Textile mills in Friuli (XIX-XX century).
Building technique analysis and seismic refurbishment

Giorgio Croatto, Angelo Bertolazzi*, Umberto Turrini

Highlights

The paper analyzes the building techniques used in the Friulian textile industry buildings (XIX and XX century), identifying the most reversible technological solutions, to improve the behaviour of the buildings in the event of an earthquake. This led to identify criteria and guidelines to be applied to all the interventions meant to prevent seismic risks, assessing within new cultural coordinates the problem of the relation between the built environment sites to be safeguarded and the present-day requirements to be met, i.e. the the preservation as well as economic sustainability.

Abstract

The conservation of industrial architectures and the refurbishment project, must take into account the growing attention to the seismic risk of the built heritage, which the recent events of central Italy have made dramatically current. The different constructive nature and structural behavior of industrial buildings, impose a different approach, combining the new functional needs - and therefore the safety of the building - with its conservation as a testimony for future generations. The work focuses the Friulian textile industry buildings (XIX and XX century), studying their constructive techniques and idenfying some guidelines for the refurbishment.

Keywords

Industrial architectures, Seismic risk, Construction techniques, Refurbishment, Reversibility

1. INTRODUCTION

For about thirty years industrial buildings have been regarded as belonging to a country’s cultural heritage. Their versatility allows them to be suitable for new uses, which – together with their role as landmarks in modern culture – has made their refurbishment viable wherever interventions have proved vastly more feasible than in pre-industrial buildings.

In the past few years, refurbishment buildings belonging to industrial archaeology [1] has therefore taken on both a national and international relevance, both from a theoretical point of view and project-related practice. Studies have underlined the cultural role of such inherited buildings as evidence of the social, economic and material transformations underlying contemporary society [2]; moreover, refurbishment projects have emphasized
the potentials of abandoned industrial sites, making their refurbishment profitable from several points of view [3]. In particular, it has proved to be economically rewarding to involve in the project both old retrieved and newly-built buildings [4], so that their life-span can be extended [5]. This may lead to better environmental sustainability [6], not only limiting demolition waste materials and reducing CO2 emissions, but also getting land reclamation under way and curbing soil consumption [7].

Knowing construction-related aspects, the materials and laying down techniques is the starting point of any refurbishment project [8]. In particular, the hybrid character of industrial archaeology deriving from the presence of modern materials (such as cast iron or reinforced concrete) coupled to traditional ones (mainly brick and wood) requires a purposely-devised inquiry into the building systems and the materials and how they will interact should an earthquake occur. From this point of view, the Umbria and Marche (1997), Abruzzo (2009), Emilia (2012) and Lazio (2016) earthquakes have underlined not only how vulnerable our Country’s monuments and historical centers are, but also how necessary it is upgrade our boundless cultural heritage so as to enforce seismic risk measures that will be applied also to industrial archaeology, by which we mean both not yet retrieved buildings and the newly-used but not yet upgraded ones [9].

The paper aims to analyses buildings considering their several components – related to materials, to construction and to structure – focusing on textile mills set up in Friuli between late XIX and early XX centuries. Such analysis has been the instrument leading to laying down criteria and guidelines underlying refurbishment and reuse interventions of our wealth of industrial archaeology in Friuli; they will allow to take on new roles in perfect safety, totally preserving the historical value of the buildings, with particular regard to the economic sustainability of the intervention. The case study proves relevant as far as seismic prevention is concerned, since Friuli is not only a high-risk area – sorely struck by the 1976 earthquake – but has also been in the forefront in passing a bill aimed to retrieve and upgrade its industrial archaeology heritage [10].

2. TEXTILE INDUSTRY IN FRIULI: DEVELOPMENT AND REFURBISHMENT

Within the framework of industrial development in Friuli, the main role has been played by the textile industry, as far as both production and architectural relevance are concerned [11]. Its development dates back to the 1850s, when even this area saw the step change from craft to industrial production,
featuring serial, mostly machine-produced. This change is typical of the Second Industrial Revolution and involved several areas of production. Even as far as textile industry is concerned, such transformation was enacted by entrepreneurial bourgeoisie that – seizing the opportunities of making money it afforded – invested large capitals, so furthering the development of industrial production. The change entailed the need to set up new buildings, especially for cotton textiles, which required purposely-meant, planned for industrial production buildings; on the other hand, silk goods were often produced in rural existing buildings.

Towards the end of the XIX century, the increase in capitals and investments in the Friuli textile industry led to defining a new industrial architecture, meant to achieve mass-production at the lowest possible cost and in the quickest possible time: spaces were planned rationally in order to optimize production times, while buildings were increasingly economic and fire-resistant, so as to guarantee continuous production [12]. To this phase, between 1840 and 1901, belong the great cotton mills: Beloz and Blanch at Torre di Pordenone (1840), Rorai (1846), the large Amman and Wepfer cotton mill at Borgo Meduna (1875), the Società Anonima Cotonificio Udinese at Comor (1884), followed by the Ancona mill (1888), the Morganti mill at Gemona (1900) and finally the last mill, Mako’ at Cordenons (1902).

The Friuli cotton mills reveal an underlying problem that they share with industrial archaeology and is related to the refurbishment project. In spite of their acknowledged cultural value as evidence of the social and economic transformations between the XIX and XX centuries, whose effects are still felt today, the refurbishment of the industrial heritage proves still difficult. Beside environmental problems (toxic waste disposal, cleansing soil and water) and achieving new functions (finding activities capable of making the intervention economically sustainable while preserving the features of the trasformazione è stata promossa dalla borghesia imprenditoriale, che, cogliendo le possibilità di profitto da questa attività, investì ingenti capitali agevolando così la trasformazione dalla produzione artigianale a quella industriale. Questo comportò la necessità di predisporre edifici specializzati per la lavorazione, in particolare quelli del cotone, per la quale erano necessari nuovi tipi edilizi specificatamente progettati e costruiti con la destinazione d’uso di edificio produttivo, a differenza invece di quelli attualmente utilizzati per la lavorazione della seta che risultavano spesso l’adattamento di altri edifici rurali esistenti, come cascine o barchesse.

L’aumento dei capitali e degli investimenti nell’industria tessile friulana favorì, verso la fine dell’800 alla definizione di una nuova architettura industriale, che doveva rispondere con il minor costo possibile e nel minor tempo possibile a grandi esigenze produttive, i cui spazi erano progettati in maniera razionale per ottimizzare i tempi della produzione, mentre la costruzione era sempre più economica e resistenti agli incendi, quale garanzia per la continuità produttiva [12]. A questa fase, compresa tra il 1840 e il 1901, risale la costruzione dei grandi cotonifici: lo stabilimento Beloz e Blanch a Torre di Pordenone (1840), quello di Rorai (1846), il grande cotonificio Amman e Wepfer a Borgo Meduna (1875), quello della Società Anonima Cotonificio Udinese a Comor, (1884) seguito da un altro ad Ancona (1888), da quello Morganti a Gemona (1900) ed infine l’ultimo stabilimento, il
building), existing structures must be upgraded so as to suit their new roles and particular attention will be paid to their seismic resistance.

Earthquakes may destroy XIX and early XX centuries industrial buildings. Their hybrid nature, flimsy internal structures, the transformations they have undergone make refurbishment and refurbishment difficult and may lead to drastic interventions, even to substituting original construction elements with new systems.

On the contrary, a refurbishment project must as far as possible preserve architectural elements, structures and original materials unchanged, though refurbishment or improving them so as to withstand earthquakes. In order to achieve this, guaranteeing the preservation of existing buildings with a view to economic sustainability, it is necessary to reconsider industrial buildings from a construction-related point of view (materials and techniques) bearing in mind their seismic vulnerability – as it has been done for both monumental and common pre-industrial buildings - in order to lay down a sustainable and reversible refurbishment project.

3. FROM HANDBOOKS TO BUILDINGS: MATERIALS, TECHNIQUES AND TYPOLOGIES

Knowing material and construction-related features is the starting point of any refurbishment project. As far as industrial archaeology is concerned, its hybrid nature caused by the presence of modern materials (such as cast iron and reinforced concrete) side by side with traditional materials (mainly brick and wood) requires a specific assessment of construction systems, of materials and of their related behavior should an earthquake occur.

Comparing the analyses of the handbooks with the results of the case studies, it is possible to trace two main – chronologically well identified – types of buildings [13].

At first – up to the 1850s – the buildings had a rectangular plan, two or sometimes three floors above ground and their basic construction elements were: a metal internal weight-bearing structure (mainly cast iron columns), wooden floors and masonry (brick or stone-chips) perimeter walls. The construction systems and materials used in these early buildings were low-cost and their fire-resistance was scanty; in the textile industry the greatest danger was caused by the oils seeping through the wooden floors and by the large amounts of either raw or finished cotton within the buildings [14].

From the 1850s onwards, the investment of sizable capitals in the Friuli textile industry caused (as elsewhere in Europe) a quick transformation of work places both from a typological and construction-related point of view [15].
In this way a new industrial architecture came to be defined: it was to achieve targets of economy and efficiency even more than former industrial architecture. Though preserving the serial and repetitive features of the architectural elements, these later buildings generally had one or sometimes
two floors and their layout was functional to production, with well-defined construction features [16].

One-floored buildings were advisable for industrial productions liable to develop fires, or large amounts of particulate, as in textile production. However, this implied the need to optimize spaces, making the rooms larger and better equipped according to the principle of the shortest route [17]. The typical plan – a regular rectangle – where most of the space was taken by the weaving room, with the looms were placed along regular rows [18]; on either of two of its sides there were service spaces (offices, engine rooms, conveniences, storage rooms for raw materials and finished goods). The weaving room received light from above thanks to its shed ceilings, with either wooden or metal elements, later also reinforced concrete elements.

Particular attention was paid to the placing of vertical (generally cast iron columns) structures. They constitute a typical feature of textile mills, in Friuli, as elsewhere in Europe: resorting to them, in fact, not only allowed to optimize the relation between form, material and resistance, but even a further reduction of costs, since they could be turned out through serial production. Inside the sheds, several cast iron columns supporting the ceiling were placed at regular intervals: their positioning was not at random, being strictly dependent on the size of the mill and of the looms, as well as the kind of productive process. Comparing the case studies with the handbooks of those times, one can notice the correspondence between measurements, placing, and above all construction-related criteria. In the case study examined, this modular pattern is kept in the four-sided plan of each section: the plan develops longitudinally, owing to the functional role of each successive section. Beside the functional pattern of textile factories, another typological pattern was applied to their construction-related features, resulting from widespread employment of new materials, such as cast iron and iron [19].

The vertical structures generally consisted of cast iron columns. Their stems were hollow, generally 2.50–3.00 m. high, 2-3 cm. thick, their sections varied between 140 and 200 mm, and had a 20-30 mm. marked thickness. Their capitals were provided with mantels where ledges were placed, while at the bases there were slabs connecting the columns to the foundation, generally consisting of a stone or concrete block, beneath the walking surface area. If the shed was higher, columns were split in two and co-axially joined by means of flanged joints secured by bolts or rivets; two-or-more-storied buildings were provided with harnesses or bridles that supported the main beams on top of which the floors were laid and with stems polished inside where the polished foot of each column was fitted and therefore held upright.

definire così una nuova architettura industriale, che doveva rispondere, ancora di più di quella precedente, a criteri di economia ed efficienza. Gli edifici della seconda generazione, pur mantenendo la serialità e la ripetitività degli elementi costruttivi, erano sviluppati generalmente su uno o due piani al massimo, assumendo caratteristiche costruttive ben definite e conformazioni planimetriche funzionali alla produzione [16]. Gli edifici ad un piano erano costruiti per quelle produzioni industriali facili a sviluppare incendi o lavorazioni con grande sviluppo di particolato, come appunto quelle del settore tessile. Questo implicava tuttavia l’esigenza di ottimizzare gli spazi, ampliandoli e rationalizzandoli secondo il principio del minor cammino [17]. Lo schema planimetrico tipo era costituito da un rettangolo regolare nel quale la maggiore parte dello spazio era occupato dalla sala di tessitura, che ospitava i telai su file regolari [18], e che era affiancata da due lati dagli ambienti di servizio (uffici, sala macchine, servizi, depositi per il materiale grezzo e quello lavorato). L’illuminazione della sala di tessitura era garantita da coperture ‘a capannone’ con elementi lignei o metallici, e successivamente anche in calcestruzzo armato.

Particolare attenzione veniva posta nella disposizione delle strutture verticali, quasi sempre colonne in ghisa. Queste rappresentano uno degli elementi caratteristici della filande, in Friuli, come nel resto d’Europa: il loro impiego infatti non solo permetteva l’ottimizzazione del rapporto tra materiale e resistenza, ma costituivano un elemento che era possibile fabbricare in serie, riducendo ulteriormente quindi i costi. L’interno dei capannoni era caratterizzato dal posizionamento modulare di numerose colonne in ghisa che sorreggevano la copertura a capannone, secondo un ordine che non era mai casuale, ma strettamente collegato alle dimensioni dello stabilimento e delle macchine, oltre che al tipo di lavorazione. Confrontando i casi studio con la manualistica dell’epoca si può notare una corrispondenza tra le misure, gli aspetti distributivi e, soprattutto per quanto riguarda quelli costruttivi. Nei casi studio presi in esame questa modularità rimane nella configurazione planimetrica quadrilatera dei singoli reparti, la cui successione funzionale da luogo ad uno sviluppo prevalentemente longitudinale. Accanto a quello schema funzionale dello stabilimento tessile, esisteva anche una tipizzazione riguardante gli aspetti costruttivi, quale frutto di un’intensa sperimentazione dei nuovi materiali, come la ghisa e il ferro [19]. Le strutture verticali erano quasi sempre colonne in ghisa, costituite da un fusto formato da un corpo cavo alto generalmente 2.50–3.00 m, dello spessore di 2-3 cm, mentre le sezioni erano di dimensioni contenute, variabili tra i 140 e i 200 mm ma con spessori marcati tra i 20-30 mm. All’altezza del capitello erano provviste di piani che servivano di base alle mensole, mentre nella parte inferiore era disposta un altro piatto che serviva a collegare la colonna direttamente alla fondazione.
The columns supported above all the large shed ceilings, affording the best lighting to the rooms below. Their wooden and iron structure was held up by continuous beams, in their turn supported by the columns, while some metal connecting rods and cast iron brackets made the overall system more rigid.

4. QUALITATIVE ASPECTS AND TECHNICAL CHARACTERIZATION: VERTICAL AND HORIZONTAL METAL STRUCTURES

As a logical-formal premise leading to the definition of guidelines for a possible methodological approach to late XIX century industrial buildings in a seismic context, based on unavoidable concepts – such as sustainability, reversibility and compatibility of the materials – construction-related technology needs to be thoroughly examined, with particular attention to geometric forms and the features of the materials: these factors, in fact, are to be deemed essential when interpreting global seismic behavior, since they may lead to quite noteworthy levels of doubtful static-performance-related results [20].

One should in fact be reminded how the essential, nay, basic assumption behind any refurbishment intervention (in the widest meaning of the word) ought to be the most thorough knowledge of the building object of the intervention. This can be achieved by means of a typological and material-related analysis carried out through well-known either non-destructive or semi-destructive multi-disciplinary techniques. When dealing with industrial buildings, their survey becomes more tricky, since the building techniques of those times were based on widely empirical-experimental methodologies of calculation, which were only partially known and analyzed and surely unsuitable for seismic prevention – an unavoidable issue nowadays. In particular, the research has focused on the analysis of some construction-related elements frequent in textile manufacture late XIX and early XX century buildings in Friuli, and quoted also in handbooks. The study has specifically dealt with internal cast iron vertical structures and with the generally wooden or metal shed roofs of the buildings, omitting the masonries that in such buildings consist mainly of brick and stone chips walls built by traditional techniques.

A first analysis, mainly based on the handbooks of those times [21], reveals the widespread resort to both simply hinged brackets on the ground gravity working that is to say capable of ensuring that the foot of the foundation would be kept in place only if subjected to axial stress, and to semi-fitted joints, - the forerunners of modern fastening elements such as cast iron stud bolts able to withstand – though partially – seismic compound stresses.

4. ASPECTI QUALITATIVI E CARATTERIZZAZIONE TECNICA: STRUTTURE METALLICHE VERTICALI E ORIZZONTALI

Quale premessa logico-formale alla definizione di linee guida per un possibile approccio metodologico al recupero degli edifici industriali di fine '800 in contesto sismico e che si basino su concetti cardine, quali sostenibilità, reversibilità e compatibilità materica, è necessario indagare la tecnologia costruttiva con particolare riguardo alle geometrie e alle caratteristiche materiche, fattori questi da ritenersi fondamentali nell’interpretazione del comportamento sismico globale, poiché in grado di generare aliquote di incertezza statico-prestazionale anche notevoli [20].

È necessario ricordare infatti come l’elemento fondamentale, nonché assunto basilare di ogni intervento di recupero nelle più svariate accezioni del termine, sia la conoscenza approfondita dell’edificio su cui si intende intervenire. Tale conoscenza trova attuazione mediante la attività di indagine tipologica e materica realizzata mediante note tecniche non distruttive o semi-distruttive di ambito multi-disciplinare. L’indagine sul costruito, nel caso delle architetture industriali, assume valenze di maggior riguardo poiché le tecniche costruttive del tempo trovavano fondamento su metodologie di calcolo ancora empirico-sperimentali, non ancora sufficientemente conosciute ed indagate e certamente non declinate in un contesto di prevenzione sismica, oggi così attuale.

La ricerca si è svolta in particolare sull’analisi di alcuni elementi costruttivi ricorrenti nelle architetture dell’industria tessile friulana tra ‘800 e ‘900 e presenti nella manualistica. In particolare sono state indagate le strutture verticali interne in ghisa e la copertura a shed dell’edificio generalmente lignea o metallica, traducendo gli interventi, eretti con tecniche ancora tradizionali in muratura di laterizi e pietrame.

Una prima analisi, fondata principalmente sulla manualistica dell’epoca [21], evidenzia il diffuso utilizzo sia di attacchi a terra a semplice corniera funzionanti a gravità, ovvero in grado di garantire il ritegno al piede della fondazione esclusivamente nel
On the other hand, from a geometrical point of view, the cast iron weight-bearing columns present rather thin sections if compared to the whole length of the columns. On average, their circular sections vary between 140 and 200 mm, though they are between 20 and 30 mm thick, being made of cast iron. Flanged joints secured by bolts all around may be present, wherever there are in-between floors not allowing the floor to be directly secured to the column, or there are construction related or building yard hindrances such as not having easy access to the site or needing to move the element.

On confronti di sollecitazioni assiali che di connessioni a semi-incastro, precorritrici dei moderni ancoraggi con tirafondi – inghiostati o meno – e in grado di confrontarsi, seppur non esaustivamente, con sollecitazioni composte derivanti da azioni sismiche. I pilastri portanti in ghisa, dal punto di vista geometrico, presentano invece sezioni piuttosto esili se rapportate agli alzati a cui si riferiscono. Medianiamente sono costituiti da sezioni circolari di dimensioni contenute e variabili tra i 140 e i 200 mm ma con spessori marcati (20-30 mm) trattandosi di ghisa. Possono essere presenti giunti flangiati bullonati di continuità qualora si presentino

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**Figure 5.** a) The base of the column resting on a weight-spreading metal plate (B) on top of a squared stone block (D) lying on a mortar-concrete substrate [Oslet 1898]; picture taken during a probe; various kinds of ground fastening [Oslet 1898].

**Figure 6.** a) Detail of the connection of the column outside the column-floor joint [Oslet 1898]; b) and c) detail of the connection of the column inside the column-floor joint [Birkmire 1892, Curioni, 1896].

**Figure 7.** a) Section of the roof employing non-standardized profiles, where the connecting rods of the horizontal plane of the roof can be seen [Oslet 1898]; b) columns detali [Oslet 1898]; c) shed ceiling Anman & Wepfer mill (Pordenone).
Thanks to the cast iron capitals, the weight-bearing columns support roof elements named shed. As regards the material used, one can notice how the construction technique of those times largely resorted to thin metal frames, which were either normalized or simple metal profiles of non-standardized sections. Trusses were connected to the columns underneath by means of cast iron capitals, horizontally connected to one another between each span by means of chain tie-beams that compensated the geometrical thrust.

In order to achieve an architectural and structural refurbishment it is necessary to take into account that the buildings handed down to us have been subjected to several transformations that have sometimes dramatically changed their original features, impairing the initial balance – as regards both function and structure.

For example, in industrial buildings the addition of in-between floors on the one hand improved the overall statics of the building by making the abutments more stable and reducing the unchecked length along which the thin columns might bend, on the other, it meant adding suspended masses that modified barycenter and rigidity, which consequently modified the “cutting plates” at the base of the columns that by the way were not secured by foundation stays or beams. To this it should be added that the new ceiling joists are sometimes given functional roles, which implies the presence of new accidental – almost lasting for ever – loads, whenever such buildings are turned into museums or libraries. Such transformations in themselves therefore (whenever they do not fit the context of the areas where the buildings rise) may potentially increase the destructive risks of seismic events. This is why it is necessary to underline the role of the preliminary analysis – regarding both the geometrical features and the materials – it is meant to define realistically the features and the residual strength that the weight-bearing elements may afford in relation with both the decay of the materials and the existing structural features [22].

5. CRITERIA AND GUIDELINES OF INTERVENTION IN INDUSTRIAL ARCHITECTURE

Proceeding further to study industrial buildings in a seismic context in Friuli, therefore, some qualitative considerations can be formulated in order to spot general criteria of intervention that may safeguard the original identity of the building, with a particular regard for architectural and structural invariants, exemplified by the capital-column, by the geometries of the joints, and by existing structural patterns.

Concerning “shed” roofs, we notice that they consist of rather short metal
elements – supporting ribs – that make up triangular-shaped typological sections affording structurally counterpoised thrusts by means of connecting rods placed at the base of the capitals. Such structures are placed at regular distances: their presence can be noticed when openings occur and there is no plaster, so the sloping profiles frame even functionally the glass-covered openings. In this way the thrust of the roof is compensated by means of connecting rods placed on the extrados of the capitals, whereas the metal beams of the roof – in the same way as the deck ribs in a ship – define its triangular geometries and are visible wherever the glass-covered openings occur.

A first approach to the construction-related methodology of slopes reveals both positive and negative aspects: as regards suspended masses and the ensuing accelerations the structure undergoes, historical roofs are quite similar to today’s. Formerly were employed rather thin metal elements together with thick roof cladding (ridge tiles or tiles having a 40 kg/sqm specific weight), nowadays, however, we resort to heavy prefabricated concrete structures and thin layered polystyrene roof cladding.

A certain analogy can be detected as far as masses are concerned, but, on the other hand, no comparison can be made regarding behavior in relation to seismic events. In historical roofs, in fact, wind bracings are completely absent along metal slopes, which, moreover, feature parallelogram-shaped geometries that are clearly liable to deformation. Besides, taking into account the possible upwinding action enacted by the horizontal plane intersecting the capitals, the presence of mere connecting rods between the capitals is not sufficient to guarantee wind bracing.

Moving on to examine the stresses on columns and capitals, the problem lies in evaluating how far the capitals are capable to guarantee the firm fitting of the two longitudinal cross-beams supporting the slopes. After pointing out that the assessment will have to be backed by careful calculations, it is anyway to be reasonably supposed – considering the type and the size of the connection at the joints – that even in this case a correct stabilizing wind bracing action of the structure – should an earthquake occur – cannot be guaranteed.

At last, if some considerations regarding the features of the material (i.e. cast iron) employed for the capitals are to be made, it cannot be said beforehand whether it is necessary to upgrade the capitals, without carefully analyzing both the material and the structure of the building. This can be easily understood taking into account both the period in which such cast iron elements were produced (the techniques and thee controls cannot be compared with present-day ones) and the elastic-fragile behavior typical of cast iron, a material that

presenti. Entrando nel merito della copertura “a shed” si nota come la stessa sia realizzata, come già accennato, da elementi metallici di ridotta altezza – centine – a formare sezioni tipologiche triangolari, ai spinte strutturalmente “compensate” in corrispondenza del capitello mediante tiranti. Queste strutture si ripetono ad interasse regolare denunciando la loro presenza in corrispondenza delle grandi finestre dove il rivestimento si interrompe e rimangono in continuità i profili inclinati a limitare anche funzionalmente le specchiature vetrate. In questo modo le azioni spingenti della copertura vengono compensate mediante tiranti metallici posti all’esterno dei capitelli, mentre le travi metalliche della copertura, a guisa di centine di tolda di nave, definiscono le geometrie triangolari della stessa e si rivelano in corrispondenza delle grandi aperture vetrate. Queste centine sono mutuamente collegate e dal piano della falda, da tiranti metallici costituiti da barre imbullonate. Una prima considerazione sulla metodologia costruttiva dell’elemento falda denuncia sia aspetti positivi che negativi. Per quanto riguarda le masse sospese e le conseguenti accelerazioni della struttura, la copertura storica è molto simile a quella che si impiega oggi. Se nel primo caso infatti venivano impiegati elementi metallici di ridotto spessore insieme ad un manto di copertura pesante (coppi o tegole con peso specifico di circa 40 kg/mq), nel secondo caso è previsto l’utilizzo di pesanti strutture in calcestruzzo prefabbricato con manti di copertura leggeri a sandwich di polistirene. Se per quanto riguarda la masse si rileva una certa analogia, per quanto concerne la risposta sismica la situazione non è comparabile. Nel caso delle coperture storiche i pavimenti mancano integralmente controventi nel piano della falda metallica che presenta altrettante geometrie “a parallelogrammo”, suscettibili quindi di evidenti deformazioni. Considerando, inoltre, la possibile azione controtentatrice a livello del piano orizzontale interscambiante i capitelli, la presenza di semplici tiranti posti tra capitello e capitello non è anche in questo caso sufficiente a garantire la necessaria controventatura. Passando ora a considerare le sollecitazioni sulle colonne e sui capitelli, la problematica è insita nella valutazione del grado di incastro che il capitello è in grado di garantire con le due travi banchina longitudinali che sorreggono le falde inclinate. Premesso che tale verifica dovrà essere effettuata da idonei calcoli, si può comunque ragionevolmente ipotizzare, considerando il tipo e la dimensione della connessione presente nel nodo, che anche in questo caso non si possa garantire la corretta azione stabilizzante di controvento della struttura per le azioni di sisma. Volendo infine svolgere anche alcune considerazioni qualitative in merito al materiale usato per i capitelli, ovvero la ghisa, in questo caso non si può stabilire a priori senza una attenda indagine materica ed analisi strutturale locale, se sia o meno necessario intervenire sui capitelli.
requires a careful evaluation of possible plastic deformations. After such premises, a clearly detailed evaluation appears necessary, otherwise a quite serious amount of incertitude might mar the results of the assessment of the joint.

If, therefore, this paper aims to lay down guidelines for a possible methodological approach to retrieving XIX century industrial buildings, all proposed interventions should follow sustainability, reversibility and compatibility criteria. It is to be remembered that the concept of reversibility of the materials employed or of the interventions carried out is underlined in all norms and rules, such as for example Ministero per I Beni Culturali “Carta del rischio del Patrimonio culturale” (1955) and the Decreto Legislativo 22/11/2004 n° 42, “Codice dei beni culturali e del paesaggio” that defines guidelines, technical norms, criteria and models of intervention for programmed maintenance.

Following the above considerations, therefore, and taking into account the fact that the structures of such buildings undergoing the stresses of non-symmetrical loads caused by a seismic event are not wholly capable to perform suitably, mainly owing to the lack of wind-bracing elements and to box behavior, the intervention guidelines are suggested below:

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<th>Ambit</th>
<th>Interventions</th>
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<tr>
<td>Roof geometry</td>
<td>placing wind braces on top of the metal structures, choosing either:</td>
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<td></td>
<td>- the surface of the slopes by means of either salitre-shaped connecting rods using as compressed springs the existing purlins, or coupled crossed boards screwed to the underlying metal structures;</td>
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<td></td>
<td>- the plane of the horizontal connecting rods of the capitals by means of new wind bracing horizontal salitre-shaped elements realized through connecting rods that connect the capitals to one another;</td>
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<td>joint between capital and columns</td>
<td>realizing wind braces:</td>
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<td>- reserving either to truss bridges set at the level of the capitals (which is less disruptive)</td>
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<td></td>
<td>- reserving by means of traditional salitre secured between a capital and the foot of the opposite column ( which is quite invasive and might cause functional problems since they completely forbid crossing from one span to the next along the whole way between two or more columns).</td>
</tr>
<tr>
<td>Moreover, if truss bridges are set at the level of the capital, it will also be necessary to statically test the column in order to assess the new horizontal stress induced by the downward thrust of the truss bridge. On the other hand, if the latter intervention is chosen, a further test should be carried out on whether the column foundation ground fastening (in addition to the stresses along its axis the new structural system has obviously increased) is capable of absorbing even the added horizontal stresses at the joint that might suggest to report to short props to ensure balance or to foundation beams in order to connect the weight bearing columns to each other.</td>
<td></td>
</tr>
<tr>
<td>walls</td>
<td>test whether the inside walls are capable of absorbing the stresses caused by the slopes; if needed, metal chain ropes – even within the thickness of the walls – will be placed, so as to enable them to withstand the possible action of tensile stress;</td>
</tr>
<tr>
<td>metal elements</td>
<td>analysis by means of special tests (Brinell hardness, etc.) of the type of material employed and of its present conditions, in order to move on to in situ resistance tests;</td>
</tr>
</tbody>
</table>

Figure 8. Synthesis table resuming parameters and guide lines related to different fields of intervention.

6. CONCLUSIONS

The survey of the plans of the buildings, as well as of the features of the materials employed in the buildings of the case study – even in the light of what can be gathered by examining the technical handbooks – has provided the ground leading to defining possible guidelines for their refurbishment in an area liable to seismic events, according to mandatory criteria of sustainability, reversibility and compatibility of the materials, which are capable of preserving the original layout of spaces of industrial buildings. Particular attention must
be paid to the geometrical patterns, to the features of the materials, as well as to the transformations undergone by buildings: these are essential aspects when interpreting their global seismic behavior, since even serious doubts may arise concerning their statics and performances.

When dealing with industrial buildings, the analysis of existing buildings is in fact more relevant, since the construction techniques of past times were based on largely empirical-experimental calculations, that did not take seismic risk into account, which is of paramount relevance nowadays.

7. REFERENCES

[8] In Italy interventions on existing buildings are regulated by the NTC of 2018 (New Technical Standards for Construction, Decreto Ministero Infrastrutture 17/1/2008), where the levels of knowledge (LC) have been included. They’re based on the knowledge of the building (geometric, material and structural components), allowing to have the factors of confidence and therefore to plan the recovery interventions.
[10] Legge n. 24 del 25/7/1997 (Norme per il recupero, la tutela e la valorizzazione del patrimonio archeologico industriale della regione Friuli Venezia-Giulia).
XX secolo, Udine: Del Bianco Editore.


[22] Referring to the New Technical Standards for Construction NTC2018, it should be noted that it is preferred to reach levels of knowledge of the building as complete as possible, to allow the project of not overestimating structural interventions and correctly contextualised to the real state of the places.