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Methods for Acoustic Classification in Buildings: An Example of Application of BIM Procedures on Wooden Buildings

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ABSTRACT

Recently private buildings built with wooden structures in the Mediterranean area have been subjected to an increasing spread. In particular, construction of new buildings made with Cross Laminated Timber (CLT) technology, which has considerable advantages in terms of construction times and several excellent performance among which mechanical, acoustic and energy saving properties. However, this technology requires a high level of design and project management, because many elements being prefabricated far away from the construction site. This is combined with an increasing demand of comfort and advanced performance for the building. The acoustic performances, that have been for long time neglected or at least underestimated, are now a basic requirement and increasingly requested with attention to detail and cost effectiveness by the customers. The aim of this work is to analyse the standards currently available on the market for the acoustic classification of buildings by applying them to a case study, pointing out the potential of Building Information Modelling (BIM),

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highlighting on the one hand the performance achieved by the case study according to the different procedures and on the other the peculiarities of the applied standards.

Keywords: Noise, BIM, Classification
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1. INTRODUCTION

Nowadays, the demand for building or infrastructures is strictly connected to specific needs, as accurate design, speed of realization, energy efficiency, easy management, durability. In a global economy of rapidly evolving markets and technologies, clear and precise rules are needed to help companies and the public administration to adapt skills to change and successfully innovate.

Noise protection in buildings is a particularly complex issue as it requires transversal knowledge in different building sectors and needs adequate coordination in the design and construction phases of buildings to meet user performance demands.

In Europe several countries have specified the minimum requirements for protection against noise in buildings. National noise classification schemes with quality classes are published with the aim of introducing an easy specification of more stringent acoustic criteria than those defined in the Building Codes or local regulations [1].

The acoustic classification procedures define a performance rating for a certain number of parameters relating to building elements or dwellings, generally the isolation from airborne noise, impact noise and the acoustic insulation of the façade or, more generally, the admissible level of noise inside of living spaces. The noise of the service equipments and the reverberation time in common areas are present only in some classification schemes, as well as other parameters required by national regulations [2].

The digitalization of the processes of design, construction and management of buildings is increasingly present in different countries, thanks also to EU regulations that require their use in certain types of construction projects. The European Directive 2014/24/EU prescribes that, for public works contracts and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar [3].

One of the fundamental aspects of the Building Information Modelling (BIM) methodologies is to represent the building geometrically and graphically through the creation of a three-dimensional model which can be associated in the various phases of the building's life, with information about functions, performance and management or, more generally, a set of data regarding the building at different levels and for different purposes.

The use of digital procedures can simplify the comparison and use of different classification procedures, including acoustic ones. The aim of this work is to analyze the different classification methods, through the use of digital BIM procedures, applying them to a case study of a buildings made with CLT technology.

2. CLT BUILDING TECHNOLOGY

Like all wooden construction types, the CLT has a series of advantages linked to the origin and intrinsic characteristics of the material. In terms of environmental sustainability, aspects such as the renewability of the raw material, which requires only land, water and sun to develop, and the positive effect on the environment, linked above all to the ability to sequester CO_2 from the atmosphere and store it for proportional times to the life of the material itself, make it one of the most suitable building materials to meet the current requirements of eco-compatibility. In terms of low cost of use, the high ratio between mechanical performance and weight, combined with the possibility of "dry" connections and achieving high levels of prefabrication, allows to significantly reduce construction times and storage spaces for materials on site, to facilitate handling, transport and assembly operations and to reduce the size of the foundation structures. All these aspects favourably affect the abatement and minimization of costs, as well as the environmental impact.

From the mechanical performance point of view, the CLT technology primarily offers the advantages of laminated wood, an industrial product that incorporates the greatest advantages of wood as a natural and reliable material and subjected to specific qualification checks. The technological process for the realization of a laminated building element, that can be considered in all physical aspects as a composite material, provides for the selection of the starting material with the rejection of the parts that present defects defined by a threshold defined by the product classification rules for the performance profile. This, combined with the possibility of joining and bending the ply, allows to overcome the limits of solid wood as building material, increasing the structural capacity and flexibility of use. Furthermore, the lightness of the material, especially compared to traditional ones, as reinforced concrete and steel, and the ductility associated with steel connection systems, make cross laminated wood a high performance product even where it is necessary to pay particular attention to anti-seismic design, since the low weight allows to activate minor seismic forces and the metal connections enable the dissipation of mechanical stresses induced by the earthquake.

The CLT also offers some specific advantages related to its implementation, as it is a flat element produced alternating layers of wood arranged orthogonally each other. This arrangement in crossed layers mitigates the typical effects of anisotropy of the wood. The cross diagram, in fact, gives the building element greater rigidity and planar stability, also limiting the phenomena related to swelling and shrinkage, determining an adequate load-bearing capacity and thus allowing the use of the building element in CLT both as a vertical supporting wall and as a flooring slab. For these reasons, it is also possible to use wood species with not particularly high mechanical characteristics, facilitating the establishment of a short production chain processes that exploit local wood species, different from those traditionally used in CLT systems, with obvious positive effects in terms of sustainability environmental, economic and social [4]. The CLT constructive solutions combine an advanced production technology with a high level of design, which must guarantee, among other aspects, the attention to construction details, responsible in large part for achieving the expected performance and durability of the structural element.

For the reasons listed above, the mechanical, thermal and acoustic performance of CLT construction systems can be easily characterized in the codes required by Building Information Modeling systems [5–9].

3. BIM AND ACOUSTIC REQUIREMENT: THE IMPORTANCE OF BUILDING DESIGN CODIFICATION

Building Information Modeling (BIM) is a process with an increasing diffusion in the construction market that leads to considerable savings in realization times and building management costs. The BIM also allows interchange of data for interoperability between various computer applications for the most varied purposes and uses (management, monitoring, performance calculation) [10].

The BIM methodology can be easily applied to the design and verification of the acoustic requirements of buildings and integrated with external tools based on the current standards for the estimation of acoustic performance of buildings from the performance of elements [11].

The sound insulation capacity of numerous constructive systems are well known through a process of analysis that starts from laboratory measurements of sound insulation and flanking transmission of airborne and impact sound of building elements, in order to obtain input data for predictive methods, and ends with field measurements for the validation of the estimation process and, possibly, for the compliance with the building requirements.

Within the BIM methodology, a key role is played by Model Checking, thanks to which it is possible to verify and validate projects not only during the design phase, but also during all the phases of the process, in order to guarantee completeness, transmissibility and congruence of all data and information. In the Information Documentation and in the Information Management Plan the rule sets must be specified, that is the set of control rules that are applied to the model, which are divided into three verification phases: rules for regulatory verification (BIM Validation), information interference management rules (Clash detection) and rules for managing information inconsistencies (Code checking).

For the compliance of the acoustic model, the code checking phase is the most important because allow to analyse conformity of the documents an design data with target values, as acoustic classes or Building Codes prescription. Code checking is performed in the different phases (design, construction and completed work) by applying the different reference standards that include the prediction of acoustic performances [12−15] or the field survey [15−18] for the determination of the actual performance values.

One of the fundamental aspects, for the BIM model to be fully usable for acoustic purposes, is the coding. If the BIM model has been appropriately coded by assigning to the specific univocal identifiers or, more simply, by using the GUID (Globally Unique Identifier) of IFC Space and IFC Elements [19, 20] it is possible to assign to each acoustic measure a unique code that identifies the rooms involved and the building elements being tested.

The coding system, if correctly used, allows the automatic and/or semi-automatic association of instrumental data with the building information model. After the association of the instrumental data, it is possible to perform field measurements and acoustic classification according to the different reference standards.

4. METHODOLOGIES OF ACOUSTIC CLASSIFICATION OF BUILDINGS

The Italian Standard UNI 11367 [21] describes the procedures to define acoustic classification of property units of a building, whatever its use (dwellings, offices, hotels, commercial activities, etc.).

Sound classification could be expressed for each requirement or as overall descriptor. Four classes are defined (from “I”, highest, to “IV”, lowest) and the requirements considered are listed below:

- façade sound insulation $D_{2m,nT,w}$;
- airborne sound reduction index of internal partitions R'_{w};
- impact sound insulation $L'_{n,w}$;
- sound pressure level from service equipments divided into those with continuous and discontinuous operation (L_{ic} and L_{id}).

The determination of the sound classes is based on the average values of the performance of all field measurements carried out on the various building elements (with reference to ISO 16283 series standards).

Classification can be based on the measurements of all measurable elements or of a number of elements through a sampling procedure; in the latter case the sampling uncertainty needs to be applied.

For schools and hospitals, classification scheme cannot be used; in the standard, reference values for these two types of buildings are included.

An important aspect introduced in the Italian standard is that acoustic classification is independent from the use of tested rooms (bedrooms, living rooms or other) and from the external acoustic climate. In other words, the acoustic class is an intrinsic quality of the building and of its elements.

The procedure for the sound classification of a dwelling involves the identification of all the verifiable technical elements and their field measurements [22]. For each measurable building element, the "net value", which corresponds to the measured value corrected with the measurements uncertainty, is determined. For each requirement, the energetic mean value of the results obtained for every technical element (referred to a single dwelling) is calculated. In this way the acoustically weaker elements decisively influence the final result.

The mean value defines the sound class of the related requirement. It is possible to classify the entire dwelling with a single class index by setting the correspondence, for each requirement, between the sound class performance and a coefficient related to the actual number of evaluable requirements of the dwelling.

For serial building, with repeated elements, there is the possibility to carry out measurements on a limited number of these elements (samples). The sampling procedure involves the identification of homogeneous groups for each requirement, in terms of element type and dimensions, test rooms dimensions and installation techniques. For non-serial buildings, with a large number of residential units whose building elements are not similar, the sampling procedure does not limit enough the number of measurements. In this case, a specific procedure described in the Italian Standard UNI 11444, based on building design check, can help to find the "worst case" and to select a limited number of building elements that have to be tested to characterize the acoustic class of the dwelling [23].

Both methods can be easily implemented in a "BIM oriented" control procedure since they are based on the identification of specific geometric, functional and dimensional properties of the building or physical properties of building elements and construction systems.

After the COST Action TU0901 [1], ISO/TC43/SC2/WG29 defined the proposal for a Technical Specification that help developers to specify a standardized level of acoustic quality other than the quality defined by national regulations, and for users and builders to require or be informed about the acoustic quality [24].

Six classes are defined (from "A", highest, to "F", lowest) and tThe requirements considered are:

- airborne sound insulation, $D_{nT,A}$ and $D_{nT,50}$;
- impact sound insulation, $L'_{nT,w}$;
- airborne sound insulation of building envelopes against outdoor noise from traffic, industry or other sources, $D_{nT,A,tr}$ (as a difference referred to a specific outdoor environment characterized by L_{den} for the relevant sound sources);

– sound pressure levels in the dwellings from service equipment, $L_{A,eq,nT}$ and $L_{AF,max,nT}$;
– reverberation time or ratio of the equivalent sound absorption area to the walkable surface in common access areas or stairwells and corridors with dwellings opening onto them.

According to this ISO/TS, verification shall be based on a number of measurements to characterize each aspect of the acoustic classes in the completed building or unit. The rooms for measurements shall be selected in accordance with one of two different procedures:

a) verification by calculations, visual inspections and field measurements;
b) verification by field measurements only.

In both cases, a sufficient number of rooms should be selected in order for the result to represent the acoustic quality of the dwelling.

As a general rule, individual dwellings, rooms or an acoustic characteristic in a building may be classified, if each of them complies with the relevant class limits. In this way, the class value is defined on the basis of the least-performed building element (or room).

Despite the differences between the ISO/TS and the Italian Standard for acoustic classification of buildings regarding the elements selection method and the how to determining the acoustic class, both documents can be analyzed to define a possible control method, based on the geometric characteristics of the building and the acoustic properties of the elements that constitute them, to be integrated in a BIM procedure.

5. CASE STUDY

A group of two residential buildings has been recently built in Olbia (Italy) [2]. The buildings were made by the same company in a short period of time (Figure 1). All building materials were sourced from the same suppliers. The two building presents the same number of flats and identical architectural layout. At the ground floor there are two apartments completely detached with a living room and one bedroom. At the first floor, one apartment is identical to the lower one and completely overlapped, the other is larger and partially offset from the underlying one. The vertical bearing structure of the building is made of 94 mm thick CLT panels, The floors are made of 145 mm thick CLT panels with a span of ~7 m. The thermal insulation is made with wood fibre panels and lime plaster. Internal linings are made with wooden framing and plasterboards. Internal drywall partitions have been realized after the completion of the interior finishes and floor coverings.

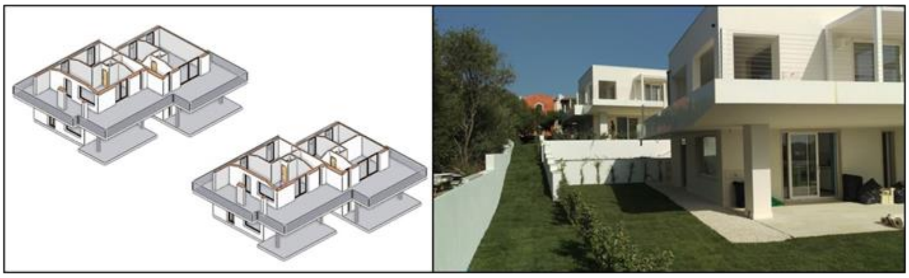

Figure 1: BIM model (left) and view (right) of the buildings analysed in the case study.

Despite it was possible to find acoustic data from laboratory measurements for many of the materials used, in some cases there were no laboratory tests of airborne and impact sound insulation for the entire building element actually used in the analysed buildings. Then, laboratory data from the closest elements were used for acoustical simulation according to ISO 12354, after a theoretical validation with specific calculation models for bare CLT structures [25, 26].

All the relevant acoustic parameters of the analysed buildings (airborne, impact and façade sound insulation) were according to ISO 16283 series, both under construction and at the end of works. The intermediate measures allowed calibration of the acoustic model based only of bare buildings elements. Moreover, they have allowed to evaluate and compare acoustical performances of the identical rooms of two separate buildings to allow for the possibility of accidental laying errors and the effects of workmanship (Figure 2).

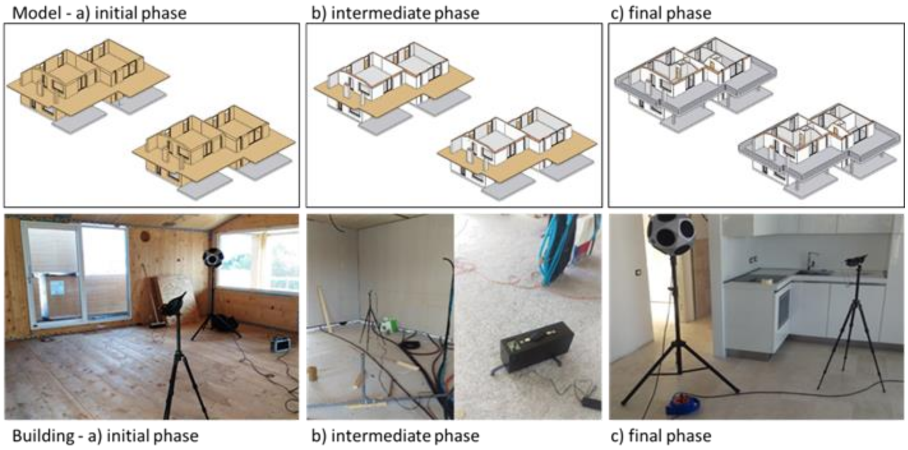

Figure 2: Measurement of the relevant acoustic parameters during the construction phases of the buildings.

Along with the elaboration of the architectural project of the buildings analysed, a BIM model was prepared to allow the control of the available information and consistency with the overall building design goals (energy saving, noise protection, etc.). The geometric model of the building was validated checking the level of development (LOD) of each element and the associated acoustic properties to be used for performance prediction according to ISO 12354 (Figure 3).

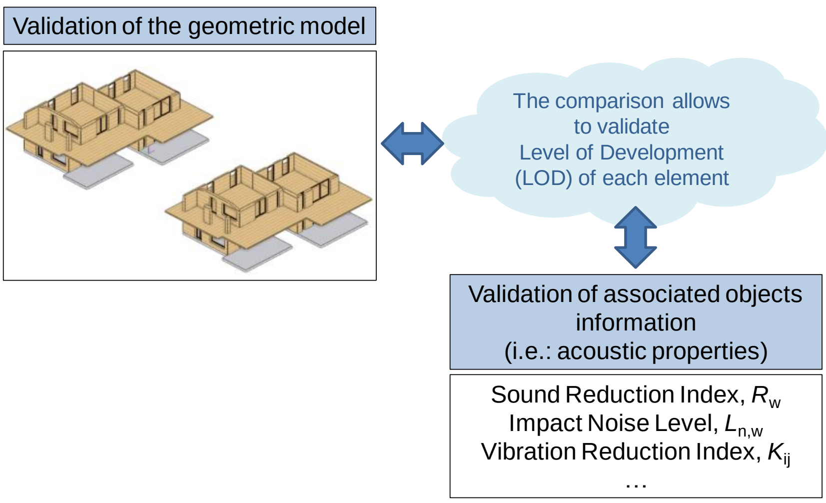

Figure 3: Validation of geometric model and acoustic properties associated to the objects composing the building.

This check is important to point out lack of input information for external calculation tools or to control the consistency of data.

The next phase of “Clash Detection” verifies the interferences between the objects that make up the building, identifying where the projects (architectural, structural, plant, etc.) collide with each other. In this way it is possible to anticipate the problems that would otherwise be encountered only in the executive phase, allowing to manage the conflicts between the different functional and executive schemes in a coordinated manner between the different designers (Figure 4).

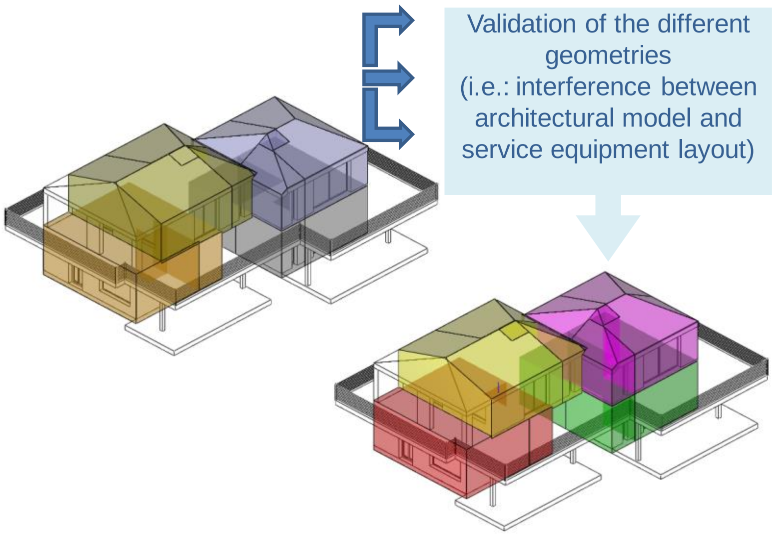

Figure 4: Clash Detection in the BIM model.

Finally, a “Code Checking” was performed (Figure 5). This is the control of the BIM model with respect to the information requirements necessary to evaluate its compliance with Building Codes performance limits as well as the levels provided by rating or classification standards.

Particular attention must be paid to the data necessary for the acoustic calculation or for the application of an acoustic classification method, as different information can be not unequivocally defined and generally managed in the BIM model.

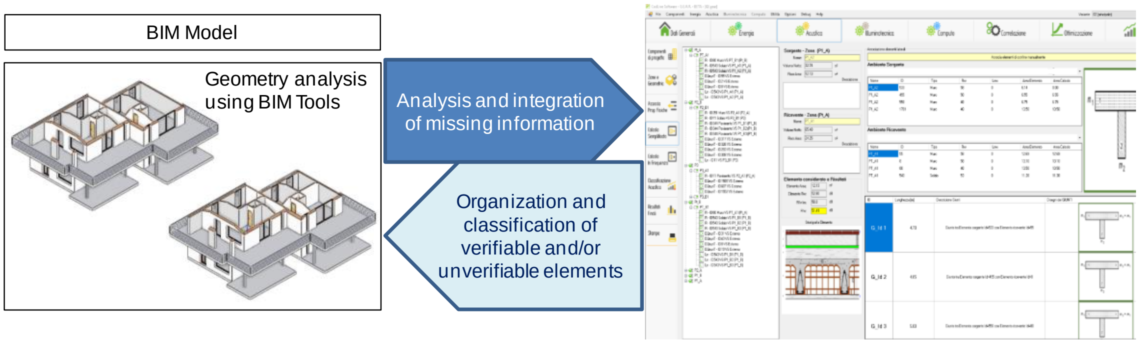

Figure 5: Code Checking in the BIM model.

Applying the methods of acoustic classification according to UNI 11367 and ISO/TS 19488 in this phase it is possible to see how the use of a BIM model can help to reduce the possibility of error in the selection of rooms or building elements.

In the case of the method described by the UNI 11367 standard, the validation of the geometric model and the clash detection phase help, respectively, in identifying acoustically verifiable environments for field measurements and for selecting the worst cases, in the hypothesis of selection of the sample based on the methods of the UNI 11444 standard.

For the application of ISO Technical Specification, BIM modelling can be particularly useful mainly for the application of the procedure "A" for the verification by calculations, visual inspections and field measurements.

A showed in the case study, all the phases of this procedure can be supported by a BIM model, reducing the possibility of an arbitrary selection of the elements to be analysed. As a matter of fact, the indications provided in the Technical Specification are too general and vague to allow the correct selection of at least 5% of the rooms and structures to be measured.

These aspects are particularly relevant for the legal and economic consequences that a classification process can have. Especially considering that the selection criterion and the minimum number of samples affects the final result of the classification and, consequently, the declared acoustic quality for the building.

The comparison between the different methods, as shown in Table 1 and in Table 2, returns a non-homogeneous result, as was to be expected considering the different method of sample selection.

Table 1: Results of acoustic classification according to UNI 11367 based on all measurable elements of the building.

Overall Acoustic Class of the Dwelling	Acoustic classification for each requirement				
	Façade sound insulation, $D_{2m,nT,w}$	Airborne sound reduction index of internal partitions, R'_w	Impact sound insulation, $L'_{n,w}$	Sound pressure level from continuous service equipments, L_{ic}	Sound pressure level from discontinuous service equipments, L_{ic}
III	II	III	IV	I	IV

Table 2: Results of acoustic classification of the analysed dwellings according to ISO/TS 19488 based on procedure "A" (element selected ≥ 5%).

Acoustic characteristic	Class						
	A	B	C	D	E	F	NPD
Airborne sound insulation			×				
Impact sound pressure level					×		
Sound insulation against exterior noise	×						
Sound from building service equipment			×				
Reverberation time (or relative absorption area) in access areas etc.							×
The classification result for the entire dwelling is Class E, which is the lowest class for individual acoustic characteristics.							

6. CONCLUSIONS

In this work the acoustic classification procedures in buildings have been analyzed developing their application on a case study realized with CLT technology. The analysis was performed with the BIM method applied to the verification of the acoustic requirements of the buildings. The application of digital methodologies allowed to evaluate the potential, both in the calculation and verification phases, deriving from the enormous amount of geometric and informational data that a BIM model makes available. The most important aspects that have emerged in the experimentation carried out have highlighted the fundamental role that the coding system has to guarantee the interoperability between the different software work tools and the interaction with the instrumental data. Finally, the application of the two classification methods to the case study made it possible to assess the critical issues and the potential of the two procedures.

The code checking performed on the case study has shown how instrumental investigations succeed in highlighting the acoustic characteristics of the building during all phases of construction and testing, improving the final result in terms of quality.

Developing BIM-based criteria for the building acoustics performance prediction and assessment process or, at a later time, for on-site surveys, should lead to significant improvements in terms of reliability and time savings in the development of simulation models, management of survey data and verification of performance parameters.

The selection of the elements for the verification of conformance with criteria for an acoustic class can be made mainly following two directions:

- evaluating the result of the calculated performances and selecting the elements that presented the most critical values automatically or semi-automatically;
- analysing the geometry of the environment, source and receiving environment, to select the most critical configurations such as partially overlapping environments or with irregular geometries, this procedure can also be done automatically or semi-automatically.

Only by establishing common criteria for the selection of the samples to be checked for acoustic classification consistent results can be obtained while applying different evaluation methods.

Methods based on BIM, using automatic code checking procedures, allow reducing arbitrary selection and, consequently, greater representativeness of the elements to be checked for acoustic classification. The CLT technology, in this case, due to its characteristics of modular and industrialized production, allows a more effective implementation of these analysis methods and a greater reliability in the definition of the acoustic quality of buildings.

7. ACKNOWLEDGEMENTS

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