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IJSC aims at publishing original scientific contributes in the field of sustainable construction and built environment.

IJSC core and innovative subject is the thematic of building sustainability beyond environmental issues, thus bridging also with cultural, social and economic aspects of sustainable development.

The conceptual basis upon which this Journal stands is precisely that sustainability in building construction is a result of relationships between a complex set of variables, the analysis of which requires complementary approaches.

Within this focus, IJSC seeks for original contributions from academics, scholars and researchers who pursue a broad perspective on the subject, placing buildings and sustainability at the core of their research.

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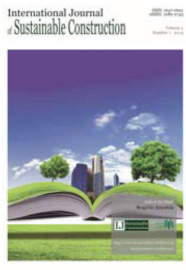

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Editorial

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The editorial –in-Chief would like to express sincere gratitude to all contributors and participants of the 2nd issue of the International Journal of Sustainable Construction (IJSC).

This second issue of the IJSC is dedicated to REHAB 2014- International Conference on Preservation, Maintenance and Rehabilitation of Historical Buildings and Structures and includes a selection of the best papers bringing together sustainability and historic buildings preservation.

Preservation of historic buildings and building sustainability comprises a complex relationship where principles of cultural significance and authenticity that may collide with technical interventions that aim to improve the sustainable performance of such buildings. Questions such as energy efficiency and use of new materials and technical systems emphasize the care that architects and other technicians must have on developing rehabilitation solutions for historic buildings.

Until now, few literature was published on this subject, showing that is important to give attention to this relationship. Therefore, the second issue of IJSC Journal wants to give an overview of some results of the research and that is being developed at international level in this field of study: "Certified sustainability for heritage buildings: development of the new rating system GBC Historic Building™"; "Structural repair of decayed old timber end beams"; "Sustainable networks in the rehabilitation of built historic heritage"; "Accessibility of urban spaces: analysis and solutions to make sustainable historical towns"; "Pull-down test of the rammed earth walls at Paga Lhakhang in the Kingdom of Bhutan"; "Basalt ropes: a new product for the rehabilitation of historical masonry"; "The need to link the tangible with the intangible: the challenges of infinite design life and perpetual maintenance"; "In-situ monitoring of thermal refurbishment on pre-1919 properties in Scotland".

The research and development in the fields of applying sustainability approaches to historic buildings is still a field of study where much is still to be done, being important that discussion and research on this field goes even further due the complexity of this subject.

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Certified sustainability for heritage buildings: development of the new rating system GBC Historic Building™

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The identification of historical value must be an integrated part of a sustainable building process aimed at the preservation and enhancement of its all previous expressions with the ultimate goal of identification, enhancement and transmission of the cultural heritage to the future generations. Green Building Council Italia is moving within this cultural context with the main goal, developed through an interdisciplinary working group, of the establishment of a voluntary certification protocol aimed at evaluating the sustainability level of restoration, refurbishment and partial integration in pre-industrial buildings. The paper presents the new rating system *GBC Historic Building*™ starting from the identification of the protocol's field of application and moving to the new topic "Historic Value", introduced with the goal of improving the building's sustainability level without compromising its cultural value. The paper also shows the innovations added throughout the new protocol and the contribution of the first registered case study.

Introduction

Existing buildings with historic and testimonial value represent a significant asset in Italy (Fabbri, Zuppiroli and Ambrogio, 2012, p.139). The improvement of existing building's performance, by deep renovation or operational strategies, is also a priority set by the European Community through the directives on energy efficiency (2012/27/EU). The actions of refurbishment and restoration of buildings with historical value have also to consider the need to preserve the related architectural and cultural aspects that characterize them. In order to achieve these goals, appropriate tools capable of leading operators in the building industry are needed.

The rating systems evaluating buildings level of sustainability are intended to respond to the needs by defining requirements to be met, suggesting approaches and computational models to demonstrate the achievement. The main contents addressed by these rating systems deal with sustainability of the sites, water efficiency, energy saving and performance optimization, indoor environmental quality, materials, waste management, both during construction and operation phases, and reduction of environmental loads.

To conjugate restoration/refurbishment actions for maintaining historic buildings and their related cultural and historical meanings still constitutes an open challenge. The Italian Green Building Council (GBC Italia) is now working to promote a dialogue between two areas that have always been highly diversified so far: the sustainability criteria of LEED® and the knowledge of the world of restoration, for which Italy plays roles of excellence in the international scenario.

A new rating system: *GBC Historic Building*™

GBC Historic Building™ is a new rating system for the voluntary certification of the sustainability level of conservation, requalification and partial integration of historic buildings, respecting and protecting their cultural value.

The choice of basing the development of the *GBC Historic Building*™ on the structure of LEED® (Leadership in Energy and Environmental Design) is related to the systemic approach that this internationally diffused rating system offers. The LEED® system approaches the building in a transversal way, developing thematic correlations between different aspects, which are framed within macro-areas. It is a set of rating systems for design, construction, operation and maintenance of green buildings.

In 2010, the Italian Green Building Council developed a local version of one LEED® rating system for New Construction and Major Renovation named LEED® Italia (GBC Italia, 2010). Although LEED® Italia is applicable to interventions of deep renovation of historic buildings, it does not include specific issues linked to the valorisation of historical and cultural aspects that the built environment might have. The new rating system is based on the type of building involved among the family of the existing products of GBC Italia for new construction (in particular the LEED® *Italia 2009 New Construction and Major Renovation and GBC Home* (GBC Italia, 2011)), progressively merge into a single product called *GBC Historic Building*™ (Fig. 1). The first one is used for residential building with more than four floors above ground or for commercial buildings, the second is only for low rise residential building (four floor above ground or lees). Basing on these two protocols, the final output of the process is a unique, specific and dedicated tool that covers all potential cases of restoration and refurbishment (Fig. 2).

Figure 1. Existing GBC Italia's rating systems as basis of the new protocol.

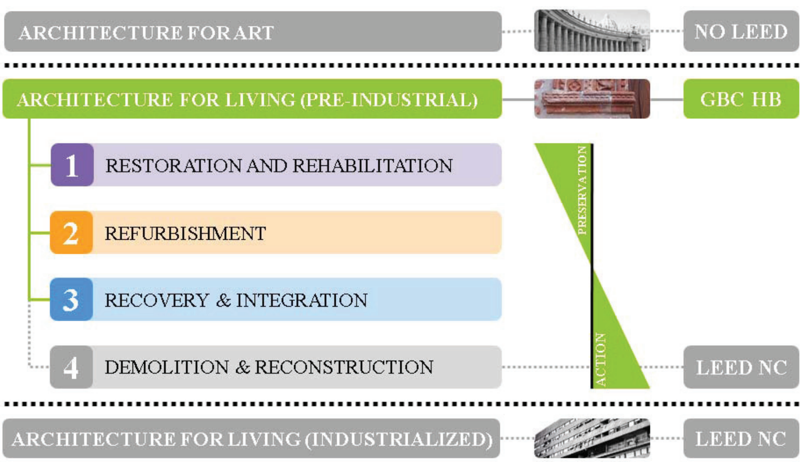

Figure 2. Design activities and type of buildings involved in the new protocol's field of application.

When to use *GBC Historic Building*™

GBC Historic Building™ is applicable to "historic buildings", meaning construction that are worthy of consideration as "material witness having the force of civilization" (Commissione d'indagine per la tutela e la valorizzazione del patrimonio storico, archeo-logico, artistico e del paesaggio, 1967). In this regard, the buildings that may fall within the scope of *GBC Historic Building*™ must be traceable within the last concluded historical cycle that, for the European zone, coincides with the industrialization of construction process and, therefore, must be built before 1945. These buildings have a pre-industrial building process (in terms of phases, tasks and operators), pre-industrial materials and construction techniques (spontaneous and local) and technical elements made through a pre-industrial processes (Dalla Negra, 2013).

The existing building (before refurbishment) must have been built before 1945 (or after 1945 if a pre-industrial building process is detached and there are historical and cultural recognized features) for a portion of at least 70% of the existing technical elements (measured in square meters of the front surface calculated without considering voids as windows and doors). If the building was built before 1945 for a portion of between 50% and 70% of the existing technical elements, the project team has the possibility to choose whether to use the protocol *GBC Historic Building*™ or, depending on the intended use of the building, LEED® *Italia 2009 New Construction and Major Renovation or GBC Home* (Fig. 3).

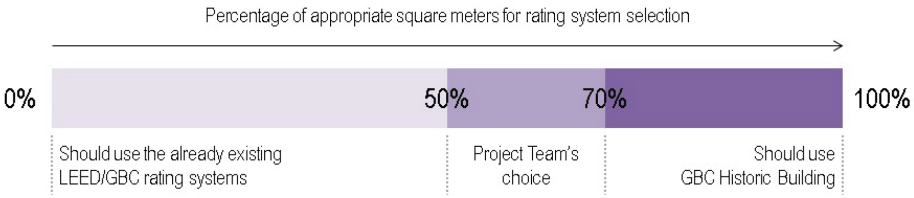

Figure 3. Guidance for rating system selection, basing on the square meters of the existing building surfaces.

Buildings object of the protocol application shall be subject to restoration, rehabilitation or recovery (also with partial integrations), which must implicate a major renovations, defined as actions that involve significant elements of HVAC systems and the renewal or functional reorganization of interior spaces, evaluating the possibility of the building envelope's performance improvement, consistent with the preservation of the existing building's typological and construction features.

In compliance with all the LEED®/GBC rating system, all aspects concerning architectural language (design choices) are not considered for the purposes of certification and, in case of buildings under protection or listed, they shall remain as exclusive domain of the governing bodies. In fact, the ultimate goal of the protocol is the definition of the level of sustainability of the intervention process, in the respect and protection of cultural and historical value, and not the verification of cultural interest of the object itself (Boarin and Zuppiroli, 2012, p.XXIV).

Existing building as historic building: a new tool

In order to verify whether the existing building can fall within the scope of *GBC Historic Building*™, a fact sheet called "Historic Building Identity Card" (HBIC) has been drafted. This tool contains qualitative and quantitative evidence of all the existing technical elements and information about which of these were made at a different historical stage from the current one (pre-industrial). The HBIC is given to the project team before the certification in order to verify if the building fits the protocol's fields of application and it is a key moment for an initial understanding of the building in its technical elements and historic value.

The HBIC consists in an Excel-based format divided into three parts to be filled with information about the existing building before refurbishment (Fig. 4). The qualitative data refer to the characteristics of the technical elements with historical nature that have cultural interest.

The first part of the sheet must contain all essential information that can help identifying the basic characteristics of the building, such as:

- climate zone, with indication of geographical coordinates;
- period/year of construction, with reference to the construction period of the original core (dating of additional transformations can be placed under item "historical overview" and, more specifically, under "time sequence list of building interventions");
- surrounding environmental setting, describing the type of context in which the building is located (isolated in a rural setting, in an urban setting; belonging to a medieval, renaissance urban fabric, etc.);

- consistency of the building (average height of the attics, total covered surface, overall gross volume, etc.).

The sheet also requires additional information concerning "urban parameters" and "regulatory constraints (degree of protection)" with special reference to the intervention categories provided by the technical implementation rules in accordance with current urban planning and any other active protection constraints on the building subject of the certification. After completing the basic information, a brief "historical overview" is required for identifying any important change stages that could have caused alterations to the original structure. Specifically, a summary list is required of construction interventions for which documentation is available.

In the second part of the sheet, basing on the UNI 8290-1 standard (UNI, 1981), the "Technological Unit Classes" described under "Technological Units" are identified. For each of these, identification of the "Technical characteristics" of the examined element is required. The description of the technical element must be sufficiently precise so that its typology can be qualified (for instance, masonry equipment with mixed facing with presence of different materials, in support of the decorative elements, with or without surface finish treatments). Subsequently, the origin of information must be clarified ("found/not found"). The description of the technical characteristics may in fact result from both past documentation and documents drafted during preliminary investigations. In case of no direct information, data to be put in the HBIC must come from studies and hypotheses concerning buildings with similar construction and typology. Lastly, the "percentage of historical/non-historical structure" must be identified for all technological units for which the technical characteristics have been indicated. The percentage of tech-nological units (e.g. external walls) should be approximately determined, which, as it is historical, is likely to be of interest in heritage terms. The percentage of technological units of an industrial nature is determined by difference, as, in contrast, it may not be of any interest.

Characterization of technological unit can be further specified by finding and tracking the "decorative architectural elements" (where present).

Once completed, the third part of the tool offers a preliminary assessment of the building, summing automatically the total amount of the existing technical elements that are present in the building (basing on the square meters of existing building's surfaces) and showing the final percentage that must be compared with the rating system selection scheme.

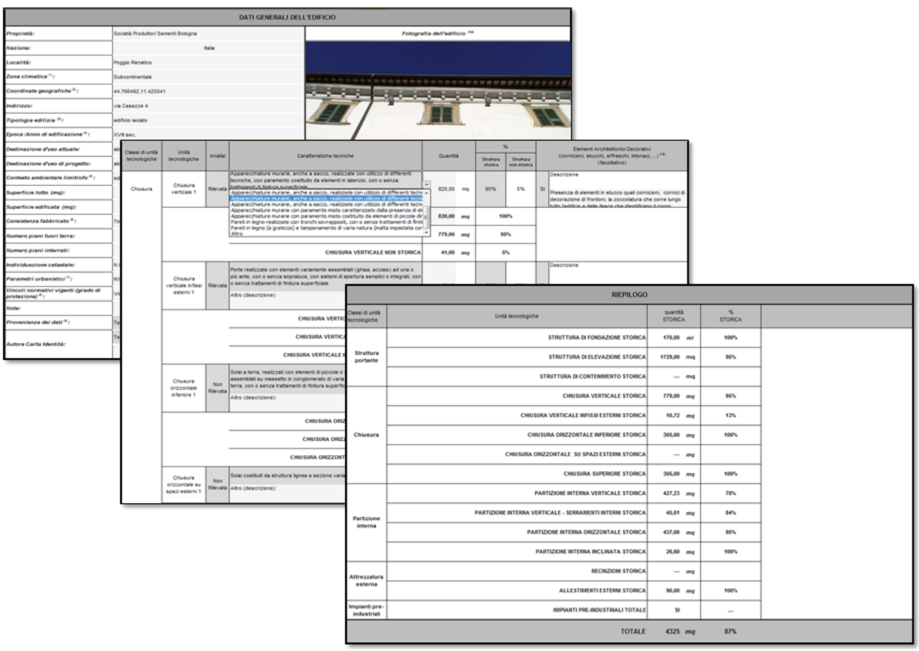

Figure 4. Screenshots of the "Historic Building Identity Card". Up: first part of the tool collecting general information of the building. Middle: second part of the tool collecting information about Technological Units, their features and measures (m2). Down: third part of the tool assessing the final percentage of historic building with cultural interest in order to verify protocol's requirements on fields of application.

Structure and main contents of *GBC Bistoric Building*™

In order to verify critical aspects of LEED® *2009 Italia New Construction and Major Renovation and GBC Home* in case of application to the historic heritage, a gap analysis process has been done through the application of the existing protocol[4] to three preliminary case studies[5], defining the following aspects:

- relevance and applicability of the existing rating systems (analyzing Minimum Program Requirements, prerequisites, credits and certification templates) in case of different levels of the conservative processes, in order to define strengths, weaknesses, opportunities and threats;
- possible modifications and integrations of the existing structure and contents, according to the seven themes that characterize the well-established LEED®/GBC protocols.

This analysis highlights that existing LEED® topics do not include specific issues concerning historic heritage renovation so that it was decided to add a brand new topic specific of the sustainable intervention in the conservation field, called "Historic Value" (HV).

The following paragraphs show all prerequisites and credits of each topic, highlighting points' allocation, exemplary performance credits and building phase in which all credits must be reviewed (design phase or construction phase review).

It is to be noticed that credits and weights are referred to the first part of the new rating system (related to *LEED® Italia 2009 New Construction and Major Renovation*) and that distribution of points among credits may vary basing on Technical Advisory Group "Historic Building" (TAG HB) further analysis and following the pilot period of application.

Topic Historic Value (HV)

The protocol lays its foundations on the transposition of the concept of sustainability to the conservative world. The restoration is sustainable because as "methodological moment in which the work of art is appreciated in its material form and in its historical and aesthetic duality, with a view to transmitting it to the future" (Brandi, 1963), it allows future generations to recognize the same cultural values that we recognize today (WCED, 1987). In particular, credits pertaining to the topic "Historic Value", through the identification of specific research methodologies and specific operational principles, seek to ensure that everything is recognized as "evidence having the force of civilization" and it is preserved for future generations, encouraging therefore high level of sustainability by taking advantage of the positive qualities of pre-industrial buildings.

Topic "Historic Value" pays close attention to the different stages of the restoration process, such as:

- the preliminary investigative stage. It is a mandatory step, without which it would be impossible to draft the project correctly and to estimate the executive intervention. It starts from a direct study of the building along with a background history research, followed by degradation analysis (with an interpretation of their causes);
- the project stage. It is the moment during which a detailed presentation of the building's critical issues are given and the intervention proposal is developed by taking into account needed performances and requirements and the conservation issues of the building itself;
- the construction stage. It is the key point of the intervention and it is the most delicate as almost every operation is irreversible and because the building always shows new "discoveries" when the initial demolition or removal begin. Naturally, the restoration site, which always includes conflicts with the initial project, requires wide experience and deep knowledge regarding materials and traditional construction systems.

Table 1. Credits overview of topic "Historic Value".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Prerequisite 1	Fundamental history structure report	Mandatory		-	D
Credit 1.1	Fundamental history structure report: energy analysis	1	3	-	D
Credit 1.2	Fundamental history structure report: analysis on materials and decay	-	2	-	D
Credit 1.3	Fundamental history structure report: analysis on structures and structural monitoring	2	3	-	D
Credit 2	Restoration process reversibility	1	2	Yes	D
Credit 3.1	Compatibility of final-use function and benefits	1	2	Yes	D
Credit 3.2	Chemical and physical compatibility of mortars for restoration	-	2	-	C
Credit 3.3	Structural compatibility	-	2	-	C
Credit 4	Sustainable restoration site	-	1	Yes	C
Credit 5	Scheduled maintenance plan	-	2	-	C
Credit 6	Specialist in restoration of buildings and sites	-	1	-	D

Sustainable Sites (SS)

This topic concerns the environmental aspects related to the place where the historical building is situated, with particular reference to the relationship between the building itself, the surrounding environment and the potential impacts that the building is capable of generating both in construction phase and in management phase or during its life. The objective of this area is the mitigation of damages resulting from a previous careless planning, which over time have generated negative effects on natural ecosystems and social systems in different ways.

The redevelopment of a building and its new functions can be an important opportunity to revive degraded urban sectors, introducing practices of sustainable design and management. It is important to stress the importance of a redevelopment compatible with the environmental context in which it is integrated, in order to prevent overload phenomena for infrastructure systems, resulting in increased pollution.

Table 2. Credits overview of topic "Sustainable Sites".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Prerequisite 1	Construction activity pollution prevention	Mandatory		-	C
Credit 1	Brownfield redevelopment	-	2	-	D
Credit 2.1	Alternative transportation: public transportation access	-	1	Yes	D
Credit 2.2	Alternative transportation: bicycle storage and changing rooms	-	1	Yes	D
Credit 2.3	Alternative transportation: low-emitting and fuel-efficient vehicles	-	1	Yes	D
Credit 2.4	Alternative transportation: parking capacity	-	1	Yes	D
Credit 3	Site development: open spaces recovery	-	2	Yes	D
Credit 4	Stormwater design: quantity and quality control	-	2	-	D
Credit 5	Heat island effect: non-roof and roof	-	2	Yes	C
Credit 6	Light Pollution Reduction	-	1	-	D

Water Efficiency (WE)

In traditional architecture, the topic of water management has been subject to variations related to the climatic zone the building belongs, defining collection devices and efficient management with great historical and cultural value, integrated with the building itself or placed in the immediate surrounding areas. Through the credits of this topic, in addition to the reduction of water consumption for civilian use, it is possible to enhance the contribution of pre-industrial devices for stormwater collection and management, through their restoration or renovation as well as improve the efficiency of fountains and other water amenities present in outdoor spaces.

Table 3. Credits overview of topic "Water Efficiency".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Prerequisite 1	Water use reduction	Mandatory		-	D
Credit 1	Water-efficient landscaping	1	3	-	D
Credit 2	Water use reduction	1	3	Yes	D
Credit 3	Water metering	-	2	Yes	D

Energy & Atmosphere (EA)

One of the innovative aspects of GBC Historic Building™ is the consideration that energy efficiency and retrofit process represent a means of protection of the historical building and not necessarily a change in the building's original material consistency (Boarin, Dotor and Onecha, 2014, p.13). This principle allows to overcome the logic that "excludes any work on properties falling under the regulations laying down the code of the cultural heritage and landscape, in cases in which a compliance with the requirements would unacceptably alter their character or appearance with particular reference to historical or artistic character"

(2010/31/EU). Topic "Energy and Atmosphere" includes the principle of building performance improvement compared to a reference condition, rather than an adaption to performance levels set and rigid (Ambrogio and Zuppiroli, 2013, p.101-104). In fact, in historical architecture, any improvement, although modest, is an important step in the direction of reducing energy consumption, reduced emissions of greenhouse gases and increasing comfort for occupants.

Table 4. Credits overview of topic "Energy & Atmosphere".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Prerequisite 1	Fundamental commissioning of building energy systems	Mandatory		-	C
Prerequisite 2	Minimum energy performance	Mandatory		-	D
Prerequisite 3	Fundamental refrigerant management	Mandatory		-	D
Credit 1	Optimize energy performance	1	17	Yes	D
Credit 2	Renewable energies	1	6	Yes	C
Credit 3	Enhanced commissioning	-	2	Yes	C
Credit 4	Enhanced refrigerant management	-	1	-	D
Credit 5	Measurement and verification	-	3	-	C

Materials & Resources (MR)

The restoration and upgrading processes are sustainable because reusing existing buildings is an important task for saving natural resources and virgin materials, as well as limiting use of soil that allows restraining the progressive extension of the cities' boundaries. Area "Materials and Resources" has the objective of ensuring that the project intervention is raised in continuity with the existing building, while preserving the material consistency as much as possible. In case of integration or partial replacement of technical elements, the topic aims at ensuring that materials have compatible characteristics if compared with the existing building.

Table 5. Credits overview of topic "Materials & Resources".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Prerequisite 1	Storage and collection of recyclables	Mandatory		-	D
Prerequisite 2	Fundamental demolition and construction waste management	Mandatory		-	C
Prerequisite 3	Building reuse	Mandatory		-	C
Credit 1	Building reuse: maintain existing technical elements and finishing	-	4	-	C
Credit 2	Demolition and construction waste management	1	2	-	C
Credit 3	Materials reuse	1	2	Yes	C
Credit 4	Products environmental optimization	2	4	Yes	C
Credit 5	Regional materials	1	2	Yes	C

Indoor Environmental Quality (IEQ)

The achievement of high standards of comfort for the occupants inside historic buildings can sometimes be very complex, due to the presence of decorations or to high artistic value of the building that does not allow any substantial interventions on the technical elements. For this reason, the topic is structured into two possible paths: on one hand the goal of conservation and preservation of historic architecture, on the other the fulfilment of occupants' conditions of comfort and indoor air quality. This dual approach allows user to respect the historic environment by protecting surfaces and high-quality materials and, at the same time, to achieve the highest levels of comfort and indoor air quality attainable, taking advantage of the potential offered by the boundary conditions.

Table 6. Credits overview of topic "Indoor Environmental Quality".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Prerequisite 1	Minimum Indoor Air Quality Performance	Mandatory		-	D
Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Mandatory		-	D
Credit 1	Environmental air monitoring	-	2	-	D
Credit 2	External air minimum ratio evaluation	-	2	-	D
Credit 3.1	Construction Indoor Air Quality Management Plan - During Construction	-	1	-	C
Credit 3.2	Construction Indoor Air Quality Management Plan - Before Occupancy	-	1	-	C
Credit 4.1	Low-Emitting Materials: Adhesives and Sealants, concrete materials and wood finishing	-	1	-	C
Credit 4.2	Low-Emitting Materials - Paints and Coatings	-	1	-	C
Credit 4.3	Low-Emitting Materials - Flooring Systems	-	1	-	C
Credit 4.4	Low-Emitting Materials - Composite Wood and Agrifiber Product	-	1	-	C
Credit 5	Indoor Chemical and Pollutant Source Control	-	1	-	D
Credit 6.1	Controllability of Systems - Lighting	-	1	-	D
Credit 6.2	Controllability of Systems - Thermal Comfort	-	1	-	D
Credit 7.1	Thermal Comfort - Design	-	1	-	D
Credit 7.2	Thermal Comfort - Verification	-	2	-	D

Innovation in Design (ID)

The objective of this topic is to identify design solutions that are distinguished by the characteristics of innovation and high environment performance developed during the preservation process. Rewarded aspects are excellence in design in case of performance that greatly exceed those required by the protocol itself or the particular characteristics of the project which, although not related to any prerequisite or credit, guarantee documented benefits in terms of sustainability.

Table 7. Credits overview of topic "Innovation in Design".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Credit 1	Innovation in Design	1	5	-	P/D
Credit 2	GBC Accredited Professional	-	1	-	C

Regional Priority (RP)

Some environmental characteristics are unique and specific to the locality in which the building is situated. In order to encourage design teams to focus on the aspects of regionalism, GBC Italia identifies up to six credits for each different local contexts of the Italian territory, having equivalent or similar environmental characteristics.

Table 8. Credits overview of topic "Regional Priority".

Prerequisite/ Credit	Title	Points		Exemplary Performance	Design/ Construction
Credit 1	Regional Priority	1	4	-	-

Weightings and certification

About credits weightings

LEED® protocols are structured on the basis of a maximum achievable score of 110 points (100 points as sum of the scores assigned to the credit of thematic areas SS, GA, EA, MR, IQ to which are added a further 10 points allocated to areas thematic IP and PR). The addition of new points specifically dedicated to the topic "Historic Value" makes a revision of the scores assigned to each existing credit needed, basing on the assessments conducted previously through the gap analysis. All aspects of the historic building that can be evaluated with existing credits, even in case of their partial applicability, are introduced through their integration or modification, so that the higher part of the existing issues are preserved. New credits

will use points coming from non-applicable existing credits to be removed in the new rating system because they do not satisfy its new field of application in terms of intent and/or requirements.
New protocol weightings compared to existing ones are shown in Fig. 5.

	LEED ITALIA NC	%	GBC HB	%
Historic Value	0	-	20	18,2%
Sustainable Sites	26	23,6	13	11,8%
Water Efficiency	10	9,1	8	7,3%
Energy and Atmosphere	35	31,8	29	26,4%
Materials and Resources	14	12,7	14	12,7%
Indoor Environmental Quality	15	13,6	16	14,5%
Innovation in Design	6	5,5	6	5,5%
Regional Priority	4	3,6	4	3,6%
TOTAL SCORE	110	100%	110	100%

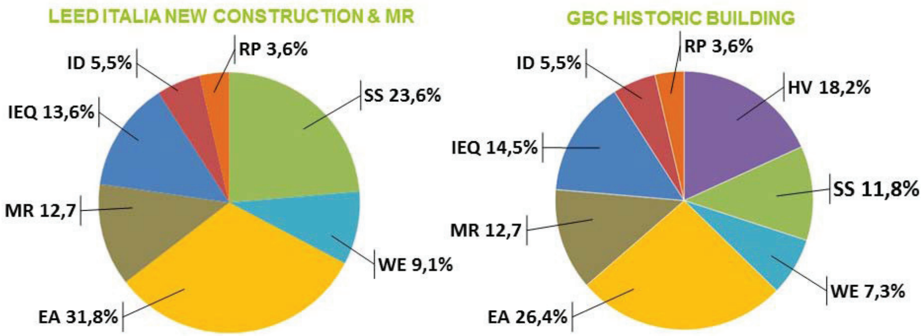

Figure 5. Distribution of points and weights for each topic in *LEED® Italia 2009 New Construction and Major Renovation* e in *GBC Historic Building™*.

About certification process

The certification process is based on the verification of conformity by a third party body. For the purposes of certification, each prerequisite and credit of the protocol has a dedicated form, useful to describe and show compliance between requirements and design/construction. This form is filled in by design/construction team and contains a list of the information required by the third party body, in order to make it able to carry out verification. External documents may be attached to the forms, if required. These documents may include drawings, calculations or any other document that may be useful to show the requested compliance.

Two separated paths are available to achieve certification. As a LEED® system, *GBC Historic Building™* certification allows a spitted review (two different phases of review first after design and second after construction) and combined review (only one phase, after construction).

At the end of the certification path, if all prerequisites (mandatory, with no points to be earned) and a minimum number of credits (volunteers, each corresponding to scores) are achieved, the certification is reached. The sum of the achieved points defines the level of certification attainable by the project, basing on the following scale:

- "Certified": 40 to 49 points earned;
- "Silver": 50 to 59 points earned;
- "Gold": 60 to 79 points earned;
- "Platinum": 80 to 110 points earned.

Supporting rating system validation: learning from case studies

The Role of case studies as a tool to develop the rating system

Case studies represent an effective tool to support the development of the rating system. A case study is based on restoration/refurbishment of buildings that fall within the scope of the rating system and is used to test the contents of the individual prerequisites and credits. In particular, the case study aims at verifying:

- "Historic Building Identity Card" (contents and type of data requested);
- performance calculation (where requested);
- performance documentation;
- benchmark used within the requirements.

The case study needs to fulfill all prerequisites and at least six credits chosen by the Owner. It does not achieve any certification level related to the rating system, but it receives a written declaration that recognizes its value for the purpose of the rating system development.

The first case study: a rural building in Guarene

Since the time of sharing the protocol short version internally with associates, GBC Italia began to record numerous expression of interest to the application of case studies from designers and entities operating within the historic property interventions. Among these, a case has already been selected and formalized by GBC Italia and began the process of verification. It is a building of rural spontaneous housing built in the late nineteenth century in Guarene, in the Province of Cuneo (Italy), that provides the opportunity to test the new protocol for interventions in "minor" manufactured housing that make up the large part of the historical and documentary nationwide.

The building has been built with a pre-industrial building process (local knowledge and operators), technologies (humid for walls and dry for floors and roofs) and materials (such as adobe bricks and bricks made locally) that are expression of a traditional building culture to be preserved (Fig. 6). With the support of TAG HB, GBC Italia is evaluating the case study documentation both of project and construction phases, including on-site inspections, and identifying critical aspects or necessary additions for the new protocol evaluation (Boarin, 2014, p.3).

Figure 6. The rural building in Guarene (Italy) is the first registered case study of *GBC Historic Building*™.

Conclusions

GBC Historic Building™ is a new Italian protocol that responds to both a market and environmental requirements to reduce resources' impact demanded by the valuable architectural heritage. Important efforts are oriented to heritage valorisation, without compromising the environmental sustainability of historic buildings that, in a holistic vision, should also perform as high efficiency constructions (Celeste and Morin, 2009). Thus, a systemic approach is the only way to intervene in the historical heritage that can guarantee the maintenance of its cultural value and LEED®-based systems have the possibility to guide the building process towards the achievement of goals linked to social, economic and environmental aspects at the same time. The increasingly urgent need to adapt historic buildings to new uses and functions must necessarily be subject to the logic of sustainability that require the achievement of transparent standards and, therefore, of a certified quality.

Endnotes

[1] Chair of the Technical Advisory Group "Historic Building" for GBC Italia. Corresponding Author.

[2] Technical Development for GBC Italia.

[3] Scientific Referee of TAG "Historic Building" for GBC Italia.

[4] The gap analysis has been done basing on *LEED® Italia 2009 New Construction and Major Renovation*.

[5] Preliminary case studies have been chosen among those with available information about existing building (in terms of measures, features, documents about history, etc.), detailed project features and about building sites. They have been built in different historic periods and they are placed in different climatic areas.

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Structural repair of decayed old timber end beams

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Timber end-beams represent portions with high risk of degradation due to biotic agents like rot fungi and insect attacks. Different repair techniques are available, with distinctive level of intrusion, but the substitution of the damaged part with a solid wood prosthesis is a methodology well accepted. The connection of the prosthesis to the original member can use screws, binding strips, stirrups and glued-in rods. Despite it is possible to find different case studies in literature, no study is known for the case of Maritime pine beams and prosthesis connected with glued-in steel rods. This works intends to fill this gap by presenting an experimental campaign aimed to evaluate a technique to repair timber end beams through the use of wood prosthesis connected to the original element by glued-in steel rods. For comparison purposes, the addition of new timber elements connected by screws is also evaluated as its represents a current practice in Portugal.

Keywords: End beams, repair, prosthesis, glued-in steel roods.

Introduction

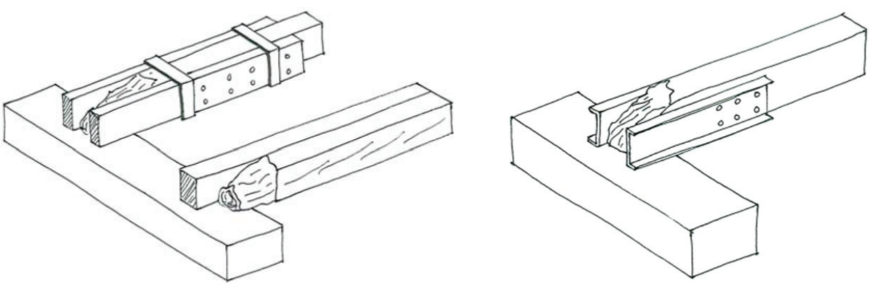
The importance of the preservation of timber structures of historical and cultural interest has increased its importance in the recent years, as can be attested by different guidance for intervention issued by national or international technical committees (e.g. international ICOMOS IWC, RILEM RC 215 AST, RILEM TC 245 RTE and Italian UNI-NORMAL WG20). These documents recognize the importance of timber structures from all periods as part of the cultural heritage, whereas some standards recommend the assessment and the conservation of existing timber structures also for technical and structural reasons: for instance, since 2003 the Italian technical codes indicate the saving of timber diaphragms as a strategic issue in the reduction of seismic vulnerability of existing buildings, do not supporting the practice of substituting these structural elements with heavier and more invasive diaphragms, such as concrete slabs (Branco and Tomasi, 2013).

The assessment of existing timber structures requires, and relies, on the determination of the mechanical properties of the individual timber members as well as the behaviour of joints and, of structural system effects (Sousa et al., 2013). In existing timber structures, the first step towards the safety assessment is the evaluation of the actual mechanical properties of the material. Despite significant effort in the development of non-destructive testing, true strength of a timber member can only be directly determined in a destructive test, which is often unacceptable in the case of historic buildings and other existing timber structures. In practice, it is the lack of knowledge about the material and its structural behaviour that normally leads to the replacement of existing wood structures, instead of their retrofitting.

In the specific case of wooden elements, it is well known that end-beams represent portions with high risk of degradation due to biotic agents (rot fungi and insect attacks). In fact, when a high level of humidity is present in masonry (e.g., due to infiltration for dis-connections in roofing) and the adsorbed moisture cannot be evaporated because of lacking in ventilation, the suitable conditions for biotic attacks are established (Carll and Highley, 1999), and therefore degradation of end-beams can be expected (see Fig. 1). This fact is well known among structural restorers and engineers familiar with timber. The first considerations about the effects of moisture content onto the end-beams were due to Vitruvio (Barbaro, 1997), whereas the suggestion of preparing aerated supports for hosting beam heads were firstly attributable to Leon Battista Alberti (Portuguese et al., 1966).

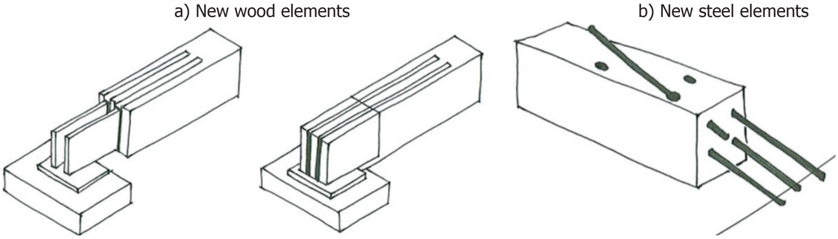
Figure 1. Examples of decayed old timber end beams.

Nowadays, several examples of techniques and methods can be found in literature for the repair and reinforcement of timber end beams (Tampone, 1996; Arriaga et al., 2002; Appleton, 2003). In fact, since the early seventies, diverse companies have purposed materials and techniques to repair decayed timber elements. It is possible to identify two distinct groups of techniques: one using wood based materials or steel elements and the other based on the so-called new materials as fiber reinforced polymers (FRP) and resins. Different levels of intrusion can be identified in the case studies reported in literature but all interventions considers the repair of individual structural elements as a mean to restore the support that has been lost. The simplest intervention consists in the substitution of the decayed part by a new element which can be made of wood (Fig. 2a) or in steel (Fig. 2b). Other approaches regards the substitution of the damaged part with a solid wood pros-thesis connected to the remaining part of the element using glued in plates (Fig. 2c) or rods (Fig. 2d).



a) New wood elements

b) New steel elements



c) Glued-in plates connecting the prosthesis

d) Glued-in rods connecting the prosthesis

Figure 2. Examples of possible repairing techniques based on the addition of new elements or wood prosthesis.

When the aesthetic value is not important, the connection of the prosthesis can be external, using nailed of screwed plates. However, usually, prosthesis are connected to the undamaged part of the element through glued-in plates or rods. Plates and rods can be in FRP (glass, carbon and aramid) but the steel ones are the more appreciated due to their reduced cost. The use of wood prosthesis become well accepted mainly due to their low intrusion level, simplicity and good aesthetic value.

The design of the repair has followed and approach based on the basic construction rules, probable simplistic but evident successful. For example, that one used for the Beta-System considered a strain distribution in repaired beam similar to that one of sound wood, and moreover imposed that the Moment of Resistance of the sound timber was equal to that one of rods used for the intervention. In such a way the total area of rods could be calculated. The length of anchorage was calculated simply basing on the resin-to-rods allowable bond stress, and on shear strength of sound timber (so, rigid bond between resin and wood was assumed as related to the design safety value of shear strength for wood). Apart from these empirical approaches, based on the allowable stresses, the adoption since 1994 of Eurocode 5 (EN 1995 1-1:2004) changed the way to handle the design approach of this kind of interventions, and nowadays in several countries specific codes exist that allow executing a proper design. The common approach is substantially similar to that described in the former standard ENV 1995-2:1997, and not appearing in the cur-rent version of EN 1995-2:2008. European Countries have obviated to this normative deficiency through national documents unfortunately, Portugal has not been the case. Therefore, experimental works are needed to evaluate the reliability in the load predicting ability of the design approach proposed by others national documents (e.g. the Italian CNR-DT 206/2007) to the Portuguese case, in terms of wood species, repairing materials, type of damage, etc.

This works try to fill this gap by presenting an experimental campaign aimed to evaluate a technique to repair timber end beams through the use of wood prosthesis connected to the original element by glued-in steel rods. For comparison purposes, the addition of new timber elements connected by screws is also evaluated as its represents a current practice in Portugal.

Experimental Programme

An experimental campaign composed by full-scale four point bending tests according to EN 408:2010 was defined to evaluate the repair of decayed timber end beams. The main objective is to evaluate the use of wood prosthesis connected to the original element by glued in steel rods. However, for comparison purposes, and because its represents the current practice in Portugal, the use of new timber elements connected by screws to the original elements was also evaluate. A total of 15 specimens were tested. Nine simulating the use of wood prosthesis and six using new timber elements to restore the decayed end beam. In this case, the use of one single element or the use of two new elements was evaluated. For the prosthesis, glued-in steel rods were used and the geometry of the connections between the prosthesis and the original element was studied. Namely, a vertical, di-agonal and mixed geometries of the joint were considered. Table 1 summarizes the tested specimens and the main variable evaluated.

Table 1. Summary of the experimental campaign.

Series	Specimens	Technique		Joint geometry
O	3	Use of a new timber element	One element screwed in single shear	Vertical
T	3		Two elements screwed in double shear	Vertical
GV	3	Timber prosthesis	Glued-in steel rods	Vertical
GD	3			Diagonal
GM	3			Mixed

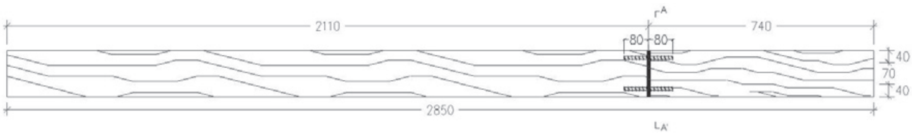
Table 2. Main tests results obtained.

Specimen	Technique	Fmax (kN)	Mj (kNm)	σm (MPa)	Failure Mode
O1	One element screwed in single shear	28.21	4.02	10.72	Wood splitting
O2		26.57	3.97	10.60	
O3		23.22	4.33	11.56	
T1	Two elements screwed in double shear	15.32	7.41	19.75	Joint rotation
T2		15.13	6.97	18.60	
T3		16.51	6.10	16.25	
GV1	Glued-in steel rods with a vertical joint	20.60	7.62	18.30	Rod withdrawn
GV2		20.60	7.62	19.30	
GV3		18.00	6.70	15.90	
GD1	Glued-in steel rods with a diagonal joint	19.70	7.28	17.40	Rod withdrawn
GD2		28.30	10.47	25.10	
GD3		24.00	8.90	21.40	
GM1	Glued-in steel rods with a mixed joint	17.20	6.38	20.70	Wood failure
GM2		14.80	5.47	13.10	Rod withdrawn
GM3		23.40	8.70	20.70	

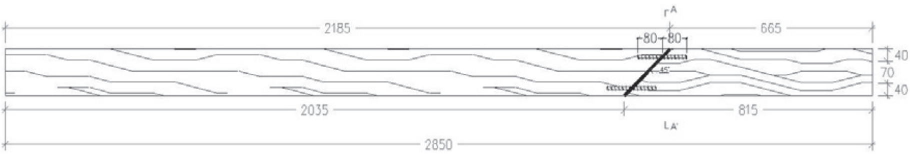
Materials and specimens

All specimens were made of maritime pine (*Pinus pinaster*) graded according to NP 4305:1995 as belonging to the quality class E, corresponding to the C18 strength class de-fined by EN 338:2003 in accordance with the establish by EN 1912:2004. Two types of screws manufactured by Rothoblaas® have been used. HBS 6x140 in the case of the specimens *O* and HBS 8x180 for the specimens identified as *T*. To connect the timber prosthesis with the original elements, glued-in steel rods were used. Rods with a diameter of 10mm and a length of 140mm made of steel of grade 5.5 have been glued using the Mapewood® Gel 120 glue.

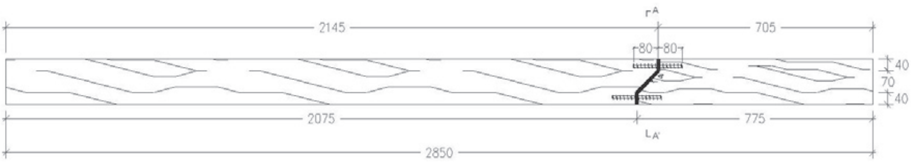
The specimens were evaluated through four-point bending tests according to EN 408:2010 with a cross-section of 100x150mm^2 and a free span of 2700mm. The prosthesis used had the same cross-section of the original element (100x150mm^2). The distinction between the specimens defined to evaluate this technique is made by the geometry of the joint (cutting). The easiest cut is the vertical despite the diagonal is the one more used in practice. However, based on some previous findings (Pizzo et al., 2013), a mixed geometry, comprising vertical and diagonal cuts was proposed (Fig. 3). In all cases, the anchorage length of the steel rod was fixed equal to 80mm.



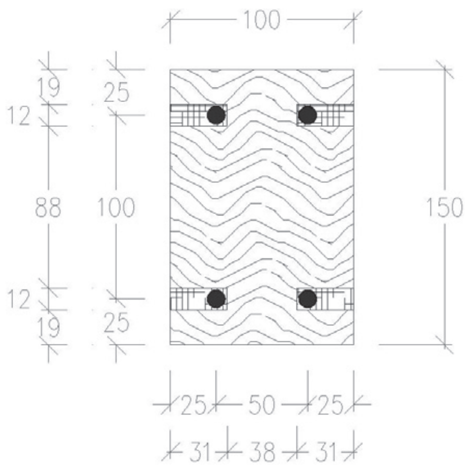
a) Vertical joint



b) Diagonal joint



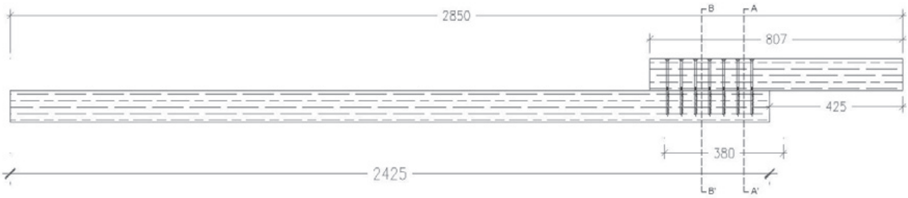
c) Mixed joint



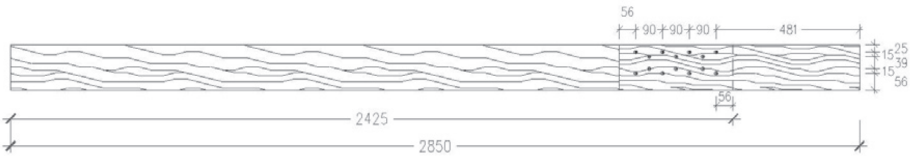
d) Detail A

Figure 3. Specimens representing the repair technique based on timber prosthesis (dimensions in millimeters).

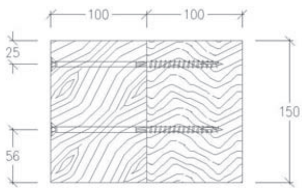
In the case of the repair technique based on the use of new timber elements, the effective cross-section was reestablish by one new element of $100x150mm^2$ (Fig. 4) or two new elements of $50x150mm^2$ (Fig. 5), in the case of specimens *O* and *T*, respectively.

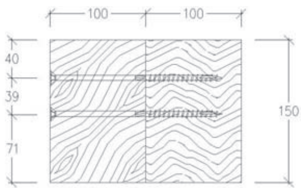


a) Plan view



b) Lateral view

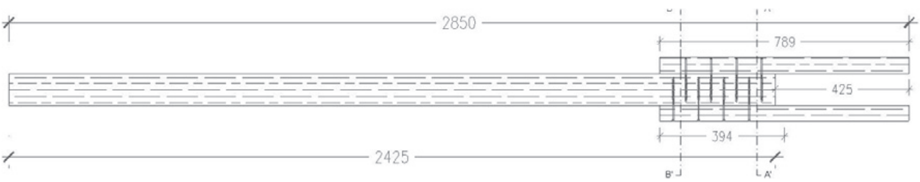




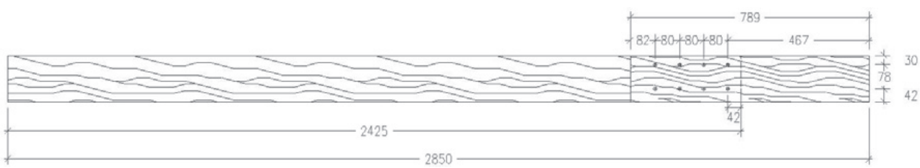
c) Detail A

d) Detail B

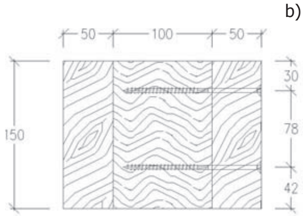
Figure 4. Specimens representing the repair technique based on one new timber element (dimensions in millimeters).

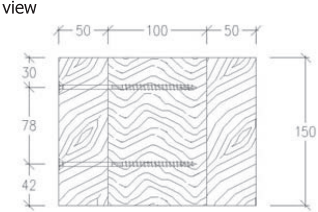


a) Plan view



b) Lateral view





c) Detail A

d) Detail B

Figure 5. Specimens representing the repair technique based on two new timber elements (dimensions in millimeters).

Specimens preparation

All specimens have been built by AOF – Augusto de Oliveira Ferreira & CA, Lda, in their own carpentry in Braga, applying the best practices developed more than 50 years of extensive field activity of intervention on existing timber structures. Specimens have been produced and after 10 days they have been transported to the Structural Laboratory of University of Minho in Guimarães. As example, Figure 6 shows the main steps in the production of the specimens used to evaluate the series GM.

a) Joint geometry

b) Cutting with a bandsaw

c) Grooves execution with a woodrouter

d) Cleaning and sealing of the grooves

e) Position of the rods inside the grooves

f) Curing of the glue

Figure 6. Main steps in the specimens repaired with timber prosthesis.

Test setup and load procedure

The four-point bending tests were conducted with reference to EN 408:2010. Those tests use a piece simply supported with a span of 18 times the depth with the loads points placed on the third of the span, as it is shown in Figure 7. The deformation at the mid-span was measured through one linear voltage displacement transducer (LVDT).

Displacement control was used for the tests under a displacement rate of 0.15mm/s. The load procedure adopted consisted in a recommended first load and unloading cycle after which the displacement was incremented until failure. The displacement rate adopted was defined in order that the maximum applied load was reached in 300 ± 120 s after the load and unloading cycle. Figure 8 presents the load procedure adopted for all tests performed.

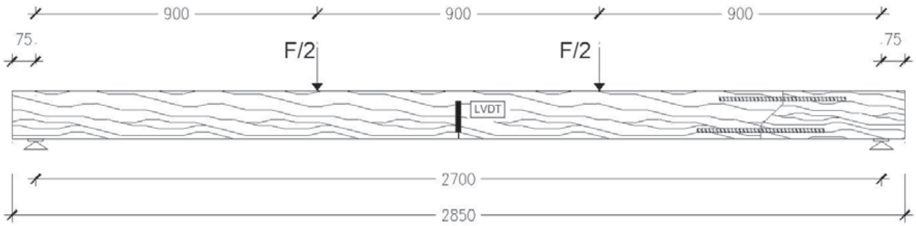


Figure 7. Test setup adopted (dimensions in millimeters).

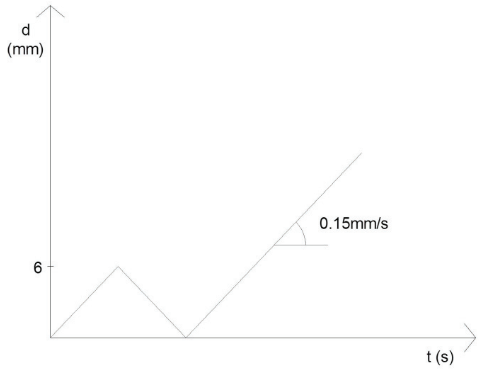


Figure 8. Load procedure adopted.

Tests results

In a first approach, the results of the tests performed are analyzed based in the maximum load value (F_{max}), the bending moment acting in the joint (M_j), the bending stress reached by the specimen in the zone of failure (σ_m) and the failure mode observed (Table 2). Moreover, the experimental load-displacement curves registered are depicts in Figures 9 and 10.

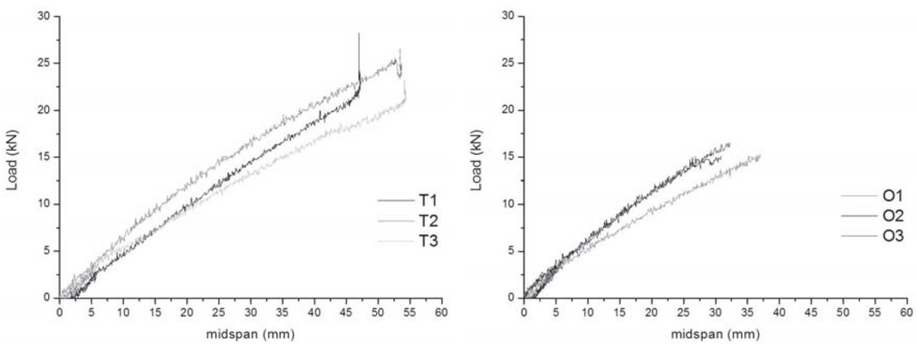


Figure 9. Experimental load-midspan displacement obtained for the series *O* and *T*.

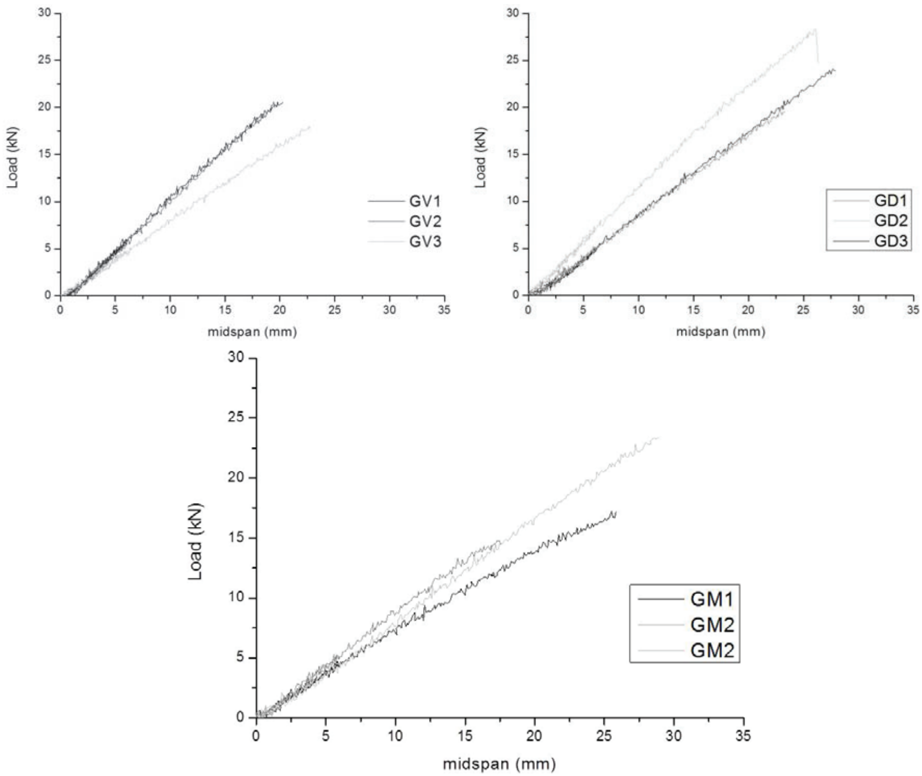


Figure 10. Experimental load-midspan displacement obtained for the series *GV*, *GD* and *GM*.

As general comment, it is possible to identify the good homogeneity demonstrated by the tests results in terms of F_{max}, stiffness and failure mode within each series of specimens. The few deviation resulted from the presence of natural defects, namely the large knots characteristics from the Maritime pine. Comparing the repairing techniques based in the use of new timber elements screwed to the original one, the specimens of series T with two new elements, presented lower values for F_{max}, but the large deformation presented by the joint in this series, leading to a significant rotation of the joint, has limited the load-carrying capacity of the specimens. Between the series using timber prosthesis, the one with the diagonal joint (*GD*) has reached the higher values for F_{max}.

Discussion

The efficiency of the repairing techniques for decayed timber end beams based in the use of new timber elements screwed to the original, was limited. In fact, due to the large de-formation demonstrated by the specimens tested within series *O* and *T*, the load-carrying capacity of these specimens is inferior to the expected value. In particular, the joint of specimens of series *T* have showed a behavior similar to a hinge (Fig. 11b). In other hand, the specimens of series *O*, with only one new timber element, have failed by wood splitting (Fig. 11a) due to tension stresses perpendicular to the grain that occurred in the row of screws located in the tension side (below the neutral axis). Those stresses could be prevent by local reinforcements but, it is important to point out that the geometry of the cross-section selected, with a reduce height, promotes this brittle behavior.

Analyzing the results obtained in the series defined to evaluate the possibility to use timber prosthesis connected by glued-in steel rods with different joints geometries, the behavior observed for this repairing technique is encouraging. First, the design method calibrated based in previous exploratory tests seems appropriate as it was possible to obtained in 8 of the 9 specimens tested, a failure in the joint by withdrawal of the steel rod (Fig. 12). This failure could be easily avoid by increasing the anchorage length of the steel rod. However, the glued-in steel rods joint were design assuming the methodology purposed by (Pizzo et al., 2013) and calibrated through exploratory tests, assuming a maximum stress value of 18MPa corresponding to the strength class C18 defined by EN 1912:2004 for the Maritime pine. In all cases, this value of the bending strength of the specimen was exceeded demonstrating the accuracy of the design method calibrated.

a) Wood splitting in series *O* b) Rotation of the joint in series *T*

Figure 11. Failures modes observed in specimens of series *O* and *T*.

a) Series *GV* b) Series *GD*

c) Series *GM* d) Wood failure of specimens *GM1*

Figure 12. Typical failures modes observed in specimens of series *GV*, *GD* and *GM*.

Conclusion

This works explores the potentialities of using glued-in steel rods to connect timber prosthesis in the repairing of decayed timber end beams. For that purpose, an experimental campaign composed by four-point bending tests was defined. Exploratory tests were performed in a previous step research to calibrate the design method to be used, ensuring that the failure occurred in the joints. Based in those assumptions, the experimental campaign was successful has almost all the specimens failed in the joint by steel rods withdrawal. Three series with timber prosthesis were considered, varying only the geometry of the joint (of the cut) between vertical (*GV*), diagonal (*GD*) and mixed (*GM*). Tests results have demonstrated that the specimens with diagonal joints behave better.

For comparison purposes, two series of specimens repaired with new timber elements screwed to the original beam, have been considered. When one new element is used, the screws were placed in single shear and in double shear when two new timber elements were employed. The efficiency of those repair techniques was limited by the small cross-section adopted for the specimens. In fact, this reduced height of the beams hindered the effectiveness of the screwed connection between the new element and the original one. Wood splitting due to tension perpendicular to the grain and significant rotation in the joint have been observed in the specimens of those series.

In sum, the experimental campaign reported here demonstrated the efficiency of the use of timber prosthesis connected to the original element by glued-in steel rods in the repair of damaged timber end beams. The intervention can be low, using small lengths of rods (8 times the diameter) and engaging a small quantity of glue. The technique used for the placement of the glued-in steel rods was defined and developed requiring its easy execution on-site.

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Sustainable networks in the rehabilitation of built historic heritage

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The research links the issue of recovery of the small Italian historic towns to the environmental issue, proposing the sustainable rehabilitation as opportunity to carry out a virtuous action in the territory. The redevelopment of minor historic centres that characterize Italy can become an opportunity to start a process of strategic regeneration of the territory, useful to produce a diffuse quality of life without which every action would have difficulty in being effectively successful. The interest for these centres struck by the earthquake of April 6, 2009, offered the opportunity to carry out research that can rediscover the environmental sustainability elements presents, to identify intervention environments and the technological solutions. The research, identified the main issues affecting the minor centres, examines the measures launched by Italian Government to activate reconstruction and energy compliance politicies. The goal is to carry on a redevel-opment involving more towns, in order to create a relation system between the centres, making the energy redevelopment organic and effective. The research applies the proposed methodology on a case study in the Province of L'Aquila: the village of Fontecchio and the territorial networks that is created with the neighboring villages of San Pio di fontecchio and Sant'Eusanio Forconese.

Introduction

At a time of global energy crisis the focus on built recovery appears on the one hand as a true need, on the other hand as a chance to save resources, economics and territorials, preserving the memory and the identity of places.

In this way, the importance of historical buildings recovery and reuse has developed interest regarding the wealth of ancient small towns that represent the historical national and territorial organization that characterize the Italian territory, both for their individual specificity, and more importantly as an overall cohesive system.

For decades, however, these small centres, located mainly along the Apennine ridge, have been affected by depopulation and abandonment conditions due to the loss of economic power and low quality of life resulting from the lack of services (Rolli G.L., 2008).

As is clear from recent studies carried out by Italian public companies such as Legambiente and Confcommercio, and private company like Norman Group, 72% of the more than 8.000 Italian municipalities have fewer than 5.000 inhabitants.

These towns are subject to different kinds of depopulation, for a long time wrongly identified with the term minor for the specificity of their size and the narrowness of their economic power (Secchi, 1984). However, this epithet is inappropriate if you recognize the wealth of architectural and environmental values these centres have protected for generations and the specific character that they represents to the national territory.

In recent decades, renewed interest in the historical villages can be attributed to a variety of factors. First, they are numerous in the area and, therefore, contribute to the diffusion of the problem. Secondly, they are significant for their historical, architectural and environmental values. Finally, there is a need for these mountain areas to recover economic attraction by introducing new housing and forms of tourism (Bonamico S. et al., 1996).

Moreover, in light of the culture of sustainability, the concept of recovery is associated with the ability to perform a virtuous action directed at re-using existing buildings, the limitation of land consumption, revaluing material culture in addition to the introduction of technologies improving energy efficiency in these contexts (Maietti F., 2008).

The situation after the 2009 earthquake and adopted policies

The ministerial decrees (Dl n.3 16/04/2009 and followings), in the initial months following post-earthquake, defined a seismic crater the area of land extending over three provinces, L'Aquila, Teramo and Pescara, for a total of 57 municipalities distributed differently among them.

The seismic crater represents a small portion of land, approximately 3000 square kilometers, the majority being mostly mountain communities, and involves a population of less than 200.000 inhabitants (Fig. 1).

In an already difficult situation, the earthquake of April 2009 struck the Abruzzo Region, aggravating the state of deterioration and abandonment in which the centres have been for decades and making inevitable changes in territorial and social organization of the settlements.

Figure 1. The seismic crater in Abruzzo Region (Design by Marchionni C.).

The recovery of the seismic crater has been slowed down by excessive bureaucracy with a succession of 143 decrees of the Delegate Commissioner for Reconstruction and 77 decree of the President of the Council of Ministers. Among these, the Abruzzo Decree n. 39.2009, then converted into the Law 77/2009 introduced the Reconstruction Plans (PdR) as a means to ensure the socio-economic recovery of the area, redevelop the town, facilitate the return of people to the recovered homes (Art 14, comma 5).

However, there is a lack of any correlations with other municipalities, as well as any reference to the introduction of incentivizing factors in energy efficiency and sustainability as a programmatic assessment of the most urgent interventions is absent.

This regulatory gap was partially filled three years later when, with the end of the emergency phase sanctioned in the article 67 bis of the Law 134/2012. Integrated programs are introduced in place of the reconstruction plans, in cases where unitary interventions are needed.

Furthermore, the range of targets to be achieved is extended by introducing among them the oblectives of obtaining «a high level of quality in terms of livability, health and safety as well as environmental and energy sustainability of urban fabric and use of modern construction materials and advanced building technologies, also to ensure the seismic improvement and energy savings, and the reorganization of infrastructure networks» (as described at the Article 67 quater).

There are no references to any guideline that clarifies the possible action mode.

As regard energy efficiency incentivizing policies, we report the subscription of all 305 Abruzzo municipalities to the Covenant of Mayors, the only case in the Europe, symbol of the Region's hope for rebirth and to start anew. This pact was founded on an initiative of the European Commission in 2008, following the adoption of the European Climate and Energy Package, to actively involve local governments in the strategy for energy and environmental sustainability.

The Covenant, in fact, is committing local governments to reduce CO_2 emissions by more than 20% of CO_2 by 2020 through the energy efficiency implementation measures. Supporting this initiative constrained municipalities to submit, within one year after the signing, the Action Plan for Sustainable Energy (SEAP), an operational tool to implement energy policies in the area. The plan contains also the BEI (Base Emission Inventory) concerning public and private transports, tertiary facilities and residential buildings energy consumption. Possible intervention are identified and described while a series of scenarios are hypothesized, with the intent of identifying the most effective combination and to minimizing potential investments (Bertoldi P. et al, 2010).

However, some methodological shortcomings are identified relative to the absence of any reference to the specific context of investigation. In the case of minor centres, there is no attention given to the question of compatibility of the proposed interventions and to historical and environmental value of this context (De Berardinis et al, 2014).

Moreover, there are no allusions to the economic impact of the scenarios considered most adept in the territory, a matter not to be ignored considering the delicate economic situation.

Starting from the identified weaknesses, the objective of this research is, therefore, to use in a compatible way the technology in the service of a truly sustainable reconstruction by providing an operational methodology applicable in important and economically weak contexts.

Therefore, the earthquake must not be considered only as an aggravating and harmful factor: the pretext of the earthquake provides an opportunity to revitalize the area with the possibility of reconstruction, where possible and reasonable, taking advantage of technological advancements to adapt comfort levels to those of today (Marchionni, De Berardinis, 2014).

Towards a sustainable redevelopment

The recovery of the built heritage and the values of material culture must act within a framework of sustainable development at a local and supra-local scale, in order to have a chance to succeed.

Knowledge plays a key role to get going the enhancement of cultures, of real estates, of anthropic areas, with a wide range of approaches to the different scales involving hybridization of cultural resources and regenerative technologies.

The sustainable recovery of the minor building is an unavoidable challenge, to be tackled only in a dimension of network between the involved actors. So that the housing problem is an element of social integration and, at the same time, promotes the protection of the territory, the environment and human health, with significant impact on the local economy

This approach involves, however, a different way of understanding the project, a new way of being regarding the problems, overcoming the reduction of reality to technical rigidity.

The goal of environmental sustainability, in fact, «is unattainable without an integrated, morphological and at the same time relational version at the same time of historic centre. There is an interconnection between the physical historic centre, of buildings, squares and streets, and the immaterial one, of values, identity, organization, imagination. The historic centre is not a machine, but an ecosystem. (...) Notwithstanding the importance of the protection of architectural and cultural heritage of historic centre, you cannot fail to mention that there is an objective of adjustment to be pursued in response to the change of the functions performed by the same, in order to move with the times» (Pilati L. et al, 2010).

The reconstruction, therefore, must not only materially provide a roof, but rather, it must generate counter measures to stop the abandonment. Furthermore, totally rehabilitate the historic centres and their economic and social relations.

In order to make this possible, it is essential to implement technologically advanced interventions that, though ensuring high levels of performance, involve considerably lower operating expenses.

The preconditions in order to develop an efficient methodology for the sustainable rehabilitations of villages were based on the following considerations: the historic minor centre is a complex reality, which cannot be separated from its environment. In fact, widening the investigation field we understand the possibility of introducing more effective and less invasive interventions on the consolidated building fabric, always respecting the territory.

We move from the building problem to the problem of historical centre, to that of a set of smaller towns interacting in the area, linked by a common rehabilitation strategy (Briatore S., 2011).

At the base of proposed methodology is the goal of operating on multiple factors identifying the specificity and the favorable characteristics of an area of land which includes more villages.

The aim is to trigger a double process: on one hand the resources sharing, both the exploitation of energy sources and the re-use of an abandoned heritage building.

On the other hand the rediscovery of the potentiality of the territory: routes and architectural and environment peculiarities exploitation, with development of productive, residential and tourist activities. The set of interventions will make the redevelopment efficient and justified.

The proposal is to create smart minor centres by strengthening networks to transfering people, informations and energy, and introducing innovative and compatible solutions.

Technological intervention, therefore, makes sense only if it helps to bring back the population in the centres, ensuring comfort conditions and production facilities connections (Marchionni, De Berardinis, 2014).

Operational methodology development

The preconditions for the development of an effective methodology for the sustainable recovery of minor historical centres are based on a in-depth phase of knowledge of the investigation context, which allows you to justify and validate the choice of an intervention aimed at "active conservation and controlled transformation" (Zordan et al., 2002) of centres.

Accepting a controlled transformation as an operational tool allows on the one hand the technological and functional upgrading of building, on the other hand the preservation of historical, formal and figurative characters.

Therefore it is proposed a compatible process of recovery of the villages affected by the earthquake, providing an operational methodology which, adapted to the individual case through the design phase, allows the adaptation of performance indices of historic centres to needs of contemporary users. This makes attractive an architecture today disconnected from economic circuits, the only ones able to allow its survival.

The developed methodology developed consists of three main steps:

– The meta-phase project:

after identifying the sustainable territories, it was decided to focus the attention on open spaces and energy networks, areas less investigated but that can offer significant performance improvements. The first are classified according to their morphological, functional and, especially, environmental aspects, through bioclimatic analysis (sunshine, ventilation) and biophysical (analysis of soil, water and vegetation) (Sala 2001).

The climatic analysis, drafted after 3D reconstruction of the villages and altitude profile, and the further use of the software Ecotect, allowed us to identify the climate behavior of the areas of interest during the main hours of the winter and summer solstices.

After performing the simulations the critical situation that characterize the open spaces are highlighted such as the humidity and low light conditions of those small space located between the dense urban fabric, the persistent sunlight conditions and the insufficient ventilation for the spaces of larger dimensions located on the margin of settlement or in correspondence with collapsed buildings.

On the other hand the biophysical analysis was carried out classifying the types of grounds present in the villages from the point of view of the ground declivity, the surface and the presence of vegetation, identifying the areas where there is residual moisture.

Regarding the energy grids, the in situ reconnaissance and research in the municipalities, although limited, has allowed to highlight a difficult situation characterized by lack of services and strong deterioration of these networks due to the lack of maintenance and modern renovation.

The first analysis, therefore, have been overlapping with those of the main energy grids present (electricity, water, gas, sewer), to highlight the critical operating situation and the lack of exercise management, as well as very high levels of executive and figurative incompatibility with the context (Pazzaglini M., 2004).

– The development of design scenarios:

is related primarily to technological scenario, which intervenes to solve critical situation listed above using different and complementary solutions.

This, however, must inevitably be supported by the functional scenario and that related to sustainable mobility, in order to make the intervention of reuse attractive to the new user and long-lasting.

The different levels of analysis, made in system with the main features of built, allowed to divide the village into homogeneous areas of intervention for critical conditions and strong points, environmental and functional, where to locate site specific where intervene that can become real energy islands, as well as urban places.

For each zones, as a synthesis of the complex process of knowledge has been possible to propose a design strategy characterized by macro-interventions in relation of the entire village, and micro interventions within the sector.

These include those that promote rational use of energy, fulfillment of environmental comfort, efficiency of energy networks and exploitation of renewable energy sources.

Of the latter, considering the sensitivity of the investigation area, we evaluate the insertion both in on-grid and off-grid modality (Marchionni et al, 2014).

In order to improve environmental (termo-igrometric, light-optical, acoustic) comfort (Olgway V., 1963), for example, a set of congruent solutions is proposed such as the use of vegetation or water as refrigerant systems, the inclusion of green area or the strengthening of trees as screening elements or windbreaks. Additionally these solutioned include the inclusion of transparent and translucent roofs to reduce ground moisture, the introduction of mirrors and reflective walls to increase the levels of illumination of the small streets, etc. (Dessì, 2007).

In the margin spaces or more open areas the inclusion of renewable energy sources is proposed. We study the characteristics of the area to understand the compatibility of other systems (photovoltaic, mini-wind turbine, biomass, mini-water and geothermal energy).

Even in the case of energy networks a number of technological solutions have been classified, that vary from the introduction of ex novo tunnels allowing the passage of most of underground services, to introduction of district heating, to intelligent lighting systems equipped by low energy consumption systems, to improvement of management systems, etc.

Identifying compliant solutions, through the subsequent case-by-case application is verifies which are compatible with the specific case study, because they exceed a complex compatibility process (environmental, technological, functional and economic), whose research provides the parameters evaluation.

Sustainable minor centres in network: identification of a case study

The described methodological phases have been applied on a representative case study, identified through the first level of knowledge described above. This is the network, understood as a system of relations, consituted by the minor centres of Fontecchio, with its suburb of San Pio, and Sant'Eusanio Forconese (Fig. 2).

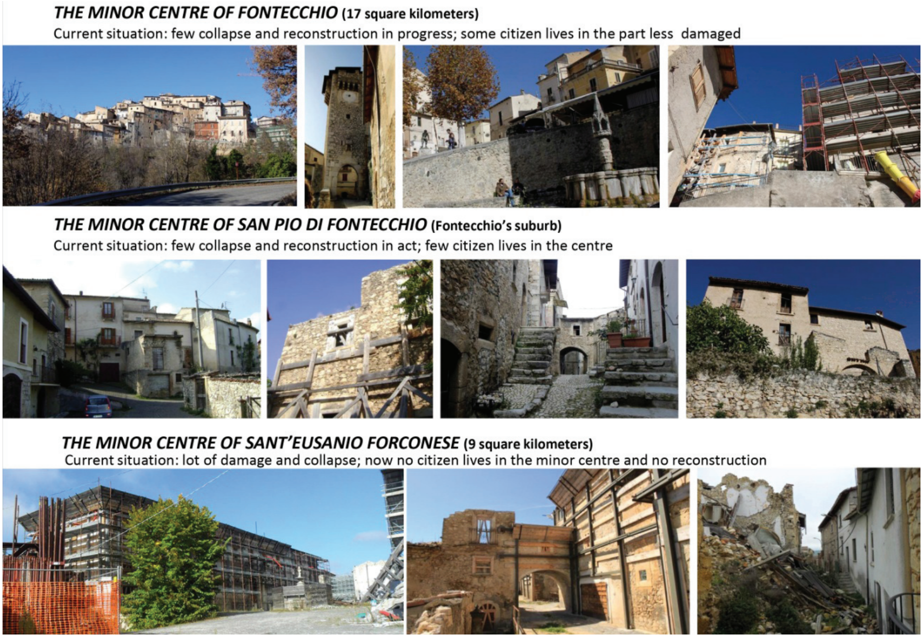

Figure 2. Identification of the case study (Design by Marchionni C.).

The territory of Fontecchio is part of the Montana Sirentina community and the Regional Sirente Park, and covers a total area of approximately 17 square kilometers over the River Aterno. The municipality includes four different settlements: the minor centre of Fontecchio and its suburb of San Pio, Pagliare, a temporary village characterized by simple and small scattered houses, and the system consisting of four Convents.

Fontecchio, historic fortified centre well-conceived in the defensive aspect, expanded several times to contain the ever-increasing population, the village has a typical military and feudal structure, sign of the fact that it focused the main economic, trade and handcrafted activities of the area. Its dense and compact urban fabric developed following the altitude profile as it is located on a sloping land and in the southern part is characterized by tall wall-houses overlooking the surrounding valley.

On the contrary, the village of San Pio, located north of Fontecchio, develops itself on a flat ground and has no real defense structures: it is characterized, however, by having great bricked property formed by the master's palace, stables, farmers' accommodations, barns, utility room for the tools and any other space or structure necessary for the care of the fields, all to testify the agricultural function of the settlement (Paolini G., 2003).

The centre of Sant'Eusanio Forconese, however, has risen in correspondence with a flat territory situated about 594 meters above sea level in the Vestina valley, between the Fossa River and the Averno River, on a small hill. The territory also includes the suburb of Casentino and covers a total area of 9 square kilometers, but the real inhabited town of Sant'Eusanio has an area of only 3 square kilometers (Barbato, Del Bufalo, 1978). It has a oval shape and it has been developed around the piazza and the basilica by narrow streets that reconnect to the distant external ring; the urban fabric is rather compact in the eastern zone of the village, sparser in the western zone, consists by numerous construction aggregates and one may identify internal sub-orthogonal axis.

The proximity of the three considered centres, far 16 kilometers and well connected to each other, and the architectural and environmental features that characterize them allowed us to carry out a organic strategy for redevelopment.

The area, infact, is well connected to the state capital L'Aquila through the state highway SS261 and to other centres thanks to the presence of the railroad. The economy of the area, mainly agricultural, in recent years saw the development of a modest tourist activity, for the presence of a morphologically varied territory and for the naturalist beauty, wherein is distinguished the presence of the famous Caves of Stiffe and the Sirente Velino Park (Centofanti M., 1975).

Design scenarios and technological applications

The design idea for the case study is to re-create a strong regional system by exploiting climatic and economic peculiarities of each centres taken into account.

We assumed a series of design scenarios that, overlapped, allow the application of different and complementary strategies using technological solutions case-by-case.

The technological scenario must be supported firstly by a functional rehabilitation, for the creation, for example, of a residential-tourist itinerary, based on several peculiarities of the territory: the presence of the Caverns of Stiffe and the Sirente-Velino Park contribute to increasing the interest for a part of region still little known.

However, many cases of redevelopment with touristic purposes show that in these inland areas is not enough trust on tourism to bring back population and work. Therefore we looks with interest the redevelopment of the typical local activities, primarily related to production and sale of local products (truffles, saffron, lentils, etc ...) and the strengthening of relevant occupational activities, such as the presence of an important health helpful reality in Fontecchio.

Furthermore, it is essential to create new forms of housing suitable by contemporary users (often young couples or singles). The idea is design some areas for co-housing: for example the southern area of the square of St. Eusanio, mainly hit by the earthquake, introducing technological solutions in open spaces that characterize this area, or supporting local initiatives such as the home-workshop of Fontecchio.

So becomes fundamental also the scenario of sustainable mobility, to ensure accessibility to these countries. This involves the upgrading of local road network and connections with the major production towns and the improvement of public transport. Moreover is expected the strengthening of bike paths system, now present just in few streets, the railway connecting the considered centres, and the introduction of new forms of sustainable mobility, such as car-sharing and bike-sharing (Fig. 3).

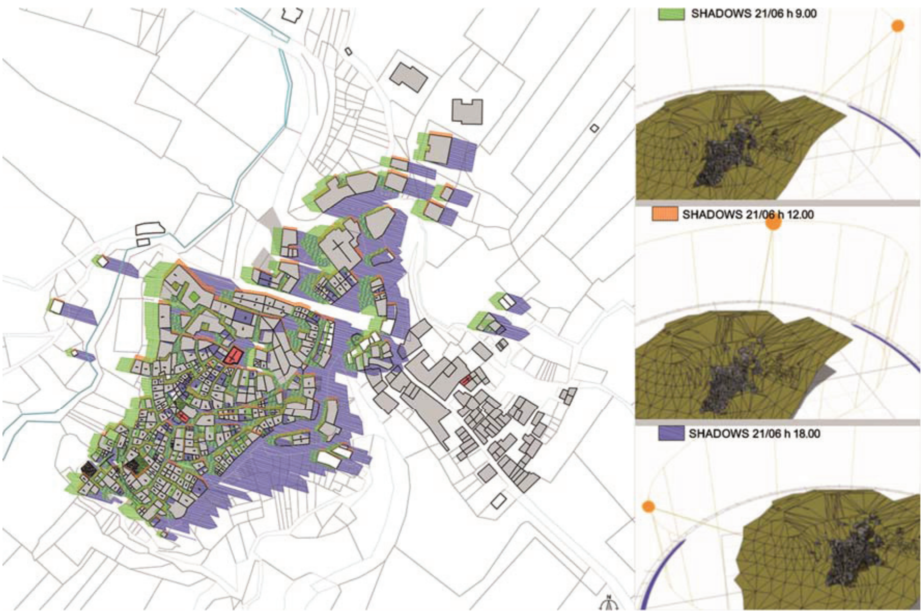

Figure 3. The scenario of sustainable mobility (Design by Marchionni C.).

The technological scenario, therefore, has been developed as a synthesis of knowledge phase, which has highlighted the critical climatic and those relating to technology networks, as well as the presence of environmental features to be strengthened.

In the centre of Fontecchio, for example, was compatible from the environmental point of view the application of technologies linked to the exploitation of biomass and solar energy.

For the biomass evaluation was firstly verified the presence of local biomass, thanks to observations in situ and data provided by the Forest Guard of L'Aquila, finding the availability of the raw material as waste and the presence of a short chain.

Regarding solar energy, the arrangement of Fontecchio on a significantly slope valley, with predominant exposure to the south-west, has left open the possibility of integrating photovoltaics and solar thermal technologies into the historical fabric.

We carried out a verification of the areas in conditions of persistent sunshine thanks to the 3D reconstruction of the villages and the further use of the software Ecotect which has also allowed to evaluate the main climatic and biophysical critical situation, in winter and in summer, mainly due to ventilation, sunshine and nature of soils (Fig. 4).

Among these the presence of a lot of zones with problems of lack of natural lighting of the streets and fronts northward exposed and a lot of moisture on the ground, due to the absence of solar penetration and an efficient system of drainage. Furthermore there are no large open spaces sunny, on the contrary in San Pio, but whole fronts in overheating risk, those of walls-houses southern facing.

Figure 4. Map of shadows in summer of Fontecchio and 3D views (Design by Marchionni C.).

Considered the available energy sources, the design choice was oriented on the deployment of a mix of micro-interventions, both in respect of the construction characteristics of the country and the pursuit of reduced environmental impact, and in view of cyclically variable consumption.

A design application has watched with interest to the area to the south part of the village: here the technological scenario has followed that related to the functional aspects and the mobility, recovering the area for residential purposes, with the upgrading of existing guest quarters through the introduction of commercial services and the recovery of the usability of open spaces through their urban regeneration, first of all the Chiassetto of Caia.

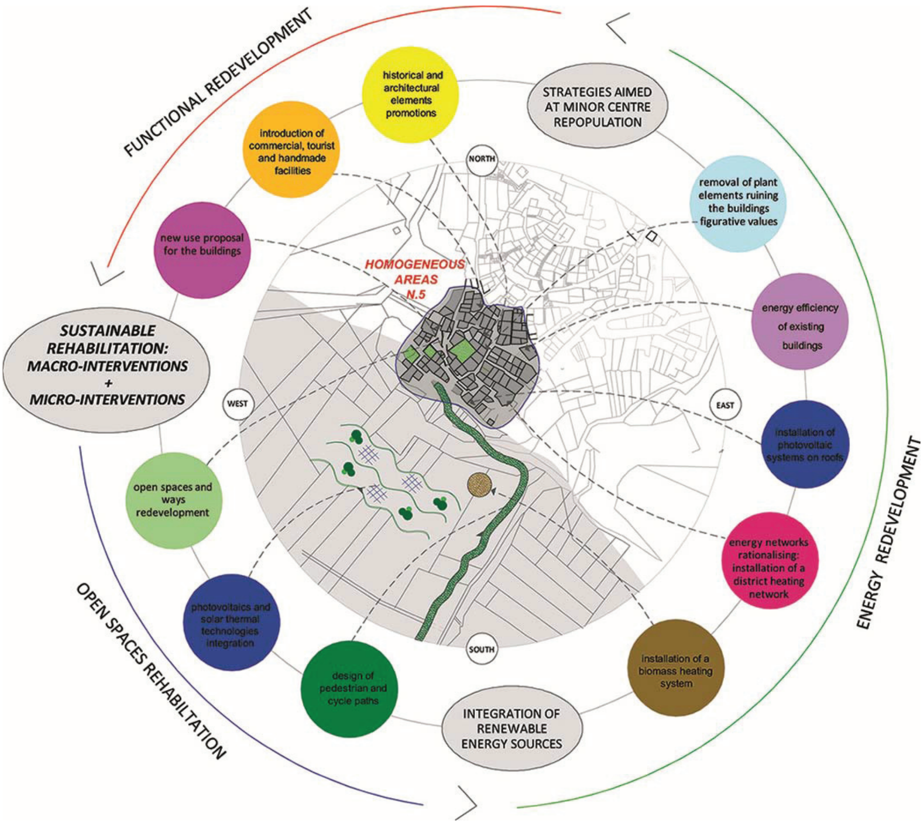

Figure 5. Sustainable strategies for the design area in Fontecchio (Design by Marchionni C., Di Natale A., De Angelis A.).

Regarding mobility and accessibility of the area, however, it has been hypothesized a development of the pedestrian path that connects the area to the wall houses situated to the north of the village, called Caia way, and the opposite way Piedi la Terra, that connects to the west area of the old centre.

To the south, however, the area is accessible through a pedestrian path, not used now, which is connected with the most downstream area, where there is a carriage road, called Via 1, which leads to the railway station. We hypothesized the recovery of this path through the ground arrangement and the introduction of high-performance energy lighting systems.

The rehabilitation of energy networks is characterized, however, by the adoption of a district heating system extended to the whole area, powered by a biomass power plant, a choice that involves three basic steps:

- calculation of the heat demand for the plant design;
- identification of the site to place thermal power plant;
- identification of the distribution system.

The choice to hypothesize a lot of small district heating networks, and not a single network in service of the whole village is dictated by several considerations: the site analysis, characterized by streets of small size and very sloping; the environmental impact that the introduction in the territory of a thermal power plant of considerable size may have. Finally, the risk of over-sizing the thermal power plant, since there is no stable usage.

In order to exploit solar energy too, the power plant will be electrically powered by a system of photovoltaic panels in polycrystalline silicon.

To complete the technological scenario, in order to meet the needs of the area of interest, it has been provided also the installation of photovoltaic systems on the roof of some buildings with a minor historic value and best orientation, such as, for example, the guestrooms.

It is also provided the formation of technological urban gardens in the green area south of the sector part, supposing the installation of well integrated photovoltaic terracing.

In the centre of Sant'Eusanio, instead, the presence of a high degradation and numerous collapses due to the earthquake allow us to hypothesize a modernization of networks, now insufficient and poorly functioning, reasoning on the entire village. Here it's possible the creation of an underground technological tunnel, which path is designed in order to be respectful of valuable paving. This allows the elimination of many technological additions and reduction of problems about inspection.

In the margin southern area of the village of San Pio, however, flatter and greater, was designed the creation of technological urban gardens. This area, well exposed to sunlight and summer breezes, and away from important and valuable buildings, was partitioned in order to be enjoyed by multiple users, and here was promoted the application of renewable energy technologies to be integrated into natural and realization of a system of accumulation and reuse of rainwater.

The application of the identified solutions occurred just after the compatibility verification with the environment, a compatibility under different aspects (environmental, technological, functional, economic) followed by indication of reversibility degree.

Conclusions and future developments

The test on case studies shows how, recognized on the one hand the values to be respected, on the other hand the need to introduce forms of energy efficiency, it is possible to overcome the normative and bureaucratic impasse that now prevents the recovery of abandoned territories.

The methodology is intended to be a support tool to main actors related to the post-seismic reconstruction, therefore public managements and designers.

In particular, to the first we would provide a tool that overcomes the present incompatibility in SEAP (Sustainable Energy Action Plan), in order to combine the mere physical towns reconstruction with the technological and energy one.

This methodology, which can be enriched with a lot of technological solutions offered by the current market, provides an organic method that avoids the simple application of standard solutions and use of market products, but rather prefers the approach to the single case, that is a key concept if we truly want to respect and take advantage of the specificity of each context.

However, even if it starts from the specific investigation context, which determines many of the elaborated considerations, the intention of the developed methodology is to provide meta-planning indications generally applicable to other sensitive areas hit by emergency situations.

The next phase of the research aims at increasing the multi-disciplinary contributions related to the recovery process of the countries. In particular it is considered valid, in phase of knowledge, the deepening obtained by the use of technology by UAV (unmanned aerial vehicle) for evaluation and thermographic study. For the scenarios validation, however, it is necessary to enrich the methodology considering the economic component and the control of the management and maintenance process.

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Accessibility of urban spaces: analysis and solutions to make sustainable historical towns

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In 2013 a group of researchers from the Department of Civil Engineering and Architecture of the University of Pavia developed a study and some technical solutions about accessi-bility and usability of the historic urban center, according to the Department for Equal Opportunities of the Municipality of Pavia. The bases of the research are the UN Conven-tion on the Rights of Persons with Disabilities and the consciousness that an accessible town is sustainable in a social and cultural dimension.

The research delineates a system for evaluating the accessibility based on objective pa-rameters; the results of this evaluation can be used to define pedestrian path without bar-riers and are also functional for programming the maintenance of the urban spaces. The solutions to make accessible the historical center are sustainable because can be useful for all (because inspired by the Universal Design) and can support different activities, both people living in town that tourists.

Introduction

The question of accessibility of urban historical spaces is extremely complex and articu-lated in a country such as Italy, that is characterized by a large number of towns (it is es-timated that there are more than 8.000 municipalities in Italy) scattered over a territory varied, ranging from coastal plains to high mountains of the Alps.

The urban structure of these towns is often a real Cultural Heritage (for example Venice or Vicenza) transmitting the historical, social and cultural reasons that produced it. It is in these public spaces of Italian towns that thousands people find their daily environment; persons with different abilities and age work, study and have fun and also a lot of tourists, coming form different countries, arrive to visit them. So the accessibility and usability of the urban system are prerequisites for both residents and visitors.

In order to achieve a sustainable development, the needs to access and use the urban spaces should be met in conjunction with the purposes of conservation and valorisation of historical and architectural heritage.

The *UN Convention on the Rights of Persons with Disabilities* (written in December 2006 and adopted in Italy in 2009) has a specific article (n. 30) about the importance of the Cul-tural Heritage:

> "Participation in cultural life, recreation, leisure and sport" and the subparagraph "c" invites to implement the necessary measures so that people with disabilities "enjoy access to places for cultural performances or services such as theatres, museums, cinemas, libraries and tourism services, and, as far as possible, enjoy access to monuments and sites important for national cultural importance".

On these considerations, the conservation's requirements of the historical urban spaces keep pace with the re-appropriation of the public use of urban spaces. And removing (or the possibility of overcoming) architectural and sensorial barriers represents a technical and design action that must be solved taking into account the needs of all users, regardless of age, gender or ability.

Thus, it is necessary a multidisciplinary and inclusive design, able to satisfy the different needs and based on a detailed knowledge of the urban structure, its historical development and growth. It is important also to act with the awareness of time, this moment and the future, considering also the changing in the society (such as the elderly population in-creasing).

Moving from these considerations and from the significance of Human Being in the re-search and design process towards a sustainable future, the University of Pavia has been conducting studies and applied research on the accessibility from 2006; the aim is to define a method for analysing and evaluating the level of accessibility and usability of the urban system and of the historical buildings as prerequisite for the design and the imple-mentation of measures to remove and overrun architectural and sensorial barriers.

This paper illustrates the methodology for analysing and evaluating the level of accessibil-ity and usability and some solutions to make the urban spaces "for all"; this study was de-velop on the "system of three squares" (Piazza Vittoria – Piazza Duomo - Piazza Cavag-neria) between February and July 2013.

Pavia: urban system and research approaching

Figure 1. Figure 1. Pavia aerial view; it is possible to recognize the Cardo and Decumano of the Roman town; the "system of the three squares" is around the Cathedral, not far from the crossing between Cardo and Decumano.

Pavia is a town in the North of Italy (30km south of Milan), characterized by an urban structure in which the Roman origin and the Medieval consistency can be easily recog-nized; it was the capital of the Longobard Reign and the base of one of the first universities in Italy (it has now more than 650 years). The morphology of the ground, the proximity of the River Ticino, the pavements of a lot of streets (often cobbled) represent some problems that people with disabilities can find moving in the downtown.

For several years now the University of Pavia has been cooperating with the Municipality to carry out studies and research to overcome the problem of architectural and sensorial barriers in order to realize a more accessible town. The aim is to provide a practicable pe-destrian system in the historical center so that everybody can use it (not only mobility impaired people, but also the visual impaired, mentally disabled, elderly, etc.). In the period between February and July 2013 the research focuses on the "system of the three Squares": Piazza Vittoria – Piazza Duomo – Piazza Cavagneria, in the Medieval downtown; that means to investigate the accessibility of these three squares and of all the streets connecting them.

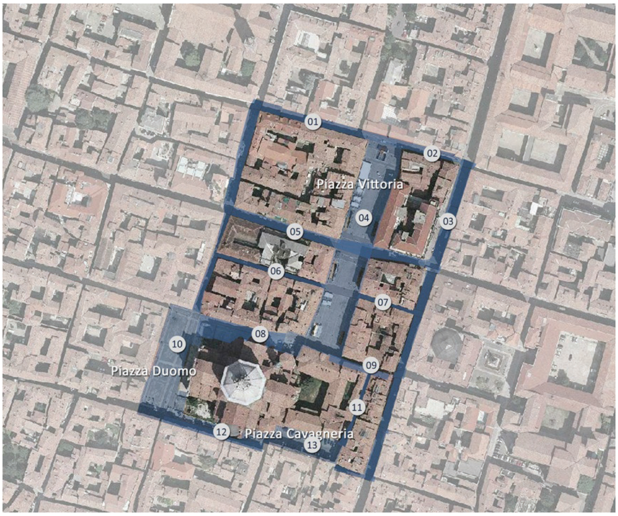

Figure 2. Piazza della Vittoria – Piazza Duomo – Piazza Cavagneria: the system of the three squares investigated in 2013.

Methods

The research was developed following the same method used in the research Pavia for all (2008) but with a new approach in order to consider three different "spaces" in which persons with disabilities have to move: the streets, the crossing and the squares.

The research can be synthetized in these steps:

- developing the assessment tools able to investigate the accessibility of urban spaces;
- numerical, material and photographical surveys;
- digitization of the survey and database organization;
- identification of the most critical points;
- development of synthesis' boards to understand the level of the accessibility;
- proposal for architectural and technical solutions to improve the accessibility.

Assessment tools

Starting from the researches developed between 2006 and 2012, it was defined an as-sessment tool with parameters to measure accessibility to the historical centre which suited everybody's needs. The aim was to overcome the difference between pedestrians and people with disabilities due to architectural and sensorial barriers.

It was referred to the World Health Organization's 2001 International Classification of Functioning, Disability and Health (ICF), which holds that a person at any stage in his life may enjoy a health status that becomes a disability in negative surroundings. We sought for parameters to evaluate accessibility for all, which were then used to create an evaluation card. Specific software programs allowed for the easy compilation and processing of these cards.

There are three different assessment tools (defined by the same viewpoint) in order to de-fine the accessibility level of sidewalks, crossings and pedestrian areas. The tools work through the identification of macro-indicators, structured on objective parameters.

The analysis of the sidewalks is divided into four macro-indicators (in brackets the pa-rameters used for each macro-indicator):

- general characteristics (length, type of footpath, pavement, covered path, lighting, path slope);
- paving of footpaths (type, characteristics);
- car parks and public transport (reserved parking, type of public transport, bus stop);
- urban furniture (areas for stopping and relax specifying furniture and their heights, furniture correctly positioned, furniture not allowing safe and inde-pendent movements).

The analysis of pedestrian crossings is structured with the same methodology, but with only two macro-indicators; they are:

- general characteristics (type, position, slope);
- paving of crossing (materials, characteristics).

Finally, an accessibility assessment tool was applied to all the pedestrian areas: the three squares (Piazza Vittoria, Piazza Duomo and Piazza Cavagneria) and the streets where cars are not allowed. In this case the macro-indicators are:

- general characteristics (dimensions, covered path, slope);
- paving of footpaths (type, characteristic);
- urban furniture(areas for stopping and relax specifying furniture and their heights, furniture correctly positioned, furniture not allowing safe and inde-pendent movements).

PAVIA ACCESSIBILE

UNIVERSITÀ DI PAVIA DICAr

Scheda di rilevamento: Progetto PAVIA ACCESSIBILE (febbraio e marzo 2013)			
Comune	Pavia		
Via o Piazza	Via XX Settembre	Codice	
Attraversamento (incrocio)	Via XX Settembre - Via Mascheroni	I1	0
Cognome e nome compilatore	Franco Annamaria		

Caratteristiche generali	Tipo	X	Non segnalato	-1
			Strisce pedonali	
			Semaforo muto	
			Semaforo con segnale sonoro	
			Presenza di segnaletica luminosa per veicoli	
			Presenza di dissuasori al libero attraversamento	
			Presenza di indicazioni tattili-plantari	
	Posizione	X	In piano	1
			In piano per rampe di raccordo nella sede carrabile	
			Inferiori rispetto al marciapiede e raccordati con scivolo a norma	
			Inferiori rispetto al marciapiede e raccordati con scivolo **non** a norma	
			Inferiori rispetto al marciapiede e raccordati con gradino	
			Non allineamento delle rampe con la direzione di attraversamento	
	Profilo	X	Completamente piano	0
			Pendenza media ≤ 8%	
			Pendenza media > 8%	
			Caratteristiche generali	0
Pavimentazione dell'attraversamento	Tipo		Asfalto	
			Battuto di cemento	
			Cubetti di porfido	
		X	Lastre di materiale lapideo	0
			Acciottolato	
			Cotto	
			Ghiaia	
			Legno	
			Gomma o simili	
			Prato	
			Terra battuta	
			Autobloccanti o piastrelle per esterni	
	Caratteristiche	X	Perfettamente complanare	0
			Sconnessioni o avvallamenti	
			Elementi instabili	
			Differenziazione cromatica rispetto alla sede carrabile	
			Rugosità accentuata (antiscivolo)	
			Pavimentazione dell'attraversamento	0
			PUNTEGGIO TOTALE	**0**

Figure 3. Example of the card for evaluating the accessibility of the system of the three square in Pavia.

Each area of investigation includes several elements to be carefully considered and the tools are structured to give automatically a value in relation to a "tick" or "not tick" of the-se elements in the evaluation card. The sum of each value gives a number (positive or negative) which is the reference to assess the accessibility level of the path detached: for values less than or equal to zero the path's section is considered "not accessible" (identified with red color in a map that was realized at the end of the analysis), for values between one and four it's considered "accessible with assistance" (in yellow in the map) and for values equal or greater than five it is considered "accessible" (in green).

Survey and synthesis

The cards were compiled between February and May 2013 and at the end there are a total of 135 (77 sidewalks, 10 pedestrian areas and 48 crossings); each card has also some pho-tos that show critical (pavement narrowing to less than 90cm, minimum awning and brise-soleil height less than 210cm, slope inclination, etc.) or significant elements for promote the independence of people with disabilities.

After the survey's phase and after that the cards were transformed in Excel files to obtain the values of the level of accessibility (as described above), the results are summarized on a drafting that shows the three different levels:

- Green lines: accessible;
- Yellow lines: accessible with a guide;
- Red lines: not accessible.

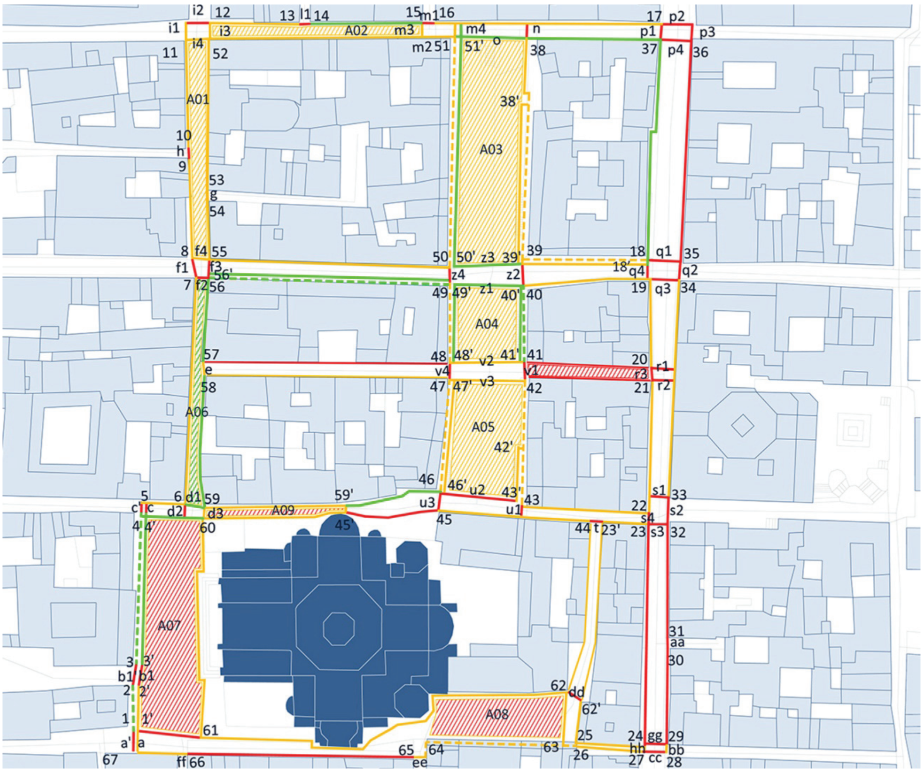

Figure 4. The final drafting with the information about the level of accessibility (green is accessible, yellow is accessible with a guide, red is not accessible) and the code of the cards for sidewalks, squares and crossings.

Observing the drafting with attention, some conclusions can be obtained:

- many crossings are not accessible, and this is often due to the lack of ramps connecting the paths and the road in addition to a poor signaling for blind and deaf persons;
- some streets are not accessible for the morphological characteristics (slope of the roadway and sidewalks) that can not be resolved in terms of design without changing the original Medieval image;
- Piazza Duomo and Piazza Cavagneria are less accessible than Piazza Vittoria, mainly due to problems related to the pavement;
- some pedestrian areas are often critical issues related to street furniture (which is sometimes hindrance to the movement of pedestrians), or to their own morphology.

Solutions to improve accessibility

At the end of the research, we developed some projects to overcome the architectural and sensorial barriers into the three squares. We made some technical drawings, referred to critical points, that show the current situation and a possible solution for overcoming it.

The aim of this phase was to provide to the Municipality a few ideas for improvements of urban public space. The solutions were designed following these principles:

- attention to the context, to avoid altering the image of the medieval environment;
- economic sustainability, to enable the Municipality to realize them;
- reversible, in order to allow their removal in the future, restoring the original image (if necessary).

The projects for Piazza Vittoria are:

- insertion of double-height handrails to overcome the difference between the paving of the square and that one of the porticos that characterize the two 'long' sides of the square;
- connection between the square and the portico “Annabella-Demetrio” with a ramp in order to solve the height difference between the square and the portico itself. It is motivated by the desire to connect without architectural barriers the bus stop in Strada Nuova (the Cardo of the Roman period) with the bus stop in Piazza Vittoria: this "interchange" is very important for person using public transports to cross the town;
- solutions to allow access to the vertical connections between the Underground Market and the square; at the moment, lift and stairs (covered by the green "shelter") are not accessible because of the non-regular pavement of the area covered by the shelter and the surrounding pavement.

We propose the following solutions for Piazza Duomo:

- doubling the stone slab adjacent to the staircase of the main entrance of the Cathedral; at the moment there is only a 60 centimeters slab and the rest of the square is cobbled. This situation does not allow easy movement for people with disability; doubling the laminate, reaching 120cm of plane pavement would allow the passage of wheelchair users or people with shopping carts, that move during the weekly market;
- new signaling information relating to the Cathedral, moving the existing one from the current position (difficulty reached even by people without disabilities as positioned on a portion of pavement heavily bumpy) and supporting with multisensory communication systems (Braille, three-dimensional map, QR code);

In Piazza Cavagneria these adjustments have been assumed:

- protection of the path on the side of Broletto; the sidewalk is 90 centimeters wide, so it is appropriate to the passage of persons with physical disabilities, but parked cars often invade the space dedicated to pedestrians, reducing the dimension of the way less than 60cm;
- creation of a paving stone slab to replace a portion of cobblestones at the secondary entrance to Palazzo Broletto and Underground Market, this would allow an easier entrance-exit from the building on a regular and adequate pavement.

Figure 5. The technical drafting showing the solution to save the path from the cars parking in Piaz-za Cavagneria; the idea is to maintain no less than 90 centimeters between the wall and the cars in order to allow persons with wheelchair moving without any problem.

Figure 6. Piazza Cavagneria: how it was before and how it is now; the Municipality realized the idea we designed even if the elements to preserve the path are made by iron (in our project they were thought in corten) and their geometry is different (they are 1.10 m height while the corten panels in the project were 0.45 m).

Conclusion

The research confirms that the medieval urban structure has some morphological and material situations that are not so easy to solve without changing the original image. However it is possible, with simple, economic and reversible solutions, improve the level of accessibility and facilitate the use of space not only for persons with disabilities but for all. In particular, the inclusion of some aids and more care in the selection and positioning of street furniture are not expensive solutions that can help all persons to move safe and independent in our historical town.

The results of the research also represent a useful tool for the planning of maintenance work on public spaces and they can be the starting point for the development of wider and more detailed projects, to improve the accessibility of the city of Pavia.

The structure of the accessibility assessment tools and the syntheses developed into the project "Pavia Accessibile" ("Accessible Pavia"), are very easy to be understood and to be applied not only for engineers or researchers, but for all.

The objective methodological approach and the systematic application of the assessment system on different study cases can represent an important aid for the planning of architectural interventions at the urban scale. The exportability of the methodology can also create an inclusive view about accessibility problems to allow the identification of possible design solutions according to a conscious process.

In addition, involving designers and researches (who are aware of the complexity of the theme of accessibility within historical contexts and public buildings) also with students, associations (e.g. UICI, the Italian association for blind and visually impaired people) and people with disabilities, can help to create a new sense of participation and inclusion. The participation of all these figures can help designers and researches during the analysis, the synthesis and finally the developing of the architectural and design solutions, improving the cultural and social dimension of architecture and engineering, and creating accessible systems for future oriented communities.

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Pull-down test of the rammed earth walls at Paga Lhakhang in the Kingdom of Bhutan

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Traditional Bhutanese buildings made of rammed earth are vulnerable to earthquakes, and their preservation, maintenance, and rehabilitation has therefore become a problem that has assumed great significance. However, few studies have focused on rammed earth structures, and almost no data from material or full-scale tests is available for the same. In this study, material tests are conducted on rammed earth core samples extracted from the Paga Lhakhang. Pull-down tests are conducted on the four remaining rammed earth walls at the Paga Lhakhang, and the relationships between the results of the pull-down test and the material test are discussed.

Introduction

Background and objective

In the Kingdom of Bhutan, rammed earth has long been used as a construction material. As such, many structures made of rammed earth exist in the Kingdom of Bhutan. But also rammed earth structures are distributed especially in the Southeast Asia, Southwest Asia, Middle and Near East Africa, and Central and South America (Jaquin & Augarde & Gerrard, 2008, Fodde, 2009). Unfortunately, many of these structures were damaged by earthquakes that occurred on September 21, 2009 (in eastern Bhutan, Magnitude 6.1), and on September 18, 2011 (near the border of India and Nepal, Magnitude 6.9). Bhutanese rammed earth structures are vulnerable to earthquakes, and their preservation, maintenance, and rehabilitation is a problem that has assumed great significance. Toward this end, it is necessary to clarify the mechanical properties and collapse mechanism of rammed earth walls in order to devise seismic reinforcement and restoration plans. However, few studies have focused on Bhutanese rammed earth structures (Aoki et al., 2012, Ezura et al., 2013), and almost no data from material or full-scale tests is available for the same (Jaquin, 2006, Jaquin et al., 2007, Jaquin & Augarde & Legrande, 2008, Illampas et al., 2013).

The Paga Lhakhang, a rammed earth structure, was destroyed by fire on February 29, 2012. Fortunately, an opportunity to investigate the Paga Lhakhang was presented before its reconstruction (Nakamura et al., 2013, Torizawa et al., 2014). This study aims to determine the material properties of a rammed earth structure and to clarify the structural behavior of rammed earth walls.

An experimental study of the Paga Lhakhang was conducted to determine the structural behavior and characteristics of rammed earth structures. Material tests were executed on rammed earth core samples extracted from the Paga Lhakhang to determine the compres-sive and tensile strength and Young's modulus of rammed earth. Pull-down tests of the four remaining rammed earth walls, one in the in-plane and the remaining three in the out-of-plane directions, were carried out, and the relationships between pull-down load and displacement and their collapse mechanism are clarified. The results of the pull-down test and material test are presented and discussed.

Outline of Paga Lhakhang

Paga Lhakhang is located on a mountain slope facing the Wangchchu River in Chhukha Dzongkhag, southern Bhutan (Fig. 1 (a)). It is believed that Paga Lhakhang was built in the middle of the 18th century by Kuenga Gyamtsho. However, according to a priest there, it was built 400 years ago. For now, the time of construction remains unclear. Paga Lhakhang was burned down by a fire due to a short circuit in the early morning of February 29, 2012. After the fire, only the inside and outside walls remained (Fig. 1 (b)). Details about the building are unavailable because little investigation data could be obtained after the fire. However, the building was considered to have four stories above ground, with a base made of stone, frame made of rammed earth, and floor frame made of wood.

(a) Before fire

(b) After fire

Figure 1. Front view of Paga Lhakhang.

Material test

Outline of test

Material tests were conducted on rammed earth core samples to determine the compressive and tensile strength and Young's modulus. These samples were extracted from the four remaining rammed earth blocks at Paga Lhakhang using a hand core drill machine (DD-120, Hilti Corporation), as shown in Figure 2. 3–7 samples with a diameter and length of 100 mm and 100–200mm, respectively, were obtained from each block. The samples were irregularly shaped owing to processing difficulties. Therefore, they were shaved off and capped with plaster to make them almost flat on both the top and the bottom surfaces.

Figure 3 shows an overview of the material test. A compressive strength test and splitting tensile strength test were conducted for rammed earth core specimens according to the Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39) and the Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496). The compressive strength test was carried out using a compressive strength testing device (1000 kN) at the Bhutan Standards Bureau, a load cell (KCM-200KNA, Tokyo Sokki Kenkyujo Co., Ltd.), and a digital data logger and switching box (TC-32K and CSW-5A-05, Tokyo Sokki Kenkyujo Co., Ltd.). To determine the average deformation, the displacements at the four corners of rammed earth core samples were measured using displacement transducers (CDP-10MT, Tokyo Sokki Kenkyujo Co., Ltd.). The relationship between the load and the displacement was obtained from the data. The splitting tensile strength test was conducted using a load cell (KCM-20KNA, Tokyo Sokki Kenkyujo Co., Ltd.) because the tensile load is very small.

Figure 2. Rammed earth block.

Figure 3. Overview of compressive strength test.

Results and discussion

Figures 4 and 5 show the example of the compressive fracture mode and the compressive stress and strain relationship, and Figures 6 and 7 show the density and compressive and tensile strength relationship, and compressive strength and Young's modulus relationship for all samples, respectively. Table 1 summarizes the average results of the compressive and the splitting tensile strength tests. The average values for all samples extracted from each rammed earth block are shown. The compressive strength is estimated considering the scale effect of rammed earth core samples. The density ranges from 1573 to 2033kg/m^3 with an average of 1810kg/m^3; the compressive strength, from 0.325 to 1.585MPa with an average of 0.845MPa; the tensile strength, from 0.027 to 0.220MPa with an average of 0.101MPa; the ratio of compressive to tensile strength c/t for each block, from 7.15 to 11.29 with an average of 8.45; and Young's modulus, from 48.1 to 320.7MPa with an average of 123.5MPa. As the density increases, the compressive and the tensile strength and Young's modulus tend to increase. However, the material characteristics of rammed earth differ depending on the construction method, and therefore, the test results vary widely according to the block number.

Figure 4. Compressive fracture mode.

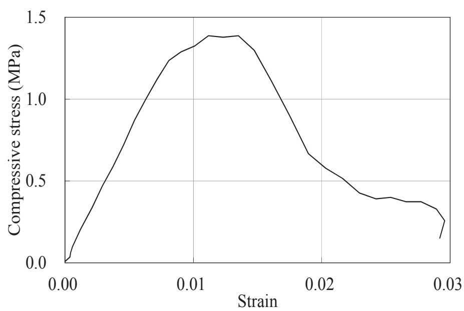


Figure 5. Compressive stress and strain relationship.

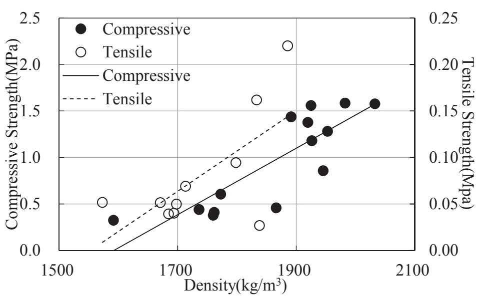


Figure 6. Density and compressive and tensile strength relationship.

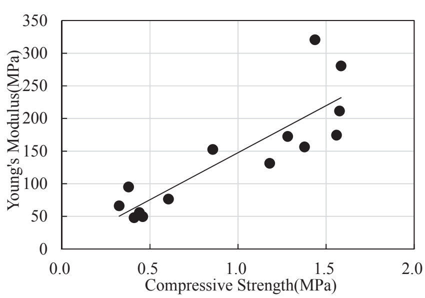


Figure 7. Compressive strength and Young's modulus relationship.

Table 1. Average results for each block.

Block	Sample number	Load	Density (kg/m3)	Stress (MPa)	c/t	Young's Modulus (MPa)
No. 1	3	Compressive	1892	1.392	7.29	208.8
	2	tensile		0.191		
No. 2	3	Compressive	1692	0.388	8.05	70.3
	4	tensile		0.048		
No. 3	2	Compressive	1920	1.117	11.29	154.5
	1	tensile		0.099		
No. 4	3	Compressive	1736	0.485	7.15	60.2
	3	tensile		0.068		
Average		Compressive	1810	0.845	8.45	123.5
		tensile		0.101		

Pull-down test

Outline of test

It is necessary to clarify the mechanical properties and collapse mechanism of rammed earth walls to devise seismic reinforcement and restoration plans. The collapse mode of rammed earth walls also differs depending on their construction method. Therefore, it is extremely important to clarify the construction methods and structural findings from the pull-down test for rammed earth walls. From the relationship between the pull-down load and the displacement, the collapse mechanism, mechanical properties, and construction methods of the rammed earth walls were clarified.

Test method

The pull-down test on the rammed earth walls at Paga Lhakhang was conducted in the out-of-plane and in-plane directions of the walls shown in Figure 8. The rammed earth walls subjected to the test were designated as Wall-1 to -4. Wall-3 was pulled down in the in-plane direction, and the other walls were pulled down in the out-of-plane direction. The height of Wall-1 was ~6.2m, which was almost from the ground line to the ceiling level of second story, and the width was ~4.1m. The height of Wall-2 was ~5.8m and the width was ~7.4m. The height of Wall-3 was ~6.1m and the width was ~2.3m. The height of Wall-4 was ~11.5m, which was almost from the ground line to the roof level, and the width was ~12.7m. Wall-4 was pulled down at the ceiling level of second story.

We connected the top of the rammed earth wall and the backhoe by a wire (Figs. 9 and 10). As the backhoe moves backward, the wire pulls the rammed earth wall down. During this time, the wire is subjected to tensile force, therefore rammed earth wall is subjected to component forces, which are divided into the compressive force in the vertical direction and the tensile force in the horizontal direction. To reduce the compressive force on the rammed earth wall, to load more pure horizontal force, and to ensure safety when the rammed earth wall collapses, the horizontal distance between the rammed earth wall and the backhoe was set to at least three times the height of the rammed earth wall (≥3h) (Fig. 9).

To avoid the local failure and to apply a distributed load on the wall, a wooden plate was placed on both the front and the back of the top of the rammed earth wall at the point where we applied the load; a hole was drilled through the wooden plate and the edge of the rammed earth wall for the wire to pass through, thus wrapping the rammed earth wall with the wire (Fig. 11). Wall-4 was pulled with two wires because of wire breakage during the pull-down test. The wire was attached to the forks of the backhoe to pull the rammed earth wall.

The load was measured by a tensile-type load cell (TLP-200KNB, Tokyo Sokki Kenkyujo Co., Ltd.) inserted between the wires, to which shackles (FH-20B, Tokyo Sokki Kenkyujo Co., Ltd.) were attached on both ends and the data was recorded on a smart dynamic strain recorder (DC-104R, Tokyo Sokki Kenkyujo Co., Ltd.). To measure displacement, the string was allowed to move along with the deformation of the rammed earth wall, and the displacement was rec orded on video. The relationship between the load and the displacement was obtained by synchronizing the time on the video and the computer used for load measurement.

(a) Wall-1 (out-of-plane).

(b) Wall-2 (out-of-plane).

(c) Wall-3 (in-plane).

(d) Wall-4 (out-of-plane).

Figure 8. Overview of rammed earth walls subjected to pull-down test.

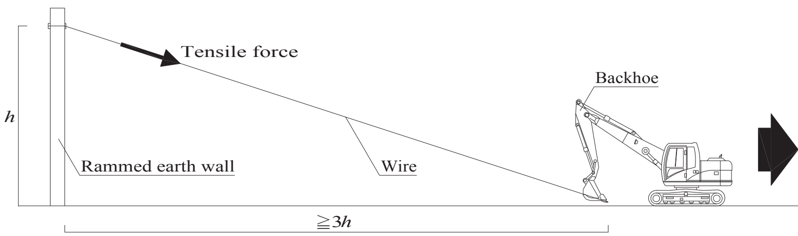


Figure 9. Schematic of pull-down test.

Figure 10. Overview of pull-down test.

Figure 11. Wooden plate.

Results and discussion

Figure 12 shows the collapse modes of Wall-1 to -4 and the load–displacement curves are shown in Figure 13. Wall-1 collapsed by the section loss of the rammed earth and restriction effect of the wooden member included inside the orthogonal rammed earth wall. Wall-2 and -4 collapsed by the section loss of the rammed earth caused by joists at the floor level of Paga Lhakhang. Wall-3 collapsed by sliding at the section loss of the rammed earth. The rammed earth walls showed very small deformation before the maximum load, and then, they suddenly collapsed after the maximum load.

The tensile stress of the rammed earth wall is estimated from the equilibrium of forces (Fig. 14). The compressive stress by self-weight is calculated as follows:

$$\sigma_{N1} = -\frac{W}{bD} = -\frac{bDh\rho}{bD} = -h\rho \tag{1}$$

where W = weight of upper part of destroyed wall; b = wall thickness; D = wall length; h = distance between top of wall and destroyed section of wall; · = density of rammed earth; and ·N1 = compressive stress generated by self-weight.

The vertical compressive stress by the component force of the diagonal pulling force is calculated as follows:

$$\sigma_{N2} = -\frac{P\sin\theta}{bD} = -\frac{Pa}{bD\sqrt{a^2+L^2}} \tag{2}$$

where P = tensile force on wire; · = angle between wire and ground level; a = distance from ground to destroyed section; L = horizontal distance from wall to backhoe; ·N2 = compressive stress generated by component force of diagonal pulling force P; f = distance from ground to bottom of wall; and H = wall height.

The tensile stress by moment is calculated as follows:

$$\sigma_M = \frac{M}{Z} = \frac{6P\cos\theta \cdot h''}{b^2 D} = \frac{6PLh''}{b^2 D\sqrt{a^2+L^2}} \tag{3}$$

where *M* = moment generated on destroyed section by diagonal pulling force *P*; *h'* = distance from top of wall to wire hole; *h''* = distance from wire hole to destroyed section; *Z* = section modulus of wall; and ·M = tensile stress generated by moment M.

The tensile stress of rammed earth ft is calculated as follows:

$$f_t = \sigma_{N1} + \sigma_{N2} + \sigma_M = -h\rho - \frac{Pa}{bD\sqrt{a^2+L^2}} + \frac{6PLh''}{b^2 D\sqrt{a^2+L^2}} \tag{4}$$

Table 2 summarizes the calculation results of each stress on the rammed earth walls. The tensile stress of rammed earth ranges from 0.012 to 0.370MPa with an average of 0.162MPa. The tensile stress estimated from the results of pull-down tests is similar to that obtained from the material tests. However, more data is required from the material or full-scale tests of rammed earth because the currently obtained data shows wide variations. In addition, the tensile stress of the rammed earth wall must be estimated in consideration of the restriction effect of the orthogonal wall.

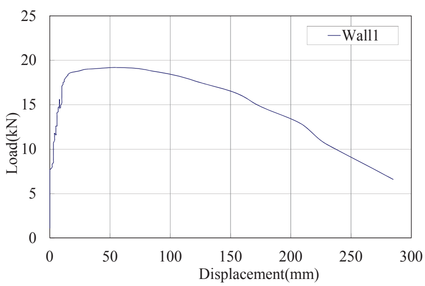
(a) Wall-1 (out-of-plane)

(b) Wall-2 (out-of-plane)

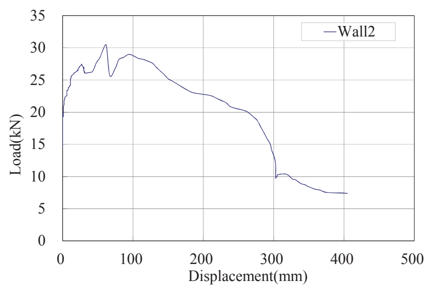
(c) Wall-3 (in-plane)

(d) Wall-4 (out-of-plane)

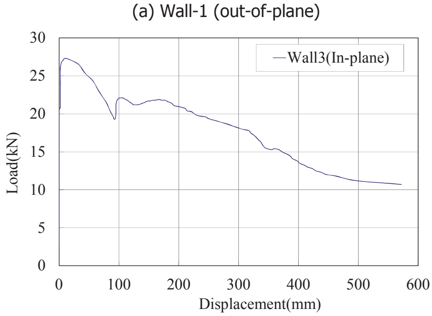
Figure 12. Collapse mode of rammed earth walls.



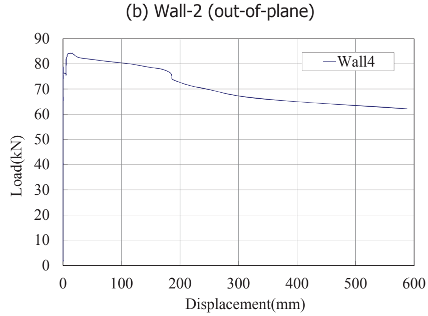
(a) Wall-1 (out-of-plane)



(b) Wall-2 (out-of-plane)



(c) Wall-3 (in-plane)



(d) Wall-4 (out-of-plane)

Figure 13. Load–displacement curve.

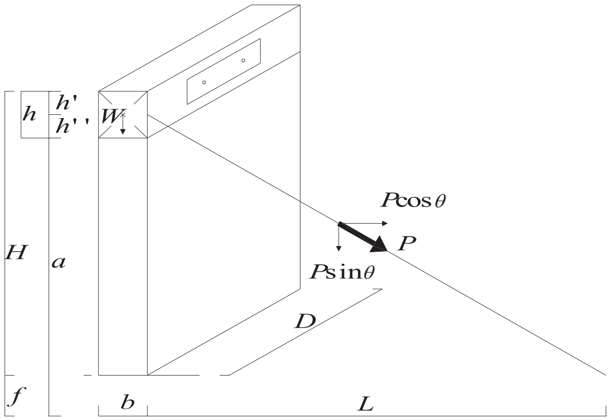


Figure 14. Schematic of force balance.

Table 2. Calculation results of tensile stress.

Stress (MPa)	σ_{N1}	σ_{N2}	σ_M	f_t
Wall-1	-0.017	-0.002	0.031	0.012
Wall-2	-0.052	-0.002	0.122	0.069
Wall-3	-0.049	-0.008	0.428	0.370
Wall-4	-0.112	-0.004	0.314	0.198
Average	-0.058	-0.004	0.224	0.162

Conclusions

In this study, material tests were conducted on rammed earth core samples extracted from the Paga Lhakhang to determine the compressive and the tensile strength and Young's modulus of rammed earth. Pull-down tests of the four remaining rammed earth walls at the Paga Lhakhang were conducted, and the relationships between the pull-down load and the displacement and their collapse mechanism were clarified. The main findings of this study are as follows:

1) The material tests indicate that as the density increases, the compressive and the tensile strength and Young's Modulus tend to increase;

2) The pull-down tests indicate that the rammed earth wall shows very small deformation before the maximum load and then suddenly collapses after the maxi-mum load;

3) The pull-down tests indicate that the rammed earth wall collapses in the out-of-plane direction upon section loss of the rammed earth and the connection with the orthogonal rammed earth wall, and it collapses in the in-plane direction by sliding upon section loss of the rammed earth;

4) The tensile stress of rammed earth as estimated from the results of pull-down tests is similar to the results of material tests, although they show wide variations.

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Basalt ropes: a new product for the rehabilitation of historical masonry

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Rehabilitation of historical masonry is a demanding task, especially in seismic zones, where vulnerable buildings and structures can suffer severe damages and losses, as recent earthquakes testify. Lessons learned by previous experiences and the knowledge acquired through researches allowed us to say that one of the most important characteristic that historic masonry should have is that of a monolithic behavior. If this characteristic is absent, strengthening bearing masonry giving it a transversal monolithic behavior is one of the first consolidating actions to do to improve its seismic performance. Stitching masonry through basalt fiber ropes is an innovative technique, able to connect the several masonry elements and to convey it a monolithic behavior. The results of tests directed to evaluate performances against "in-plane" actions (vertical compression, shear and compression) indicate the effectiveness of this retrofitting system, increasing the monolithic behavior of masonry wall specimens.

Introduction

As shown by several authors (Giuffrè, 1991; Doglioni, 1994), historical masonry buildings subjected to earthquake do not show a global structural behavior. If the building was made through good quality masonry, it has the tendency to split itself in several parts, called macro-elements which respond as single units to seismic action, and for which the main features of the collapse mechanisms are at least approximately known. So historical masonry buildings response to earthquake is the one offered by the number of macro-elements. Once macro-elements and their most probable collapse mechanisms are identified, possible damages can be predicted and countermeasures adopted. Masonry quality defines if this approach could be considered reasonable: in fact only good quality masonry is able to guarantee monolithic behavior. On the contrary, if it has been used poor quality masonry, a chaotic failure has to been expected and it is not right to reasoning about failure mechanism activation. Moreover, also a low earthquake could be enough to determine disastrous collapses, as has been seen in L'Aquila earthquake in the year 2009. Masonry structural effectiveness directly depends from its quality, and when it has been made following "rule of art" prescriptions a masonry can be considered of "good quality" (Fig. 1).

Figure 1. Masonry structural effectiveness directly depends from its quality: good quality masonry subjected to out of plane loads responds like a monolithic body (left), while poor quality masonry is characterized by a chaotic failure (right). For medium quality masonry (center), can be expected a middle behavior.

Essential features are presence of transversal connection elements, horizontality of the courses, the stagger of the vertical joints, shape and dimension of the single units, mortar quality and material strength of single units (Donà & De Maria, 2011). If the lacking of these features could be recognized, every structural assessment is quite reliable and the first thing to do is to improve masonry quality. A masonry typology often found in Italian historical building heritage is the "three-leaf wall", where an inner core of rubble material is included between two outer brick or stone shell. If three-leaf masonry presents poor or absent connection between the external leaves, due to the lack of elements so long to crossing wall section, it could result very weak under eccentric and horizontal loads.

In fact, it could meet problems of buckling of the external shell, due to its slenderness, and of weak resistance to action that could involve out-of-plane mechanisms, due to a global behavior nearest to two thin panels than a monolithic one (Fig. 2).

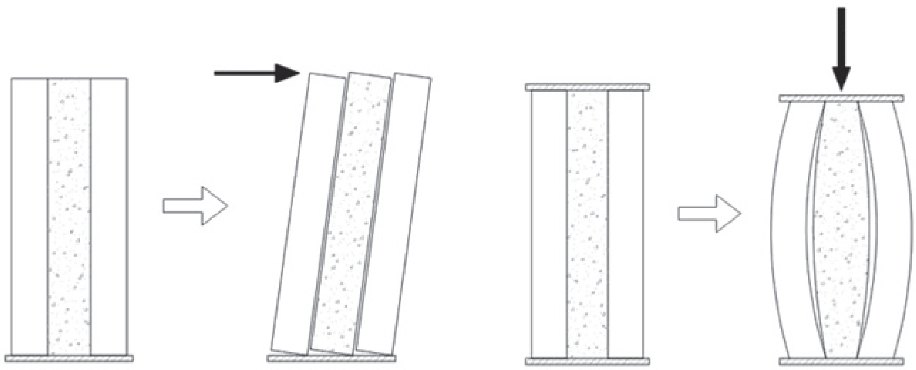

Figure 2. Vulnerability of "three-leaf wall" subjected to horizontal load.

Nowadays there are many different techniques for strengthening masonry panels. Some are traditional (and usually most invading) like grout injection, jacketing with reinforced plaster or the introduction of artificial connectors (metallic rods) and some other could be considered innovative, like the use of composite strips (Corradi et al., 2002). However, when it is wanted to maintain the original aspect of the masonry brickwork, these techniques cannot be applied. A possibility could be represented by repointing of the masonry joints, which consists in replacing the damaged mortar on the wall surfaces inserting also in mortar bed joints steel rods as reinforcement that could convey an important strength increase (Modena et al., 2002; Tinazzi et al., 2000; Valluzzi, 2005). Recently, innovative reinforcing fibers and products, like basalt ones, are emerging in constructions field. From the awareness that one of the worst structural defects of an historic masonry wall is the lack of monolithic behavior, arises the idea of a strengthening technique able to connect the several masonry elements, stitching them. The proposed technique is based on the reinforcement and connection of external masonry shell of "three-leaf wall" (this work focuses on this masonry typology) using basalt fiber ropes. The technique has been already tested using synthetic adhesives (resins) and showed good results in improving the behavior against compression load (Quagliarini et al., 2012a; Quagliarini et al., 2012b). In this paper, the results of an experimental campaign aimed to test the technique effectiveness also excluding synthetic adhesives (with an enhancement about reversibility an sustainability) are presented.

Materials and methods

Basalt fibre ropes

Basalt is a natural material that is found in volcanic rocks originated from frozen lava. Continuous basalt fibers are obtained by melting basalt and are characterized by high modulus, heat resistance, good resistance to chemical attack and seem to be a good alter-native to glass fibres (Van de Velde et al., 2003; Wei et al., 2010; Sim et al., 2005). In construction field, basalt is proposed in form of short fibres for insulating material (basalt wool), for reinforced concrete (chopped fibres) or like reinforcing material in restoration and rehabilitation of concrete (Sim et al., 2005) and masonry structures (Papanicolaou et al., 2011), or like reinforcing material for fibre reinforced polymer (FRP) bars used in concrete technology (Brik, 2003). It is also important the application in passive fire protection field (Landucci et al., 2009). Continuous basalt fibres can be processed with classic textile transformation to obtain also ropes, unlike other kinds of reinforcing fibres. Basalt fibres ropes of 4mm of nominal diameter (declared by manufacturer), have been used in this experimental program (Fig. 2). A mechanical characterization of this product has been developed by (Quagliarini et al., 2012c) and reported in Table 1.

Figure 3. The basalt fibre rope.

Table 1. BF ropes mechanical features (values from Quagliarini et al., 2012c).

Basalt fibre rope mechanical features	
Nominal diameter [mm]	4
Failure load Fmax [N]	3157.27
Failure strain εmax	0.05

Technique description

The proposed technique aims to connect outer brick masonry shell to exclude buckling failure and to impart monolithic behavior, without modify masonry original aspect. It consists in insertion of basalt fibre ropes in the mortar bed joints previously partially cleared out and refilled with simple mortar only to cover the ropes and restore original appearance and homogeneity. The holes disposition has been chosen following an appropriate and tailored designed path. The main operative phases for a correct execution of the intervention are: (i) execution of crossing hole by means of drill equipped with a bit long as the wall depth; (ii) cutting of the bed mortar joints creating a groove at least 10mm high and about 30-40mm deep on the two wall faces; (iii) removal of powder or rubble; (iv) placing of a first layer of mortar; (v) placing of the basalt fiber rope; (vi) placing a second layer of mortar over the rope to cover it sufficiently. Respect insertion of steel or FRP bars, as in repointing application, come out the opportunity of working with a lighter and versatile material and able to connect the masonry elements also in the panel depth direction.

Experimental program

To assess the effectiveness of proposed technique, laboratory tests have been performed. The masonry reproduced was the "three-leaf wall", where an inner core of rubble material is included between two outer brick shell. 12 "three-leaf" masonry samples have been made, and tested under vertical compression (6) and shear-compression (the others 6) load. The masonry wallets have been made on steel plates (to have the possibility of easily move them) and cured in the same condition for the same time (about 60 days). Specimen dimensions (better presented in Fig. 4) have been chosen similar to the one suggested by the Italian standards on masonry compression test (UNI EN 1052-1) and comparable to the ones used in other analogous experimental experience available in literature (Binda et al., 2006; Vintzileou et al., 2008). Before testing, 8 masonry samples have been reinforced through proposed technique, in particular in 4 of these, BF ropes have been arranged only in horizontal bed mortar joints (reinforcement called "RO", Fig. 5), while in the other 4, BF ropes have been inserted also in vertical bed mortar joints (reinforcement called "RR"). Only 4 masonry samples have been tested in unreinforced condition ("NC"). The experimental program is better explained in Table 2. Figure 6 reports the final aspect of masonry wallets at the end of reinforcing process. Vertical compression and shear-compression tests (performed under load control) have been carried out placing sample into a steel frame (Fig. 7). Forces has been applied through pressure jacks and measured by means of pressure transducers; vertical and horizontal displacements have been monitored by means of transducers placed on the top and on the sides of the wall, in order to measure transverse deformations of wall and separation between exterior leaves and filling material.

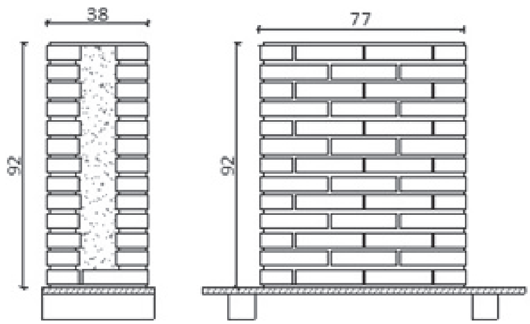

Figure 4. Masonry sample metric survey (values in centimeters).

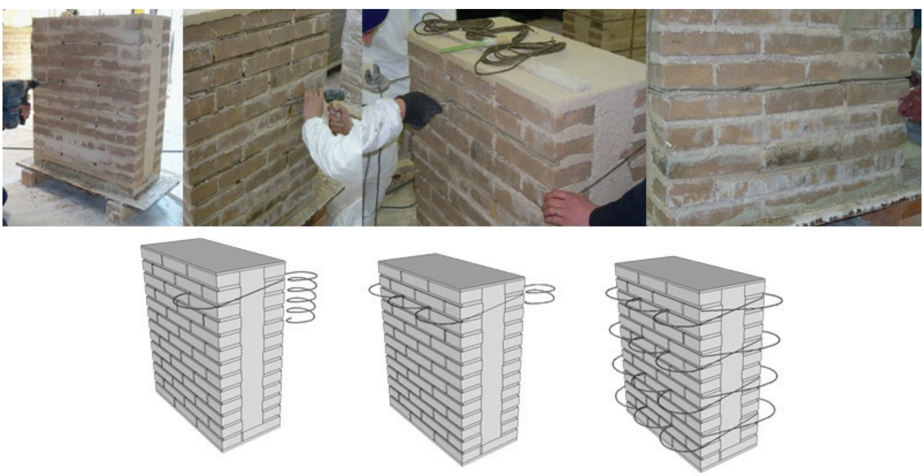

Figure 5. Operative phases for the application of "RO" reinforcement.

Table 2. Experimental program.

Masonry sample built: n.12					
Samples subjected to vertical compression tests: n.6			Samples subjected to shear/compression tests: n.6		
N.C. n.2	R.O. n.2	R.R. n.2	N.C. n.2	R.O.n.2	R.R. n.2

Figure 6. The final aspect of masonry wallets at the end of consolidating process. Sample after "RO" strengthening on the left and after the "RR" one on the right.

Figure 7. The test device used for vertical compression test (left) and the test device used for shear-compression test (right).

Masonry components: mortar, brick and inner core mixture

The tested technique is turned to Italian historical building heritage, so the material used in external shell of specimen is brick masonry. A non-hydraulic lime mortar was adopted to build the samples, mixing 1 volume lime putty (with a volume ratio between water and lime powder of 0.7) to 3 parts washed, well graded, sharp sand, according to literature experiences (Lanas, 2003; Faria, 2008; Moropoulou, 2005). For materials characterization flexural and compressive tests on mortar samples and compressive tests on bricks have been carried out according to Italian standards UNI EN 1015-11 and UNI EN 772-1. Average results obtained are reported in Table 3. As regard inner core, a mixture of flake, rubble bricks and mortar, was used, according with historic handbook (Rondelet, 1817; Sacchi, 1879). To obtain mechanical features of this mixture, compressive tests were carried out on three $150\times150\times150 mm^3$ cubes, cured and tested following UNI EN 12390-1-2-3 recommendations. Average results obtained are also reported in Table 3.

Table 3. Average results of test carried out to obtain mechanical characterization of masonry component (brick and mortar) and inner core. ff represents mortar flexural strength, fc mortar and brick compressive strength, E30-60 elastic modulus secant modulo values corresponding, respectively, to 30% and 60% of maximum compressive strength. All these values are reported in MPa. S.D. is the standard deviation of values recorded.

Material	ff [MPa]	S.D.	fc [MPa]	S.D.	E30-60 [MPa]	S.D.
Mortar	0,39	0,057	0,468	0,109	26,2	19,68
Brick	---	---	16,9	0,6	358,16	74
Inner core	---	---	0,159	0,045	6,95	2,5

Results

In this section, the main results concerning the testing of the three-leaf masonry samples are discussed. As predictable, under vertical compression load, unreinforced samples exhibit the same failure mode, characteristic for three-leaf masonry: separation between the interior filling material and the external leaves and buckling collapse of one of them (Fig. 8, on the left). This fact is probably due to the inevitable eccentricity of the applied load. Reinforced samples, instead, exhibit a different failure mode: the external leaves work together to carry the applied load and the failure occurs due to overcoming of material ultimate strength (Fig. 8, in the center and on the right). This fact is well underlined by the cracks appeared on bricks of reinforced samples: only in that cases the materials have been entirely subjected to the stress generated by applied load (Fig. 9).

Figure 8. Three-leaf masonry samples after vertical compression tests: on the left the unreinforced ones ("NC"), in the center the ones strengthened through BF arranged only in horizontal bed mortar joints ("RO") and on the right, the ones strengthened through BF arranged both horizontal and vertical bed mortar joints ("RR"). The sample aspect after test shows the effectiveness of the proposed technique.

Figure 9. Cracks appeared on bricks of reinforced samples subjected to vertical compression test.

Comparing the graph that binds vertical stress and transverse strain (Fig. 10), come out as the intervention, discarding buckling collapse and better exploiting material properties, contributes to impart a monolithic behavior to the masonry panel. In fact, the stitches application is able to reduce transverse strain of 70% ("RO") and 80% ("RR").

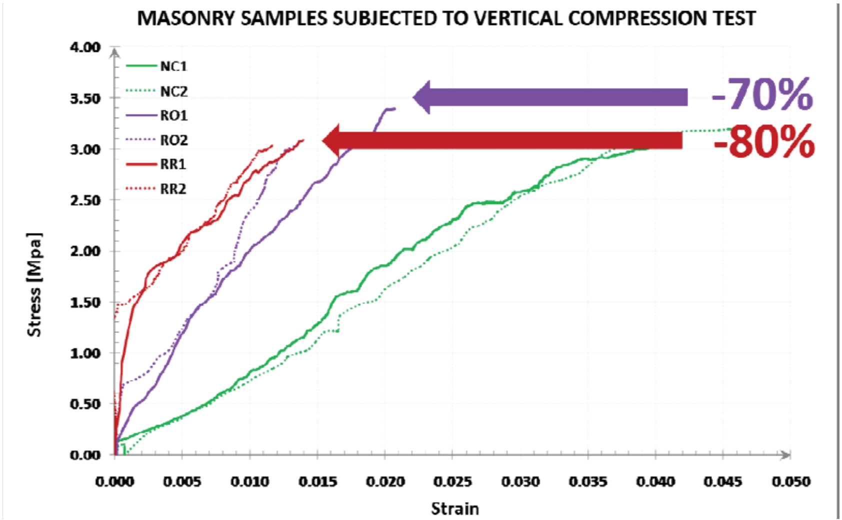

Figure 10. Comparison between stress-transversal strain graphs recorded for three leaf masonry samples subjected to vertical compression test.

Also from shear-compression tests come to light that under this kind of load three-leaf masonry has a behavior nearest to several thin panels than a monolithic one. In fact in "NC" samples, it could be seen a crack pattern typical of shear stress (Fig. 11, on the left) and a separation between interior core and outer brick leaf. In this case the "RO" strengthening is not able to produce clear improvements, on the contrary of the "RR" one that seems to be able to modify panel failure mode (Fig. 11, on the right) in the way to sustain a more serious crack pattern, and to improve substantially the system pseudo-ductility (Marcari G. et al., 2007) as can be seen in Figure 12.

Figure 11. Three-leaf masonry samples after shear-compression test: on the left the unreinforced ones ("NC") and, on the right, the ones strengthened through BF arranged both horizontal and vertical bed mortar joints ("RR").

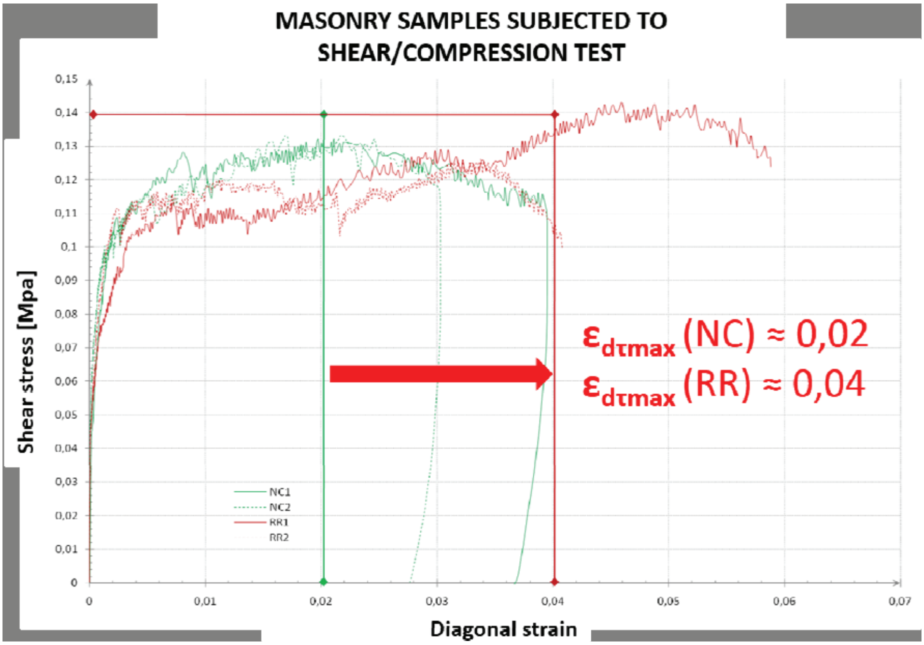

Figure 12. Comparison between shear stress/diagonal strain graphs recorded for three leaf masonry samples "NC" and "RR" subjected to shear compression test.

Conclusion

This paper presents the results of an experimental program with the aim of investigate the strengthening of "three-leaf" masonry walls through the employment of basalt fiber ropes, used for stitching masonry panel. The proposed technique is able to change the failure mode of "three leaf" masonry wall, exploiting material properties, and to determine a transverse strain reduction under compression load: in brief it is able to impart to masonry monolithic behavior. It also means that it is able to improve the ultimate strength of bearing panel that, in a real wall, more slender than the tested ones, could be strongly limited by buckling failure. Moreover other advantages are represented by the fact that: (i) the application is very fast and so cheap, (ii) the material used (basalt) presents an high compatibility with masonry: stone stitches stone; (iii) the reinforce is almost totally reversible; (iv) it is invisible, respectful of masonry original aspect; (v) it improves but not replaces original materials, (vi) it is fire and chemical resistant and, finally, (vii) it does not use synthetic adhesives. On the other hand, it has to be said that tests have been conducted on a masonry typology characterized by no features that could suggest a monolithic behavior, with a global behavior nearest to two thin panels than a monolithic one. So further developments of this work should be directed to investigate the technique pertinence also on others masonry typology. Furthermore, also the evaluation of the technique effectiveness against other kinds of load (i.e. "out-of-plane" loads) should be studied in depth.

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The need to link the tangible with the intangible: the challenges of infinite design life and perpetual maintenance

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The challenge of providing a heritage home with perpetual maintenance requires one to think beyond the individual home's boundaries to the collection of other heritage homes in the region surrounding it. The issue with this change in scale from the one to the many is to verify that enough work exists in the region in question for the trades responsible for the individual home's maintenance.

A formula to calculate a wood sash maker's work boundary is proposed. This formula calculates the number of new in-kind replacement windows a given region would generate. This value represents the work needed to support a wood sash maker and apprentice through their professional lives and by extension, guarantee a trans-generational transfer of knowledge. The formula is applied to Nova Scotia.

The larger issue identified in this paper is the symbiotic relationship between a heritage home and the trades who work on the home. Any definition of sustainability needs to recognize and embrace this relationship.

Maintenance in perpetuity

Most buildings are not expected to last forever (Addleson, 1972). The exception is a designated heritage building.

Once heritage status is confirmed, the building's life cycle no longer has an end of life phase (Feilden, 1982). With this change in the building's design life span comes a change in society's relationship with the building. Of particular interest in this paper is how the change to an indefinite design life brings into focus the dependence a heritage building and the trades and crafts responsible for maintaining it in perpetuity have to their local community.

The conversation starts with a review of how a building's relationship to sustainability changes once it becomes a heritage property.

Sustainability

Most interpretations of sustainability (Jorgensen et al., 2013) are based on the Brundtland definition of sustainable development: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987). Today in Nova Scotia, most non-heritage building are built, retrofitted, and when maintained, to a standard that minimizes the amount of operating energy needed to create a conditioned indoor space[1]. This single-minded approach toward sustainability emphasizes operating energy conservation and, by extension, minimizing the environmental impacts associated with the burning of fossil fuels.

Conserving operating energy can be detrimental to a building's durability whether it be heritage designated or not (Lstiburek, 2008). Yet, this single-issue conservation agenda can be justified because the local culture puts more economic, cultural and ecological value on limiting operational energy consumption than it does on a premature design life and its associated impacts.

With a heritage building, maintaining the building's design life is paramount. Longevity rather than energy efficiency, concerns for trans-generational knowledge and the cultural values associated with the building become the primary concerns for any maintenance program (Jerome, 2010). Building codes are changed (Part 10, Nova Scotia Building Code Regulations, 2011) and reducing operating energy consumption may not be a priority. It is an acceptable, albeit an uncommon practice, to decide to not insulate a heritage building's walls as part of a proposed rehabilitation/maintenance program (Rose, 2005).

Society puts more value on the cultural sustainability of a heritage building. It is no longer considered a machine optimized to meet specific intra-generational objectives but an icon whose trans-generational subjective values outweigh its intra-generational environmental impacts (Jackson, 2005).

Authenticity

A heritage building is made up of a set of materials and systems. The idea of an infinite life span applies to the whole building, not its parts. There is an expectation that over time, the building's parts will wear out and need to be maintained on an as need basis guided by the test of authenticity and practiced according to two principles of heritage conservation, minimal intervention and repair rather than replace in-kind (Alderson, 2006).

These practices' roots go back to Ruskin and have been a consistent theme in all subsequent Western conservation charters and protocols. This approach is intended to keep as much of a building's original fabric in place (Venice Charter, 1964). Along with the values these practices promote comes a bias toward the tangible.

This bias has a detrimental effect on the ability to safeguard the built environment's intangible heritage: the trades and crafts tasked with working on the buildings. As presently practiced, the pursuit of authenticity does not create a sustainable environment with in which a heritage building can be maintained in perpetuity.

For a building maintenance skill to last between generations, the symbiotic relationship between the tangible and intangible has to be nurtured. What is being suggested is that the practice of authenticity be changed or adapted to include the values of the intangible. An exploration of this change is not the direction of the present paper, but it is mentioned as one of the institutional issues that need to be addressed if a heritage building is to be maintained in perpetuity.

The intangible

An example of a traditional building trade that has moved from the mainstream to the periphery is wood sash making. In Nova Scotia, most heritage buildings at one point in their design life had traditional or historic wood windows. These windows are made from solid pine, and can most easily be identified by their single pane, true divided light sashes. The push to energy efficiency has resulted in a number of these wood windows being replaced in both non-heritage and heritage buildings over the past forty years. However, there are still historic windows in the province as well as a demand for replacement in-kind work, the replacement of the old window with a new replica.

Good work, work that is profitable, challenging and not derivative, is sustainable. In the case of wood windows, repair work such as epoxy fill, replacement of sills or re-puttying will meet the demand requirement of "work on the table", but it is not the type of work that will allow the trans-generational transfer of the required skills that need to be learned about how to make a window.

The work must not only challenge the trade, but it has to be of the type they learned. A window maker makes windows. Replacement in-kind of a window is an example of this type of work. It is in making the new that they are doing what they learned.

There must also be enough of this work so that the craftsperson can maintain his or her skill levels. The objective is for the quality of craft to be equal to past generations, and at the same time, allow what the present generation knows be passed onto the next generation.

Too much repair work will not meet these conditions. It is ultimately derivative work. Craftsmen copying and pasting onto existing pieces are not challenged to create new pieces.

For a window maker to be available when needed for a single heritage building, there has to be enough work in the vicinity of this building and the sash maker's shop. As mentioned above, society applies the ideas of sustainability differently to a heritage building. If at some point, the test of authenticity is expanded to include both the tangible and intangible, then the opportunities for work have increased. Even if the above two conditions offer a work opportunity, there is still the question of is there enough replace in-kind work in the vicinity of the window shop.

The wood sash maker's work boundary

Borrowing an idea from life cycle thinking, the question of whether there is enough work comes down to a boundary identification problem. There are two choices: a single building boundary or a wood sash maker's work boundary.

The single building boundary focuses on the single building and its maintenance needs. Immediately one recognizes that replace in-kind work as part of a single building's maintenance plan would occur intermittently through a generation and re-occur on a trans-generational scale. This is not enough work to keep the sash maker trade viable as it relates to the single building.

The wood sash maker's work boundary encompasses the number of heritage and non-heritage houses in a given area that are required to generate enough in-kind window replacement work to keep a craftsperson and apprentice employed through their professional lives. A constant, available material supply is assumed a given for the present exercise. It is assumed that the heritage houses in this area that need window replacement work are a subset of the larger house population.

A distinction has been made between houses and buildings. Buildings include houses, commercial properties and apartments. For the purposes of the present work, given the author's expertise, there is a focus on houses.

The following heritage window in-kind replacement equation (1.0) calculates the number of in-kind replacement windows that would result from a set of heritage houses per year.

$$W \text{ replaced in-kind} = (H \,.\, fhh \,.\, fw) \,.\, (Wwh \,.\, fwi\text{-}k). \tag{1.0}$$

W replaced in-kind = number of heritage windows that will be replaced in-kind per year within the boundary;

H = total number of houses within the boundary;

fhh= fraction of heritage houses within the boundary;

fw = fraction of heritage houses that will have window work done within the boundary per year;

Wwh = number of windows per heritage houses that will have window work done within the boundary; and

fwi-k = fraction of windows that need to be replaced in-kind from the total number of windows per heritage houses that will have window work done within the boundary.

As an example, values are used to calculate this boundary for a sash shop based in Halifax, Nova Scotia. These numbers are first order approximations and they should be assessed as such.

W replaced in-kind: 348 (Parsons Lumber Company Ltd. 2013)

It takes 11.5 man-hours to fabricate a 6/6 30″ x 30″ vertical slider. 348 6/6 30″ x 30″ vertical sliders or their equivalent need to be made in 50 weeks per year to keep a craftsperson and apprentice occupied.

fhh : 0.01

This value is based on information from the Halifax Regional Municipality website[2].

fw : : 0.01 (Parsons Lumber Company Limited. 2013)

This value is based on author's observations of the heritage window market in Halifax Regional Municipality over the past eight years.

Wwh : 20 (Parsons Lumber Company Ltd. 2013)

This value is based on field observations of heritage buildings in the Halifax Regional Municipality.

fwi-k: 0.5 (Parsons Lumber Company Ltd. 2013)

This value is based on author's observations of the heritage window market in Halifax Regional Municipality over the past eight years.

H = 348,000 houses. In Nova Scotia, 348,000 homes (heritage and non-heritage) would be in an area that includes Halifax Regional Municipality and its surroundings.

To maintain one house, one needs a region

Several iterations of equation (1.1) were executed using different fraction values. The above example is representative of this larger set of work.

The greatest change in values of H occurred as a result of order of magnitude changes in the values of the three fractions. Of the three fractions, the one with the greatest potential for an order of magnitude change is fhh, the fraction of heritage houses within the boundary. In the Halifax Regional Municipality, heritage designation is voluntary.

While the specific values for H varied with each calculation, the set of calculations generated answers for H that were within the same order of magnitude (100,000s). These results suggest that the wood sash maker's work boundary is on the regional scale. The extent of this boundary will vary by region and local conditions but the conclusion is the same. The perpetual maintenance of a single heritage home depends on a pool of heritage and non-heritage homes in the 100,000s contained within a region. Working within this boundary, and taking the sash maker's shop as the boundary area's hub, a sash maker will have enough work for both the present and next generation.

It is not an unexpected conclusion that to keep a building trade economically and culturally viable it needs more work than that which can be generated by a single residential scale heritage house; but there is also another set of conclusions that can be drawn from the work. The sustainability of a perpetual maintenance program depends on recognizing and supporting the relationship between the tangible and the intangible. There is a specific, mutual symbiotic relationship between a set of buildings and the trades responsible for their maintenance. This relationship has to be made explicit in the dialogue about any maintenance program. To date, the recognition of this relationship has come in the form of a unique definition of sustainability as it applies to heritage buildings, the start of a conversation about how the concept of authenticity can include the intangible and what was described in this paper, the work boundary for a given niche building trade.

The boundary idea suggests that there is a critical number of heritage homes required within a specific area for any one of these heritage homes to be maintained in perpetuity. If the number of heritage homes within the region drops below this critical number, the support structure needed to maintain this set in perpetuity will crash. The idea of sustainability as it applies to this problem requires a solution at the community scale, because only at this scale can the relationship between the tangible and intangible be identified and supported.

One has to think beyond the single building when interested in maintaining its infinite design life since there is only so much that can be done at the single building scale. The problem identified in this paper is at the community scale. Ultimately, it will come down to the compromises a community is prepared to make about its heritage buildings that will decide whether these buildings will exist between generations. Any decisions made about a community's heritage buildings must be done knowing the impacts these decisions will have on the trades responsible for maintaining them.

Endnotes

[1] "Energy Solutions" accessed December 16, 2013, www.efficiencyns.ca/energy-solutions/?user-type=4.

[2] http://www.halifax.ca/qol/AffordabilityStats.html#housingtype;

https://www.halifax.ca/planning/HeritageProperties/#ListHeritageProperties.

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In-situ monitoring of thermal refurbishment on pre-1919 properties in Scotland

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This work describes the use of in-situ monitoring techniques to establish the building performance of pre-1919 traditionally constructed buildings and evaluate different thermal refurbishment strategies using component U-values as a recognised indicator of building envelope performance. The buildings monitored were of traditional construction (solid wall), some of which were listed or in a conservation area, constructed from lime-bonded rubble or ashlar, typically circa 500 mm thick, with natural slate or tile roofs, timber doors and single glazed windows. In-situ pre-intervention U-values were obtained after monitoring each building component constituting the existing building envelope and again at post-intervention; where insulation materials were added at varying interfaces. Using the improvement data two case studies were modelled using the UK Standard Assessment Procedure (SAP) software; showing that significantly reduced levels of building heat loss and carbon dioxide emission were achieved after thermal rehabilitation.

Introduction – context & background

This paper sets out the pre and post-intervention monitoring work carried out by the SEC at Edinburgh Napier University in collaboration with Historic Scotland Conservation Directorate as part of the energy efficiency refurbishment pilot scheme for traditional buildings. The research starts by measuring the actual thermal transmittance of building components followed by quantifying the thermal improvements achieved by selected upgrade measures.

The research originates as the topic of refurbishing or retrofitting the existing housing stock in Scotland is a concern to the Scottish Government, hence the involvement of Historic Scotland who have the responsibility of safeguarding Scotland's historic environment. The priority is to reduce energy demand and carbon dioxide (CO_2) emissions, currently attracting much attention in the UK (Jones, 2013). Although the focus of the current research is based in Scotland, the results are applicable to the UK and other EU countries where large numbers of a similar archetypes exist and retrofit is of interest. Traditional and historic housing have shaped the urban landscape for centuries, therefore evaluating the thermal performance of these buildings is a priority in meeting global targets.

Current scenario - the housing stock & energy use/ CO_2

Currently the UK housing stock comprises of more than 27.3 million dwellings of different archetypes and ages; with differing thermal performance. It is estimated that 5.8 million dwellings in the UK were constructed before 1919, as shown in Figure 1a, this is 22% of the UK housing stock (Palmer, 2012). Scotland has 2.37 million households; 459,000 of which are pre-1919 construction, typically considered to be poor energy-performing houses unable to provide required internal thermal comfort for occupants. In the UK fewer than 180,000 new homes are built each year (Palmer 2012), balanced against a small percentage of homes which are demolished or upgraded; resulting in an impoverishing housing stock that is thermally poor (Palmer, 2012).

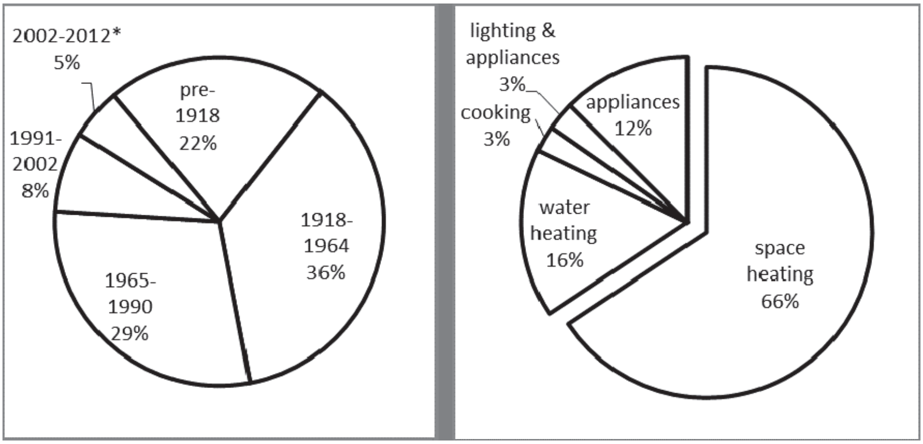

Figure 1. a. Age distribution of UK housing stock (Palmer, 2012); b. Percentage breakdown of typical household energy consumption (DECC, 2013).

Conventionally the energy performance of houses is embedded during design and construction stage. Opportunities for enhancing energy efficiency only arise during infrequent refurbishment activities. Traditional solid wall buildings typically have a wall thickness of over 500mm and are perceived as thermally poor with high fabric and ventilation heat loss, especially during the heating seasons. This is due to a thermally inefficient envelope, with high U-values and low air-tightness, or poor permeability.

Around 50% of the UK's energy use and carbon dioxide emissions are associated with buildings, of which 28% is attributed to housing (DECC, 2013). Figure 1b, shows the percentage breakdown of energy use in the UK domestic setting. 66% of all household energy use is related to space heating (DECC, 2013), this is a significant amount therefore warrants an effective strategy to reduce fabric and ventilation heat loss through the building envelope (Palmer, 2012). Recent surveys and studies have shown that 7.8% of pre-1919 dwellings are failing to meet tolerable standards; accounting for 49% of the dwellings that fail thermal performance criteria set by the Housing (Scotland) Act 2006 (Scottish Parliament, 2006). Nationally published statistics in the recent Scottish House Condition Survey, (Scottish Government, 2011) show that pre-1919 dwelling types contribute more to domestic CO_2 emissions than any other house age.

Historic building architecture

The properties featured in this paper are typical examples of construction types in Scotland dating before 1919. All of the properties are of traditional construction (solid wall), and some are catalogued for their preservation (listed). Most are constructed from lime-bonded stone rubble or with both rubble and an ashlar frontage. Wall elements are typically 400 to 600 mm thick, with natural slate or tile roofs, and timber floors, windows, and doors. The properties in this research paper have been selected from eight sites which represent a range of building types from across Scotland.

Methodology

This paper describes a study assessing in-situ measured U-values from a range of traditional building elements and components: walls, floors, ceilings and windows. This paper presents the results of a range of thermal enhancements applied to two selected dwellings.

Principles for investigating thermal transmittance

Measuring the thermal transmittance, or U-value, through elements of traditionally constructed buildings provides an insight to the thermal performance of the envelope of that building. The U value, of a building element or component is defined in BS EN ISO 7345:1996 as the "heat flow rate in the steady state divided by the area and the temperature difference between the surroundings on each side of a system". Its units are defined as watts per meter squared degree Kelvin (W/m^{2}K).

The testing methodology for calculating the in situ U value measurements has been applied by Baker (2008), Baker (2011) and Rye (2011). ISO/DIS 9869-1:1994 was followed to conduct In-situ U-value measurements presented and discussed in this paper.

The methods set out in BE EN ISO 6946:2007 for the calculation of steady state U-values were used, in conjunction with BE EN ISO 10456: 2007 to derive the thermal conductivity values for each material. These calculations were performed to validate the in-situ measurements.

To obtain a baseline figure, pre-intervention in-situ U-value measurements were obtained of the building component, following that the properties underwent thermal upgrading (retrofitting) in the form of insulation being added to various elements. Concluded the retrofitting, the U-values were re-measured, thus comparing the pre and post-intervention U-value and quantify the improvements.

Sensor type

The in-situ U-value measurements were taken using Hukseflux HFP01 thermopile-based heat flux transducers (Fig. 2) of 80 mm diameter and 5mm thickness. The expected typical accuracy averages ±5%. These were attached internally to each building element being tested throughout the period of monitoring, typically above 14 days as described by Baker (2011). Where possible, two of these devices were co-located in order to promote spatial averaging, and to provide protection against potential equipment failure.

The elemental U-values were determined by recording differential voltage from the heat flux transducers through the element together with internal surface and external air or surface temperature using calibrated K-type thermocouples (Accuracy: ±0.5°C) both connected to Grant Squirrel data loggers with 24bit A/D conversion resolution (Accuracy ±0.1°C).

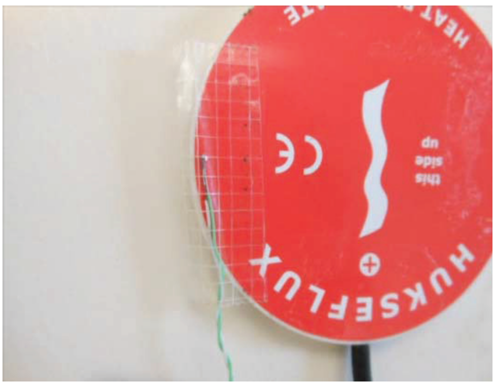

Figure 2. K-type thermocouple mounted to face of heat flux transducer, placed on test wall.

Where required, calibrated Tinytag temperature (Accuracy ±0.3°C) / humidity loggers (Accuracy ±3.0% RH at 25°C) were used for verification purposes and where thermocouples could not be affixed adequately.

Calculating the building energy performance

The Standard Assessment Procedure (SAP) is the UK's adopted software for complying with the European Directive 2010/31/EU for energy performance rating. It produces an energy performance certificate providing ratings for energy performance and environmental impact (CO_2). This is achieved through the calculation of space heating required (kWh/m²/year) to maintain an internal temperature whilst balancing heat losses and heat gains. External temperatures are derived from one national weather file and internal temperatures accumulate the useful gains such as metabolic and solar gains, and heat losses from fabric and ventilation. For the normal SAP heating schedule, the heating season comprises 68 weekend days with 16 hours of heating and 170 weekdays with 9 hours of heating (2 hours in the morning and 7 hours in the evening). Summer months are included here only for consideration of cooling (BRE, 2011). The SAP scale of performance ranges from 0 to 100; higher score depicts higher energy efficiency and less environmental impact (CO_2) which is then supported by a band of performance and impact from A (highest) to F (lowest).

SAP methodology is criticised for its single centralised weather file used for every dwelling in the UK (Ingram & Jenkins 2013). There are also doubts on how accurate SAP models are for assessing historic and traditional buildings (Kelly et al., 2012). Results are considered inaccurate with predictions often underestimating thermal performance of the existing fabrics and overestimating potential savings after refurbishment (English Heritage, 2007).

Case Study 1: Wells O' Wearie

Wells O' Wearie cottage is a small single storey detached building dating from the early 19th century, with an east - west orientation. The cottage is constructed of sandstone rubble, bound with lime, and finished with ashlar quoins and margins. The property is owned and managed by Historic Scotland (Curtis & Jenkins, 2012). It is located in Holyrood Park area of Edinburgh (Scotland) on a sheltered site below the road level (Fig. 3). Pre-intervention monitoring took place during October 2010 whilst the property was unoccupied.

Heat flow mats were positioned to monitor heat transfer through the walls, floor, ceiling and window glass. Four heat flow mats were attached to three walls during the pre- and post-intervention stages. Two heat flow mats were added to the north wall on either side of the window, a single mat was added to the west wall and one to the east wall, all attached to the internal surface of the wall. A heat flow mat was also added to the centre of the window (Fig. 4). Data was logged at two minute intervals over a period of three weeks. The average outdoor temperature recorded was 8°C with a relative humidity of 75%. Internally the average temperature was 15°C at 49% relative humidity. Post-intervention monitoring took place between February and March 2012 during a three week period. The heat flow mats were reinstated on the same locations as the pre-intervention period; average readings showed: internal temperature of 18°C at 60% relative humidity and external temperatures of 9°C and 80% relative humidity.

Figure 3. Wells O' Wearie facing north west.

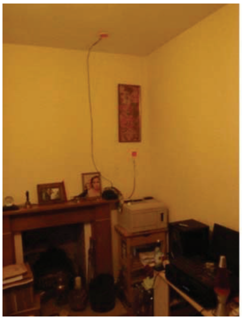

Figure 4. Heat flow mats on north east wall & window.

Thermal enhancement strategy and results

Two approaches were taken to improve the thermal performance of the walls. Shredded cellulose material was blown in the 30 mm void between the lath and plaster finish and the face of the sandstone wall lining on the north and east-facing walls, creating an insulated layer between the timber studs, (Fig. 5a); while an aerogel lining was applied to the internal surface of the west wall (Fig. 5b). These interventions are applied when internal timber finishes, cornicing and window details must be retained, or where it would be difficult to apply material to the face of the lining. The north (2 heat flow mats) and east (one heat flow mat) facing walls U-value improved from 1.3 W/m²K measured pre-intervention, to 0.6, 0.8 and 1.0 W/m²K respectively for the three different test points at post-intervention – both walls had lose cellulose in its cavity.

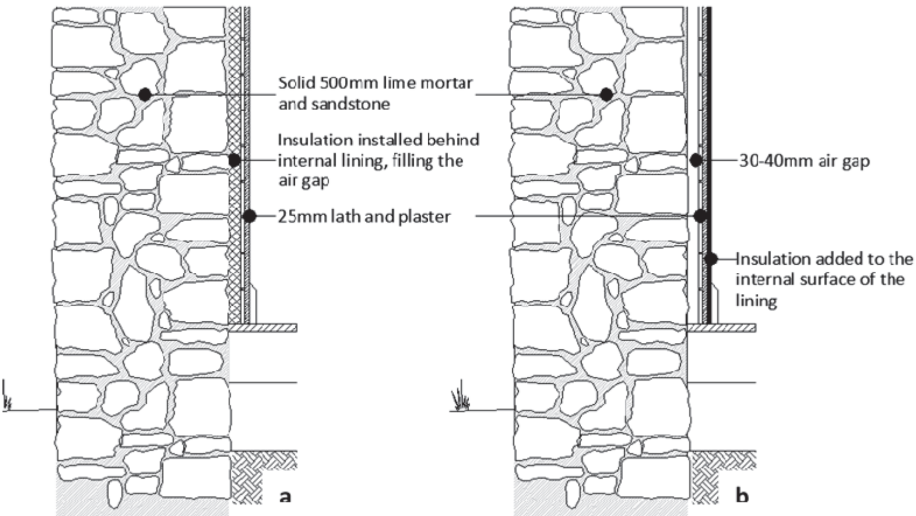

Figure 5. Construction details showing application of insulated to wall at Wells O' Wearie, a. insulated blown into cavity, b. Insulation applied to internal lining.

The 10mm aerogel lining was attached to the internal surface of the lath and plaster and affixed with a mesh liner then fastened with thermally decoupled fixings. To allow proper coverage of the wall, the skirting boards and decorative facings were removed and two coats of renovating plaster were then applied to finish, skirting boards etc. were then reinstalled. The U-value changed from 1.4 W/m²K with no insulation to 0.7 W/m²K with the aerogel addition. The addition of 280mm sheep's wool insulation placed above the lath and plaster ceiling, laid between and above the ceiling joists, improved the U value from a nominal 1.4 W/m^2K to 0.2 W/m^2K. The suspended timber floor also showed an improvement; from an original U value of 2.4 W/m^2K, which, after wood-fibre insulation batts were installed underneath the floorboards, fixed with battens, dropped to 0.7 W/m^2K.

Secondary glazing with a magnetic tape securing a proprietary single sheet of transparent polycarbonate was affixed to the inset of the window frame reducing the thermal transmittance from 5.4 W/m^2K to a value of 2.4 W/m^2K, which is comparable to the U value delivered by a double-glazed window unit. This glazing arrangement allowed the shutters to continue to function, adding further reduction in thermal heat losses and air leakage.

Case Study 2: Wee Causeway: Culross: Fife

The building is a detached cottage referred to as 'Wee Causeway' (Fig. 6), located in the village of Culross, Fife, cared for by the National Trust for Scotland.

The original fabric dates from the mid-18th century. It consists of a sandstone rubble masonry wall bound with lime, although has been re-pointed with cement in several areas. Internally the walls in the ground floor rooms are lined with lath and plaster, others have plaster 'on the hard' (i.e. directly onto the masonry). All rooms had a standard cornice detail in place (Curtis & Jenkins, 2013). It has a pitched pan-tile roof common to the east coast of Scotland and the windows are single glazed sash and case.

Figure 6. Front elevation of Wee Causeway Cottage.

Figure 7. Heat flow mats on ground floor walls.

Pre- and post-intervention in-situ U-value measurements were taken from five elements across two rooms in the cottage. On the ground floor, heat flow mats were fixed to the surfaces of the West and South facing walls (Fig. 7). On the first floor the heat flow mats were fixed to the West and North wall and the ceiling.

The pre-intervention monitoring took place at the end of November 2010 whilst the property was occupied. The monitoring lasted 15 days during which time the internal temperature averaged 13°C and the relative humidity 53%. The outdoor temperature averaged 5°C, with temperatures dropping to 0°C during the night and late evenings. The external average relative humidity was 76%. At post-intervention, data logging equipment was installed for 15 days during February 2012; the same elements were tested providing consistency in the findings. During this occupied time, internal temperatures averaged 15°C, with peaks reaching 23°C with an average relative humidity of 55%.The average external temperature was 10°C, with night time temperatures reaching 3°C with an average relative humidity of 73%.

Thermal enhancement strategy and results

Pre-intervention monitored walls recorded similar U-value results, 1.3 W/m²K and 1.5 W/m²K for the uninsulated walls with lath and plaster lining and 1.2 W/m²K and 1.6 W/m²K for the uninsulated walls with plaster on-the-hard. These values fall within the U-value range previously reported by Baker (2011) & Rye (2010) for similar construction elements.

Ground floor and first floor walls were insulated in different ways. Ground floor walls were insulated with polystyrene beads blown into the cavity between the stone wall and lath and plaster lining. The U value decreased to 0.5 W/m^2K at both measurement points.

The first floor walls received 10mm of aerogel blanket secured directly to the internal surface of the plaster on the stonework. Again the addition of the insulation harmonised the U-value result, both heat flow meters returned a U-value of 0.9 W/m^2K, showing an improvement of 0.3 and 0.7 W/m^2K respectively against pre-intervention results. Hemp wool insulation was added above the ceiling laid between and on top of the timber ceiling joists, as a result the U value improved from 1.2 to 0.2 W/m^2K.

Whole room heat loss

To contextualise the thermal step change achieved in each dwelling, SAP modelling software was used to generate space heating requirements, energy efficiency and carbon dioxide ratings. This was only carried out for the trial rooms and does not necessarily represent the other rooms in each dwelling or the building as whole.

Wells O' Wearie was modelled using the U-values discussed in Section 3.1, the nominated heating system was electric portable room heaters. The SAP results show a pre-intervention heat loss/ space heating requirement, for that one room at 489 kWh/m²/year. Using predicted EU energy performance certification, at pre-intervention the energy efficiency rating was G11 with an environmental impact CO_2 of F23. Post-intervention heat loss calculations found that space heating requirements for that room reduces to 266 kWh/m²/year, the energy efficiency rating improves to F35 and an environmental rating improves to E42. A further improvement reached 199 kWh/m²/year E45 energy efficiency rating and E50 environmental rating when including the chimney balloon in the flue to restrict air movement in winter.

Wee Causeway property was modelled using the U-values discussed in Section 3.2 with a nominated gas boiler heating system with room radiators as heating emitter. The results show a pre-intervention heat loss/ space heating requirement of 251 kWh/m²/year for the two rooms, E53 energy efficiency rating and E53 environmental impact CO_2 rating. At post-intervention the heat loss/ space heating requirement reduces to 167 kWh/m²/year total for the two rooms, the energy efficiency and environmental rating improves to D62 and D64 respectively.

Conclusion

This paper has discussed the results obtained from in-situ U-value monitoring of two dwellings of similar archetypes and thermal problems. They both presented thermal envelope deficiencies with high energy demand profiles in order to reach adequate thermal comfort. The study has highlighted how after thermal upgrades, the U-values decrease considerably while also reducing the environmental impact and energy demand. It has highlighted how with the use of Heat Flow apparatus under the ISO/DIS 9869-1:1994 methodology, measurements of pre and post-intervention can demonstrate the thermal benefits of such upgrades to the dwellings envelope.

The case studies demonstrated how various components were tested and monitored producing substantial reductions in thermal transmittance. For example, it was observed that in the Wells O' Wearie dwelling, the two walls monitored at pre-intervention had an average improvement of 30% in U-value at post-intervention. The same applies to the third wall where pre-intervention and post-intervention improvements reached 50%. Other components showed similar improvements; Ceiling, 70% and floor, 85%. In relation to Windows, the single sheet of polycarbonate used in the north east window, is effectively behaving as a fully-removable secondary glazing unit, reaching a reduction of 55% in U-value.

The Wee Causeway property tested two rooms. Ground floor walls were treated with polyurethane beads blown into their cavities presenting a decrease in thermal transmission of 65%. Equally first floor interventions with an aerogel blanket on the internal face of the walls showed improvements of 25% and 44% respectively. The ceiling in first floor also saw improvements of 85% where Hemp insulation was laid in-between and on top of the ceiling joists. These improvements were also evident through the SAP calculations of each room where space heating requirements reduced substantially as well as its impact on the environment with the reduction of CO_2 pollutants into the atmosphere. Wells O' Wearie presented 50% reductions while Wee Causeway 34% improvement.

In order to ensure that historical buildings are preserved and are energy efficient and economically viable, it is important to carefully consider methods and materials which will be sympathetic and understanding to the buildings original fabric and characteristics. It has become part of the culture within architectural technology to pursue low U-values, however this is not the only means by which to assess a successful retrofit programme. Reducing CO_2 emissions through lower space heating demand has immediate results for occupant's fuel bills. Equally important is the knowledgeable selection of insulating materials, associated hygrothermal properties, and behaviour into existing building fabric.

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