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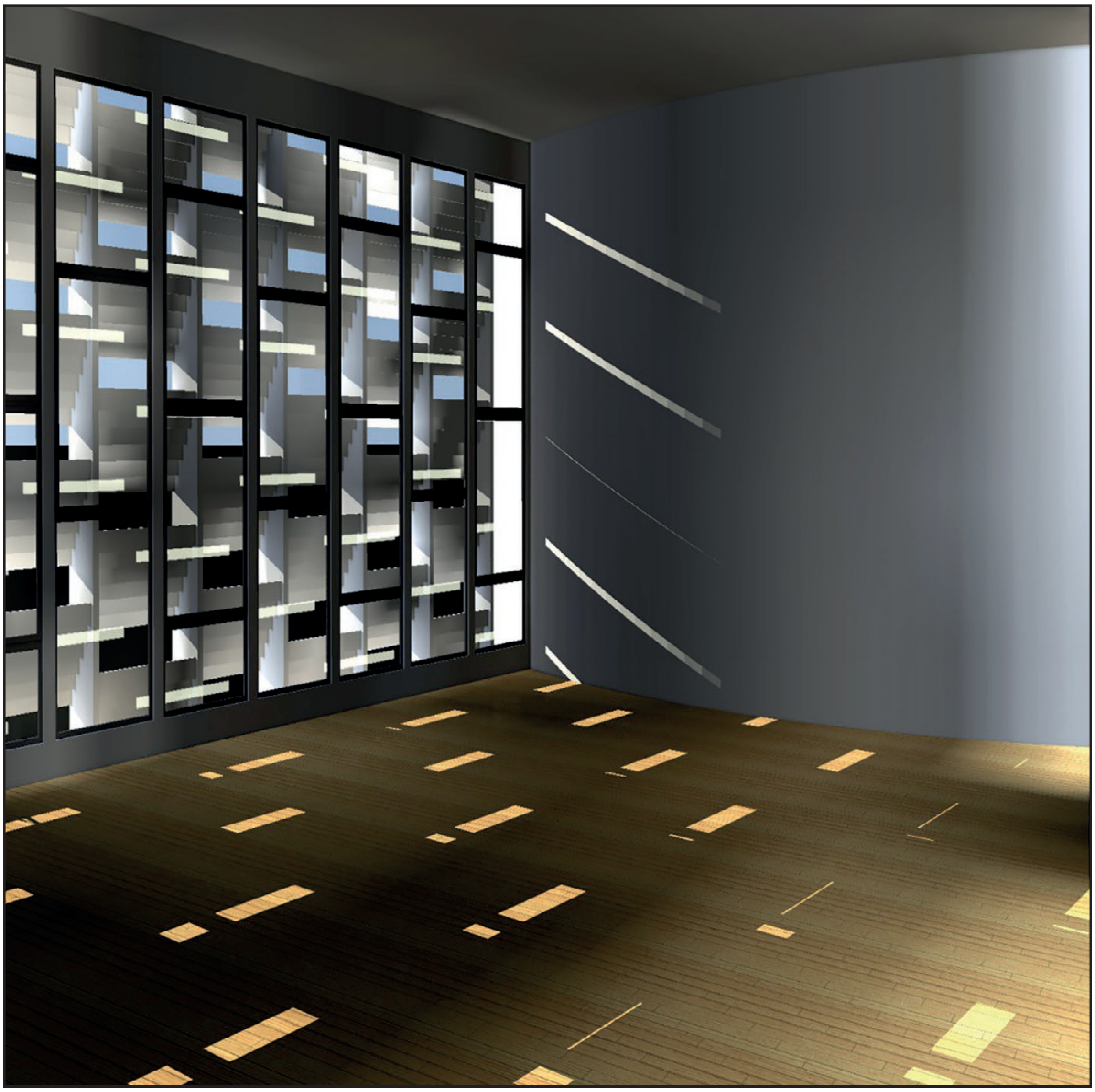

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MAINTENANCE CRITERIA FOR EXISTING BUILDINGS AND NEW DESIGN IN THE 21ST CENTURY – CONCRETE 2022

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Cover image: Interior lighting trough the brise-soleil double-skin facade. Former Law School building, Valencia. Moreno Barberá, architect. (1959/63). © L.M. Palmero Iglesias, 2014.

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Table of contents

Ex Manifattura Tabacchi factory in Verona - Internal render of a reuse solution using a wooden nested building. Image by the authors.

Nested-building as an effective strategy for the reuse of reinforced concrete industrial buildings. The case of the ex-Manifattura Tabacchi factory in Verona (1930-65)

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Abstract: Nested buildings today represent an efficient alternative to traditional recovery interventions in terms of cost-effectiveness, sustainability and compatibility with the existing building. The Italian territory has many disused industrial buildings on which it is necessary to operate with new recovery and re-market strategies. This article presents the results of the research, currently in progress, carried out by the ICEA department (University of Padua). The research concerns the recovery of industrial buildings in reinforced concrete from the 20th century. In these buildings the prefabrication allows a considerable optimization of the recovery interventions focused on modularity and prefabrication to fasten the construction times together with flexibility and reversibility. The analysis of the functional, structural and construction types made it possible to identify general intervention criteria which – as the identification of the average span dimensions – led to two design scenarios of wooden housing modules, following nested-building strategy. After a phase of study and critical analysis, criteria and guidelines for intervention were identified which – as the identification of the average span dimensions – led to two design scenarios of wooden housing modules, following nested-building strategy. The ex-Manifattura Tabacchi factory in Verona was chosen as a case study on which the results of the research were tested.

Keywords: industrial building, re-use, nested buildings, sustainability in buildings.

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1. Introduction

In Veneto there are about 11,000 disused buildings (Savino, 2019), while at the national level the number grows until nearly 7 million (ISTAT, 2017). The abandon process grew rapidly since the 2009 economic crisis, as a clear sign of a productive crisis with profound repercussions on the social and economic tissue, as well as on the environment.

The demolition of abandoned building stock was often seen as the solution to the problem: in Detroit, for example, following the crisis since 2014, 200 empty buildings units have been demolished per week.

Demolition, however, does not solve the problem (Myers *et al.*, 2004; Rovers, 2004; Power, 2008), but instead increases the environmental impact (Pearce, 2004). In Italy, for example, more than 33 million tonnes of waste from demolition were produced in 2014, out of a total of 39 million (EU, 2015). These materials, despite being often recyclable, are disposed of in landfills where they constitute 25-30% of the total volume. This strategy has also risk for the health: according to the National Asbestos Observatory this substance is still responsible for 6,000 deaths/year, only in Italy.

At the international level, the debate and scientific research highlighted – since a long time – the convenience of the building reuse, especially disused ones, by an economically (Latham, 2000, Ball 2002; Douglas, 2002; Pearce 2004, Bullen, 2007) and environmentally (Kendall, 1999; Cooper, 2001; Rohracher, 2001; Kohler and Hassler, 2002) point of view. In particular, the reuse would allow the reduction both of land consumption (Savino, 2019) and CO_2 emissions related to the process of extraction and processing of raw materials, and from the transport of finished construction products (EU, 2015).

The need to ensure economic sustainability and not only the environmental one, however, requires the development of new flexible and smart strategies enabling the process of recovery and reuse of abandoned buildings, following the Circular Economy.

The paper presents the results of research carried out at the ICEA Department (University of Padua), relating to the 20th century abandoned industrial buildings, focusing on the r.c.-built ones.

The research goal was a set of criteria and guidelines for their refurbishment and re-use, based on the building types analysis (functional, structural and materials). This led to a nested building strategies, which were therefore applied on case study, whose common denominator is reversibility, flexibility and replicability.

2. Goals and methodology

The goal of this first step was to develop intervention criteria and guidelines for the reinforced concrete buildings of the first half of the 20th century, focusing on the nested-building strategy. An important aim was the respect of building's value (architectural and spatial) by the flexibility and reversibility of intervention. The criteria generality is aimed by ensuring the replicability of the intervention and therefore its economic sustainability also over time. The most innovative aspect has been the definition of modular interventions, adaptable to the main types of industrial buildings: to achieve this result, their in-depth study has been carried out in relation to the new needs for new functions. This led to a system able to integrating with the greatest number of existing buildings. The standardization of technological solutions allows a significant reduction of time, and therefore of costs, for the building reuse. Research has been developed through several logically and methodologically linked phases:

- analysis of industrial buildings in reinforced concrete dating back to the first half of 20th century. This allowed to identify the main architectural types and evaluating the main characteristics (geometry, structure and construction);
- definition of operative guidelines, based on the former analysis, according to criteria of reversibility, flexibility, replicability and modularity related to nested building intervention strategies;
- checking the guidelines by the case study of the ex-Manifattura Tabacchi factory in Verona, focusing on two raw tobacco warehouses, built in 1932 and in 1961.

3. Current strategies for Building reuse and nested building

The great number and heterogeneity of the industrial building stock requires a flexible and smart approach. It is necessary to think again at the intervention strategies where demolition – once regarded as the cheaper – must remain the last choice, since in the reuse of industrial buildings a wider range of operations can be carried-out (i.e. conservative restoration, functional refurbishment, energy and structural upgrading).

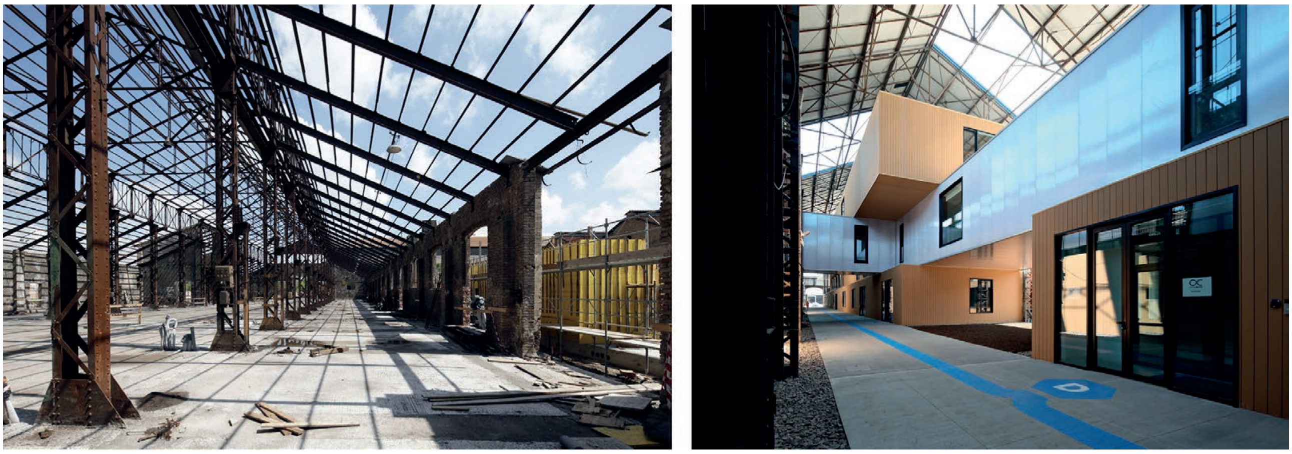


Figure 1 | Contemporary nested building examples: Capannone 17 Officine Reggiane (2020) before restoration works (left) and after (right).

This approach, however, requires a different design approach, able to give new life to the building and to exploit its potential combining as much as possible the different needs related to reuse: the preservation of the possible historical value of architecture, functional transformation and its management in a perspective of economic as well as environmental sustainability (Grecchi, Malighetti 2008; Turrini, 2013).

Nested building is an alternative approach to traditional reuse and refurbishment: instead of increasing the performance of the existing building – an expensive and difficult strategy – it foresees the insertion of a new volume, with functions complementary to those of the outer casing. In this way it is possible to bring the complex (existing building plus inserted building) to levels of performance and comfort in line with those required for the new building (Turrini, 2013).

Today this strategy has declined both as the insertion of new architectural volumes formally and constructively autonomous from the existing building (Lucchini *et al*., 2015), and new "shells" interior where the outer shell remains as simple outer skin (Malighetti, 2016). In both cases, however, the interventions are of the "closed" type, that is designed for a single building and characterized by a low reversibility (Fig. 1). The seriality and the repetitiveness of the industrial building would allow instead a new "open" approach, where the new volumes were defined according to the geometric and structural characteristics of industrial buildings. They will be able to adapt to different building types in a reversible and flexible way depending on the changing functions over time.

4. Typological and formal aspects peculiar to reinforced concrete industrial buildings

The 20th century Italian situation shows construction features linked to the masonry tradition of walls in the residential buildings and the use of new technologies into the industrial factory. Objectives such as: high structural performance in terms of load capacity, fire resistance, formal freedom are effectively achieved through the use of reinforced concrete.

In addition to this, the economic convenience and the possibility to adapt to the most varied load-bearing configurations, even with high structural lights are added.

Already from the nineteenth century, the main industrial models are oriented towards two different types of functional layout: the one characterized by a multi-storey vertical volume and the one by a single-storey horizontal volume, respectively called intensive and extensive (Fig. 2).

The advantages offered by the different spatial configurations can be summarized as: a greater overall compactness of the building volume, in the first case, and a greater planimetric size (one or two naves) but with lower height, in the second case, where one or more lateral spans ("aisles") or quadrangular shapes divided by pillars can be found. (Utz, 1926; Mellis, 1953).

The distance of the pillars and in general the measure of the structural mesh are determined by purely functional needs related to the industrial activities carried out, where geometry limitations are dictated by the technological features of the use of concrete in that period.

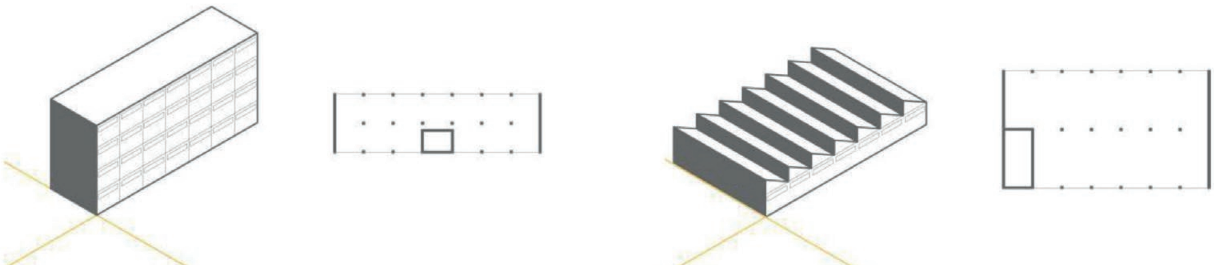


Figure 2 | Industrial building types: intensive (left) and extensive (right).

While since the mid-20th century the use of prefabricated elements has been noted, before the use of reinforced concrete is the norm, although structurally the two types of building show substantial differences.

In intensive buildings with 3-4 floors, r.c. frames are made by beams and pillars. The floors could be built with single or double load-bearing structure according to the variable loads expected and then related to use. The extensive buildings, generally consisting of a single floor, instead are made by r.c. portals (in buildings with longitudinal layout), and single pillars with shed roofs in buildings (in buildings with quadrangular plan) (Nelva, Signorelli, 1990).

These structural patterns were however placed on well-defined structural meshes that, in the hypothesis of a functional reuse, today constitute inexorable geometric design constraints, especially in multi-floor space frame buildings.

Fort this purpose, the research included a phase of identification of these limits using different sources (i.e. technical manuals and surveys) in order to statistically determine the average size of the building spans used in the Italian industrial building both extensive and intensive.

The research analysis covered an extensive set of buildings and highlighted recurring dimensions for the formulation of the intervention guidelines and criteria.

The span dimensions, is 5.00 m on average (minimum and maximum values are between 4.5 m and 6.00 m). The most recurring length values were noted around the 5.00 m, while the width has values mainly comprised in the range 2.5 m-5.00 m. The floor height varies between 4.00 m and 9.00 m.

For extensive buildings the mean of the axes width values and the average pillars distance are 5.87 m and 4.92 m. The floors and roofs levels vary between 7.3 m and 11.00 m considering that the heights of the vertical structures are on average 5.00 m, plus the height of the sheds (Fig. 3).

5. Refurbishment strategies and guidelines

Today the reuse of industrial buildings goes on without strategies representing the real characteristics and limitations of the industrial building typology. The research instead tried to set operative guidelines related both to the re-functionalization needs and to safeguarding the building structural features.

These guidelines can be considered an operational tool for good practice of intervention, where the knowledge of the existing building remains the essential basis for technically effective and economically sustainable action.

The geometrical and operational requirements [Table 1] and the related intervention criteria were identified beforehand, in the context of reinforced concrete industrial buildings. These criteria were then applied to two case studies relating to the types of buildings identified. Through this operational verification and "on site" validation it was possible to really contextualize the considerations carried out.

6. Lightweight construction technologies for the building module: Platform Frame and Cross Laminated Timber

The abovementioned criteria show the need to operate with specific approaches related to the type of

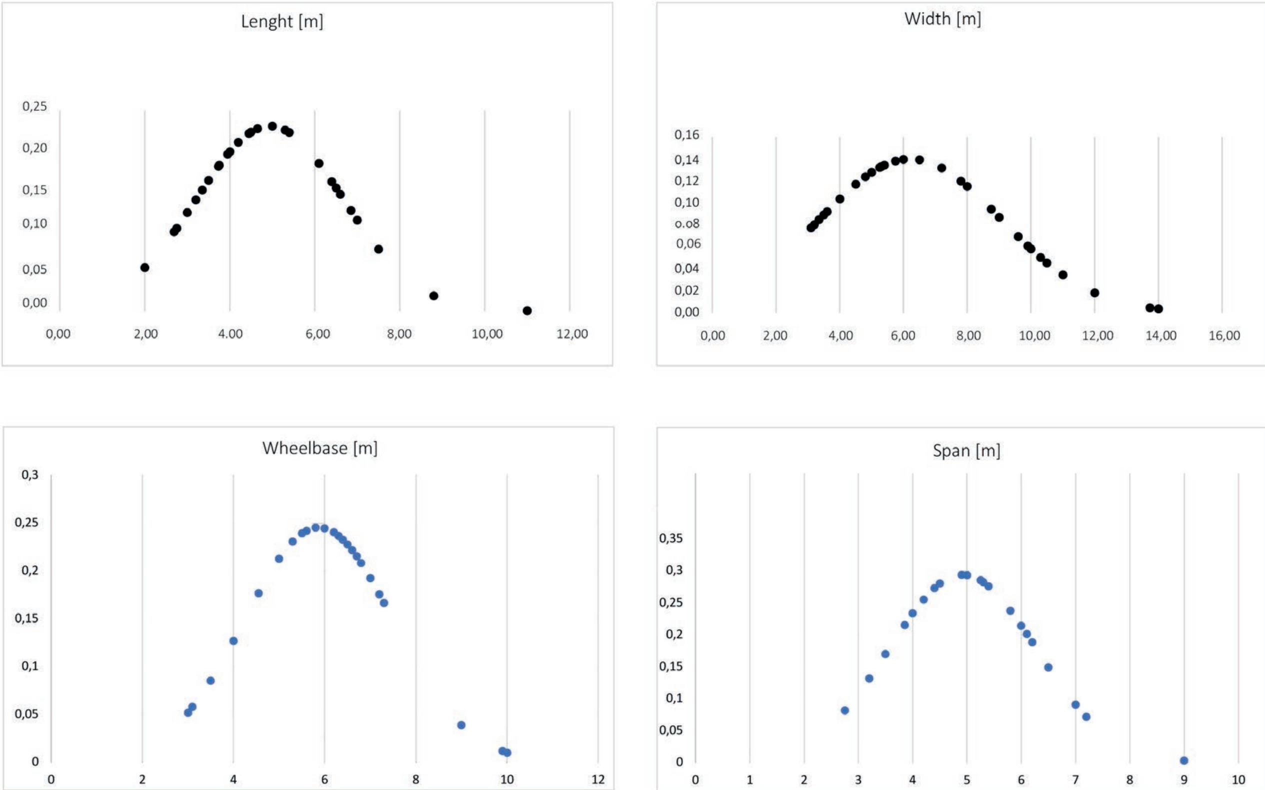


Figure 3 |Normal distribution of the main geometric parameters in the intensive (top) and extensive (bottom) industrial building of the twentieth century.

construction (extensive or intensive), defining the new functional modules able to address different features of industrial buildings, since. different characteristics require different strategies.

The most appropriate construction technologies, in compliance with the criteria and guidelines formulated, were the "Platform frame", for intensive buildings and the CLT (Cross Laminated Timber) for extensive buildings. New modules were build by these techniques, based both on wood (a load-bearing material with great thermal-acoustic insulation). The modules are independent by the existing structure allowing their reversibility and reuse also in other buildings.

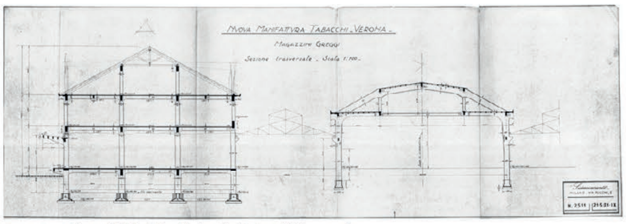
From an operational point of view, moreover, the "dry construction" technology and the modularity of the panels reduce the construction times and simplify the installation inside the buildings.

The choice of the two construction systems depended by the specific characteristics of the two buildings types; a modular wooden frame structure (platform frame) is used in the intensive buildings, characterized by regular spans of small dimensions due to the presence of pillars and of thick beams in the floors (Fig. 4). This light wooden frame consist of two standardized 1.25 m width panels made by OSB (Oriented Strand Board) and fixed to the frame by screws. The final module is 3 m x 2.5 m, to allow both transport and installation within the existing

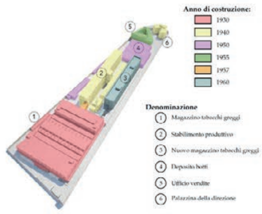
Table 1 | Criteria for intervention related to constraints.

Constraints	Description	Criteria of intervention
Geometrical	Height of floors, distance between vertical structures	small modular solutions
Operational	Containment of additional loads on the existing structure	• use of light elements • analysis of the interface between the modules and the existing building
	Reduction in installation time	• use of a high level of prefabrication • installation of dry elements
	Ease of transport	

Building 01 - Tobacco warehouse (1931)

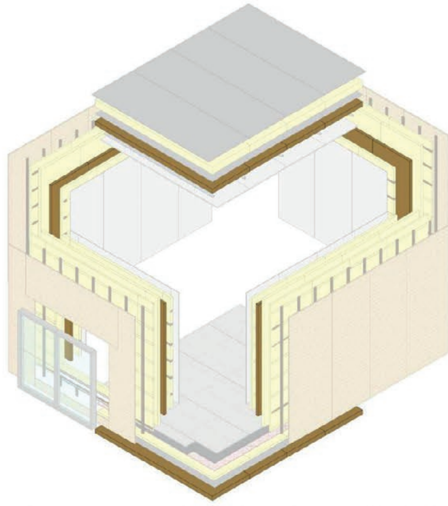


Cross section, 1931 (Archivio di Stato di Verona)



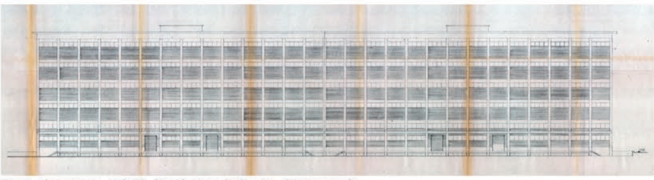
Interior view of the main building

Transversal amd cross section and internal view of the intervention

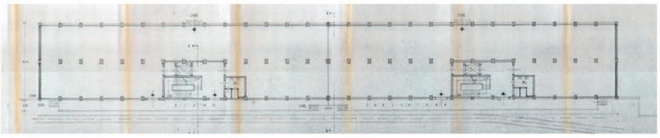


Axonometric exploded view of the module (*Cross Laminated Timber*)

Building 02 - New tobacco warehouse (1963)

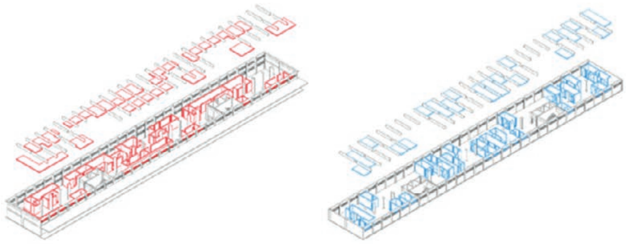


East elevation, 1963 (Archivio di Stato di Verona)

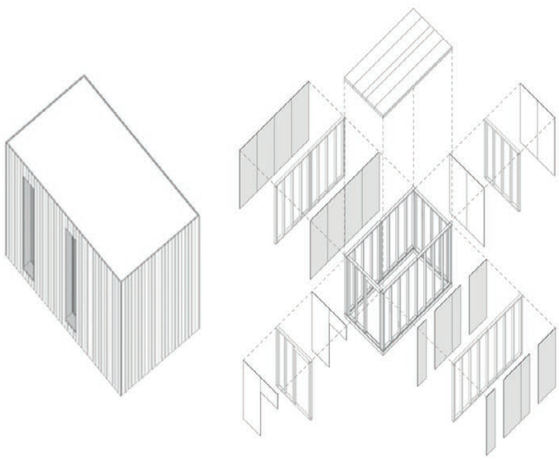


Ground floor 1963 (Archivio di Stato di Verona)

Interior view of the first floor



Axonometric exploded view with new function



Axonometric exploded view of the module (*Platform Frame*)

Figure 4 | Summary table of modules and their insertion in the two buildings of ex- Manifattura Tabacchi of Verona.

buildings. The dimensions of the module results from the need to respect the value between 4.00 m and 6.00 m that allows the placing of the volumes in the 80% of the cases, according to a transversal direction, and in 70% of the cases, according to the longitudinal one.

Starting from the basic module many aggregations are possible, articulating even complex spaces inserting even different functions.

Lightness and assembly criteria with "dry construction" technique (Fig. 4) allow to obtain high levels of adaptability, reversibility and limited, if not in many cases absent, structural reinforcement of the existing. This is due to the considerable remaining values of load-bearing capacity of industrial buildings, which may also foresee significant values of the range of 8-10 kN/mq, allowing to carry both the loads given by the new module and the variables loads for buildings open to the public (see NTC2018 and Circ. Min. for detailed variable actions).

The extensive buildings, on the other hand, are characterized by larger spaces with regular spans (5.87 m×4.92 m) and great interior heights. In the absence of such restrictive limitations as in the case of intensive buildings, it is possible to proceed with more engineered construction technologies, such as CLT (Cross Laminated Timber) by the use of panels with a maximum height of 2.95 m for a length of 4.88 m, a measure that fits into almost all industrial buildings of extensive type (Fig. 4).

In this case, the modularity and reversibility of the system is greater than the one of the "platform frame", because the CLT is a more prefabricated and standardized technology and allows easy future relocation following new customer needs.

7. The case study: the ex-Manifattura Tabacchi factory in Verona

To validate the intervention criteria found, a representative case study of the "building type" has been identified. This is the ex-Manifattura Tabacchi factory of Verona, an industrial building complex built between 1931 and 1965. It is located within the "Zona Agro-Industriale" (ZAI), south of the historic centre. The validation of the "on site" research involved two buildings with different uses: the new tobacco warehouse and the raw tobacco warehouse (Fig. 4).

The first one, characterized by a rectangular plant of dimensions of 112.5 m×15.00 m, was built between 1963 and 1965. The design was carried out by the Technical Office of the State Monopolies. It is 25.00 m high having five floors; its structure has 29 longitudinal spans made by reinforced concrete frames at a distance of 4.00 m, as well as two transverse spans of 7.10 m.

The second, consisting of three buildings connected functionally to each other is the warehouse of raw tobacco, designed and built between 1931 and 1932 by the company Siderocemento in Milan with the advice of Eng. Arturo Danusso. The central hall is characterized by fourteen 24 m-span r.c. portals with composed trusses spaced out 12.00 m. Constructively the central building has joints to the perimeter and is therefore structurally independent from the two lateral ones.

Considering the dimensional parameters of the second extensive factory building, the oldest, it was most useful to insert modules in CLT. The functions provided are mainly catering and restaurants of different types; the individual activities are articulated through several connected modules. The layout is therefore according to the modules themselves and to the geometries of the vertical internal structures so as to form a non-linear path, alternative to the longitudinal direction of the nave. The choice of commercial, restaurant and sales activities was also dictated by the presence of the double height, thus enhanced (Fig. 4).

In the most recent intensive building, the wooden frame was used because of the smaller geometric dimensions of the spans. The design hypothesis has provided for a single module that can be aggregated in different configurations that could accommodate multiple functions with a tourist-receptive, commercial and office vocation. The vertical development of the building and the possibility of controlling the access/exodus routes suggested the transformation of the building into an office structure, a solution also favoured by the possibility of giving each room at least one window.

The modules with more articulated functions have been inserted on the ground floor to take advantage of the greater height of the decks and spans with their planimetric dimensions of 3.50 m×6.00 m and under-beam height of 5.10 m.

In the four upper floors, with a free height of 3.10 m and a span of 3.50 m×6.40 m, "typological" planimetric configurations (low and high density) were provided. The single module is positioned with the major axis perpendicular to the façade. The aggregation of the elements occurs only parallel to the smaller sides, the direction in which the central pillars are less binding.

The office modules have been designed in such a way that they can vary their size depending on the increase or contraction of demand, taking advantage of the completely "dry construction" that allows quick insertion and reuse.

8. Conclusions and future developments

The nested building construction technology is proving a great potential if we consider parameters such as reversibility, economy, execution speed and respect for the building to be reused.

The research – still in progress and illustrated here – proved that this approach can be very useful into industrial reinforced concrete buildings of the 20th century. The critical analysis of the main and recurrent features in these buildings allowed to define two different strategies to be used in the project of reuse of intensive and extensive industrial buildings.

Some intervention criteria were thus defined and validated by means of an operative research in the case study, provided by the ex-Manifattura Tabacchi factory in Verona.

The main result achieved at the methodological level was the definition of the logical framework within which the different design scenarios were developed: from research on industrial building types and construction techniques of reinforced concrete, to the analysis of the case study, its geometric and functional problems and the development of design solutions. To achieve these objectives, two "light" and "dry" construction systems have been used, allowing the creation of low-weight modules capable of provide high levels of adaptability to the structure and possible changes of use, with potential benefits in terms of economic sustainability.

The validation of guidelines on the Tobacco Manufacturing has also provided specific indications on possible future developments, such as the deepening of further energy and economic aspects of the building/modules system. The final aim will be to verify if the hypothesis underlying the "nested building" system, that is the insertion of new high-performance volumes, can become the effective way to guarantee comfort levels without refurbishing the entire existing building thus ensuring a significant reduction in costs.

On a more general level, the research gives thoughts to build buildings –industrial or not– with particular attention to the Circular Economy. The traditional approach to the issue of reuse through demolition and reconstruction is opposite the more innovative one related to assembly and disassembly. Architectural and functional renovation must be realized in a context in which the buildings –especially the 20th century ones– must be considered as a new territory "to be re-established and re-used".

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