In 1863, the New Building Regulation of Palermo limited the possibility to upraise existing constructions. In the case of new streets, the proportion between the width of the road and the height of building façades was reduced up to 1:1, because this ratio was considered ideal for assuring health conditions.
In the case of existing streets more than 30 palmi (around 8 m) wide, the Regulation stated 60 palmi (around 15.5 m) and 1:2 as the maximum height and width/height ratio. If the existing street was less wide than 30 palmi, the façades should not exceed 45 palmi (around 11.5 m). Nonetheless, the practice of additional storeys still persisted in the first half of XX century in public and private buildings, in the historic centre and in the more recent districts.

Frequently, the construction features of additional storeys are precarious and the hygienic conditions are poor. This mix of deficiencies affects the structural safety and the environmental quality of both buildings and urban space. In the recent past, even systematic demolitions have been proposed for the upper storeys in historic districts. However, they are interesting expression of traditional construction techniques and contribute to the urban landscape of historic towns.

Through historical additional storeys, relevant scientific topics may be investigated in the field of cultural heritage conservation, notably the integration among structural safety, environmental quality and building energy efficiency. From this point of view, the historic architecture of Palermo is significant as a case study, since additional storeys are diffuse and show numerous technical solutions and deficiencies.

2. CONSTRUCTION FEATURES OF ADDITIONAL STOREYS IN THE AREA OF PALERMO

Rich literature describes materials and techniques [5], masonry typologies [6] and structural deficiencies [2] recurring in the historic architecture of Palermo. This framework shows variegated construction solutions for additional storeys too, because of the persistence and diffusion of this building practice both in major and minor architecture.

In the upraising of a new storey, the reduction of the related load was the most relevant problem. Therefore, additional fabrics were characterised by limited cross-section and lightweight materials.

The remarkable wall thickness which characterises lower storeys (not rarely, intentionally oversized) allowed large additions (fig. 1). Furthermore, masonry crushing is infrequent, due to the mechanical properties of materials (generally calcarenite stone) and the construction features of the structure [2]. Nevertheless, in several buildings, excessive reduction of wall thickness can be observed still in the intermediate storeys [3].

Especially in minor architecture, the top-floor walls are made up of slender calcarenite blocks laid on edge and their thickness commonly ranges from 20 to 25 cm [5, 6]. This excessive slenderness limits also the effectiveness of
transverse walls as bracing for the façade. Consequently, the building front is particularly vulnerable to tipping over, also because of the daring ratio between the thickness of the wall at the bottom and its overall height (up to 1:30÷1:35).

On the top floor, slender and very lightweight structures were commonly built by means of timber frames, filled with thin calcarenite blocks or just cladded with reed matting in case of internal partitions [5, 6]. This construction technique solved the frequent misalignment between top and underlying wall, when the additional storey was placed behind the building front in order to obtain a little terrace, but it cannot rest on a wall at the back of the façade (fig. 2) [5].

Figure 1. Historic additional storeys in piazza San Domenico, Palermo. In the building on the left, the accretions follow the façade. Conversely, the additional storey at top of the construction on the right is located behind the building front. In both cases, the gradual reduction in wall thickness is visible from outside, although this solution is not frequent in the cultural heritage of Palermo.
Lightening the structure could be not sufficient for preventing the underlying masonry from collapsing. Besides being generally precarious, the construction features of additional storeys contributed to the heterogeneity of the building fabric. Problems of structural compatibility are clearly expressed by Carlo Dolce in his *Reflections upon the earthquake occurred in Palermo on 5 March 1823*. As member of the civil engineering office, he observed that the old structures had tended to expel the additions, especially overlapped volumes and projecting elements, which drove the external front to tip over [7].

Upraising an additional storey frequently required substantial works on the existing structure, in order to overcome both original construction defects and alterations caused by complicated transformations. From this perspective, it is interesting to mention masonry made up of pietra e tajo, consisting of irregular stones bounded with earth-based mortar (sometimes added with ash). It has been ascertained that this technique was used in the XV century and common in monumental buildings until the XVII century, but later it was limited essentially to minor architecture.

During the XVIII and XIX centuries, the structural deficiencies of this structural typology were known to the technicians, who described the buildings using pietra e tajo as contorted and deformed. Frequently, in order to build a new storey on these constructions, a complementary structure of pillars and arches was added, whose mechanical behaviour was rather different from the walls they were included in.

*Figure 2. Building in piazza Beati Paoli. The additional storey was erected behind the building façade.*
If the existing construction was considered reliable in terms of structural safety, increasing the wall thickness was preferred. For this purpose, a masonry layer was built besides the wall and an appropriate number of cross blocks was used to guarantee that the added layer was integral with the existing structure (fig. 3).

Structurally precarious and vulnerable to seismic action, the top storey of the historic building is the portion most exposed to rain and solar radiation, especially if it emerges from the surrounding constructions. In Palermo, enamelled tiles, roof tiles or slabs were used as wall covering in order to facilitate the flow of external water [4]. Since they generally derived from dismantled floor coverings, the enamelled tiles were applied to the wall following frames and geometric motifs.

In the additional storeys, this covering was applied to external walls without openings and sometimes to the main front, especially if this was behind the surface of the building façade. The covering was mainly used on walls oriented to North or North-West, which is the prevalent direction of rain in Palermo. Enamelled tiles were applied also to the surfaces particularly exposed to water action because of roof geometry and rainwater disposal solutions. Close to the sea, this protection limited the damages related to the wind-driven salts, which kept the wall damp because of their hygroscopic properties. Furthermore, the smooth and waterproof surface of enamelled tiles impeded the proliferation of salts and dusts.
microorganisms. Lastly, this covering reduced the risk of summer overheating if realized on surfaces exposed to solar radiation (fig. 4), but it is not ascertained that the historical technicians were conscious of this benefit.

3. PERFORMANCE DEFICIENCIES OF ADDITIONAL STOREYS

Because of their construction and morphological features, the additional storeys of historic buildings adversely affect the structural safety, environmental quality and energy consumption of the built environment. These deficiencies, mostly known to the XIX-century technicians, are evident in the current framework of requirements and performances for the building sector. Besides the interest in using these spaces as parts of building units or as independent units, conservation needs must be respected. On the one side, historical additional storeys contribute to the urban landscape of historic towns. On the other hand, they are examples of traditional building techniques and, therefore, expression of material culture. Consequently, the solution or the reduction of these deficiencies should be based on the concept of performance improvement [8, 9].

In the additional storeys, the material and construction characteristics of the envelope show the ambivalence of deficiencies, both structural and hygrothermal, and the possibilities to integrate the respective upgrade

Figure 4. Building in discesa dei Giudici. The additional storey at top of the construction is located behind the building façade. The transverse wall, oriented to the West, is covered by enamelled tiles.
measures. However, they also influence the effectiveness of intervention. Masonry slenderness reduces the practicability of reinforcement bands at roof level. For the same reason, the wall shear resistance may not be sufficient for the use of tie rods, while the cross walls may not be able to bear the load transferred by the chains. Furthermore, increasing the masonry thickness is frequently unfeasible because the structure is not supported by an underlying wall.

Due to the little cross section, the thermal lag and attenuation related to the envelope walls is limited in additional storeys. Indeed, thermal inertia is a distinctive feature of massive historic buildings and is strictly related to the significant thickness, which is peculiar to traditional structures. The surface mass of a stone wall 25 cm thick is 379 kg·m⁻², if it is made of calcarenite blocks (21 cm, ρ = 1,500 kg·m⁻³, λ = 0.63 W·m⁻¹·K⁻¹, “tufo” from UNI 10351:2015) and plastered on both sides (external plaster 2 cm thick, ρ = 1,800 kg·m⁻³, λ = 0.90 W·m⁻¹·K⁻¹; internal plaster 2 cm thick, ρ = 1,400 kg·m⁻³, λ = 0.70 W·m⁻¹·K⁻¹; respectively “malta di calce o di calce e cemento” and “intonaco di calce e gesso” from UNI 10351). Nonetheless, the thermal transmittance of this component, U = 1.81 W·m⁻²·K⁻¹, is far from the limit Ulimit = 0.45 W·m⁻²·K⁻¹, which the national regulation (d.m. 26/06/2015) states for the opaque vertical envelope in the climatic zone B. Furthermore, as far as periodical thermal transmittance is considered, the value Y = 0.58 W·m⁻²·K⁻¹ characterises the analysed wall.

Despite the limits to application, realizing a top band shows that the structural reinforcement may also result in increased energy efficiency. According to the national legislation on constructions, raising the existing roof eaves is allowed in order to carry out this upgrade measure. The consequent modification of roof geometry may improve the envelope thermal performances. Since the limited height of the attic could impede the installation of a false ceiling, it is frequent that just the timber roof guarantees protection from the outdoor environment. According to a very common construction solution for traditional roofs in Palermo, a continuous layer of chestnut joists is mounted on the beams and supports the brick tiles, directly or by means of a screed [5]. This stratigraphy is affected by high thermal transmittance (1.9 W·m⁻²·K⁻¹ without screed) and low thermal lag and attenuation. Raising the roof elevation facilitates including a false ceiling or applying an insulation layer, especially in small attics, where these upgrade measures would reduce unacceptably the height of the ceiling.

The hygrothermal deficiencies of additional storeys affect the indoor environmental quality of the entire building, such as their construction attiude of esigenze e prestazioni per le opere di costruzione. Accordo all’interesse per lo sfruttamento di questi spazi in aggregazione ad altre unità immobiliari o in autonomia, le supralevazioni storizizate pongono esigenze di conservazione. Dato un lato, infatti, sono parte integrante del paesaggio consolidato della città storica; dall’altro, sono tecnicamente di tecniche costruttive tradizionali e quindi espressione di cultura materiale. Dunque, gli interventi velti a mitigare o eliminare le molte carenze di questi corpi edilizi devono essere impostati al concetto di miglioramento [8, 9]. Le caratteristiche materiche e costruttive dei componenti d’imvolucro di un particolare costruzione, è strettamente legata l’ambivalenza, sia statico sia energetico, di tali criticità e le possibilità d’integrare le rispettive misure di miglioramento, ma influenzano anche la praticabilità e l’efficacia degli interventi. L’esigenza spesso costruttive delle murature limita le possibilità d’inserire cordoli sommitali in muratura armata. Per la stessa ragione, la struttura d’ambito spesso non offre resistenza a taglio sufficiente all’inserimento di catene metalliche, né le pareti trasversali, anch’esse di sezione ridotta, riescono ad assorbire l’azione trasversale trasmessa dalle catene. Inoltre, un ispessimento delle murature è inapplicabile nei frequenti casi di disposizione in falso rispetto alle strutture sottostanti. Sezioni trasversali ridotte comportano anche la scarsa predisposizione delle murature ad attenuare e sfascare gli scambi di calore con l’ambiente esterno. Infatti l’inerzia termica, che spesso si ritiene prerogativa delle architetture storiche, è strettamente legata alle consistenti sezioni trasversali che caratterizzano le strutture tradizionali. Per una parete spessa 25 cm, realizzata in calcarenite (21 cm, ρ = 1,500 kg·m⁻³; all’esterno 2 cm di “malta di calce o di calce e cemento”, ρ = 1,800 kg·m⁻³; all’interno 2 cm di “intonaco di calce e gesso”, ρ = 1,400 kg·m⁻³; da UNI 10351), la massa superficiale è pari a 379 kg·m⁻². Tuttavia, la trasmittanza termica corrisponde a 1.81 W·m⁻²·K⁻¹; ben lontana dal limite di 0.45 W·m⁻²·K⁻¹ che il decreto ministeriale del 26 giugno 2015 ha stabilito per le strutture opache verticali degli edifici esistenti in zona climatica B. La muratura considerata, inoltre, assicura una trasmittanza termica periodica di 0.58 W·m⁻²·K⁻¹. Nonostante i limiti di applicabilità, la costruzione di un cordolo sommitale mostra come il consolidamento strutturale possa tradursi anche in una maggiore efficienza energetica per l’edificio. Per realizzare quell’intervento, le norme tecniche per le costruzioni conservo consentano l’inserimento della quota di gronda delle coperture. Questa forma geometrica può migliorare le prestazioni termiche dell’involucro. Infatti l’altezza limitata degli spazi sotto tetto non consente sempre l’inserimento di un controsoffitto. In molti casi, dunque, la protezione dall’esterno è garantita dalla sola copertura lignea, nella quale il sistema di chiusura delle
precariousness affects the overall vulnerability of the structure. Thermal dynamic simulations, carried out on two historic buildings in Palermo [10], point out the significant role, which the top levels of vernacular buildings play in determining their energy performance. More in detail, in a four storey building classified as “catioio semplice” (P.P.E. del Centro Storico, 1993), the energy demand of the top floor (consisting of a room, which is part of a single residential unit) represents 49% of the overall heating demand and 62% of the cooling demand. Similarly, in a four storey “catioio multiplo” (P.P.E. del Centro Storico, 1993), where a fifth level emerges behind the façade, 70% and 74% of the energy demand for heating and cooling is related to the two upper floors, which represent a residential unit. Consequently, the hygrothermal improvement of the envelope in additional storeys may enhance substantially the energy efficiency of historic buildings.

4. CRITICAL REPERTOIRE FOR THE PERFORMANCE IMPROVEMENT OF ADDITIONAL STOREYS

The construction features of historic additional storeys can be analysed through the scientific literature focusing on materials and techniques typical of local heritage. However, the structural safety and environmental quality of historic buildings and towns are also influenced by the morphology of additional storeys and their aggregation to adjacent constructions. Furthermore, upraising new levels was a common practice even in public buildings, although only sometimes the structural and architectural result was positive. Therefore, it is appropriate that the additional storeys at top of historic buildings should be mapped. This would support analysing the distribution of these volumes in the urban fabric, examining their location relative to roads and outdoor spaces, proposing typologies based on building morphology and aggregation.

In the case study of Palermo, the additional storeys at top of buildings can be identified by means of the current urban plan P.P.E. (1993), which regulates the building activities in the historic centre. The Plan focuses on the historic town and its building typologies through a cadastral map dating back to 1877 and previous representations. On this basis, the Plan distinguishes between historic additions and inappropriate accretions, although this distinction is not supported by a case-by case analysis, which should focus on size, age, construction and aesthetic features of the building top level. The Plan classifies the additions built after 1877 as inappropriate accretions and states their demolition. Volumes built prior to that date are considered historic and the same type of intervention as the building they are part of is allowed. Apart from this, building classified as “catioio semplice” (P.P.E. del Centro Storico, 1993), the energy demand of the top floor (consisting of a room, which is part of a single residential unit) represents 49% of the overall heating demand and 62% of the cooling demand. Similarly, in a four storey “catioio multiplo” (P.P.E. del Centro Storico, 1993), where a fifth level emerges behind the façade, 70% and 74% of the energy demand for heating and cooling is related to the two upper floors, which represent a residential unit. Consequently, the hygrothermal improvement of the envelope in additional storeys may enhance substantially the energy efficiency of historic buildings.

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from this distinction, P.P.E. does not provide systematic rules or suggestions for the performance improvement of historic additional storeys.

The available maps do not allow to carry out a homogeneous analysis of additional storeys all over the town territory. Outside the ancient city walls, a map on a scale of 1:2000 provides the elevation for a limited number of buildings. Conversely, for the historic centre, a map on a scale of 1:500 (1982) accurately describes geometry and elevation of the roofs. Moreover, by means of this map, the inappropriate accretions identified by P.P.E. can be located, while the several building transformations occurred in the last decades can be detected by comparison with recent aerial or satellite photographs. Together with the building height, the location of the additional storey (with respect to the underlying structure and the adjacent constructions) has remarkable influence on the seismic vulnerability of both the building and the surrounding outdoor spaces. From this point of view, the distinction between additional structures above and behind the underlying façade does not allow a thorough typological description. In general, the morphology of constructions on the top of pre-existing structures varies greatly with the building geometry and size, its aggregation in the urban fabric, and the organization of building units.

The building top addition may coincide with the floor area of the level below or just with a part of it. In the latter case, the addition may be erected on a building corner, or along its main façade, or close to private or shared courtyards. These differences impact on the structural cooperation with adjacent constructions, and consequently their analysis make the seismic vulnerability assessment of outdoor spaces more accurate. From this point of view, inner courtyards are a significant example, since generally they are considered safety for occupant evacuation, especially in public buildings. Nonetheless, daring and precarious additions were often concentrated close to these spaces, because visibility from public roads was limited.

5. CONCLUSIONS

Historic additional storeys, especially at top of buildings, involve remarkable structural, energy and comfort deficiencies for the architectural heritage and its urban spaces. In Palermo as in several local contexts, these additions are often precarious and contradict the good practices of traditional construction. On the one hand, it is necessary to preserve the material and aesthetic features of these accretions. On the other hand, substantial upgrade measures are essential to meet the current needs for safety and operational efficiency.
6. REFERENCES


