Strengthening the confidence in bio-based building materials – BIO4ever project approach

Anna Sandak[1], Jakub Sandak[2], Marta Petrillo[3], Paolo Grossi[4]

[1] Trees and Timber Institute - National Research Council of Italy (CNR-IVALSA), via Biasi 75, 38010 San Michele all'Adige (TN), Italy, e-mail: anna.sandak@ivalsa.cnr.it

[2] Trees and Timber Institute - National Research Council of Italy (CNR-IVALSA), via Biasi 75, 38010 San Michele all'Adige (TN), Italy, e-mail: sandak@ivalsa.cnr.it

[3] Trees and Timber Institute - National Research Council of Italy (CNR-IVALSA), via Biasi 75, 38010 San Michele all'Adige (TN), Italy, e-mail: petrillo@ivalsa.cnr.it

[4] Trees and Timber Institute - National Research Council of Italy (CNR-IVALSA), via Biasi 75, 38010 San Michele all'Adige (TN), Italy, e-mail: grossi@ivalsa.cnr.it

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ABSTRACT

Recent advances in building materials have delivered several solutions for the construction sector. However, while considering bio-based materials dedicated for buildings, the operational durability is still a limiting factor in many applications and environments. Biomaterials, defined here as materials derived from organic sources, have become recognized as an attractive alternative to several traditional building solutions, often called "building materials of the 21st century". These can efficiently sequester carbon, balancing emissions from other materials. However, compared with traditional building materials possess some properties that are less understood and/or remain difficult to control.

The BIO4ever project promotes usage of innovative façade biomaterials with minimal environmental impact, but also substantially improve sustainability of biomaterials by controlling their transformation at the end of use. The experimental data are used for development of the numerical models simulating the material deterioration in a function of time and exposition. Accurate service life prediction, service life costing and aesthetical performance models of recently evaluated bio-based building materials are foreseen as the most important deliverables. Dedicated algorithms simulating material modifications by taking into account original material characteristics and degrading process parameters are developed at the micro, mezzo and macro scale. Software visualizing bio-materials' performance will be dedicated for investors, architects, construction engineers, professional builders, suppliers and other relevant parties, including also final customers. The appropriate numerical tools, able to capture the multi-scale evolution of damage are recently tested under realistic conditions within field trials and surveys on structures in service.

INTRODUCTION

The trend for rapid deployment of innovative material solutions at reduced-costs through predictive design of materials and innovative production technologies is observed nowadays. Such materials are optimized for specified applications, assuring at the same

time expected properties and functionality at elongated life, minimizing the environmental impact and reducing risk of product failure. As a consequence, higher numbers of well performing (also in severe environments) construction materials are available on the market. It is extremely important for the bio-materials production sector to follow this trend and to continuously improve its offer.
The expansion of bio-based products availability and its wide utilization in modern buildings is a derivative of the Europe 2020 strategies. It is foreseen that bio-materials will play an increasingly important role in the future, in order to assure the full sustainability of the construction sector.
The development of really innovative and advanced bio-products relies on the deep understanding of the material properties, structure, assembly, formulation and its performance along the service life. Today's bio-based building materials, even if well characterized from the technical point of view, are often lacking of reliable models describing their performance during service life. Another aspect, often underestimated (but critical for the sustainable use of bio-based building materials), is related to the transformations of building materials after their service-life. The advantage of the elevated resistance for degradation can become a restraining factor in recycling, reuse or depose/landfill.
The overall goal of BIO4ever project is to contribute to public awareness, by demonstrating the environmental benefits to be gained from the knowledgeable use of bio-based materials in buildings. A dedicated software simulating bio-materials performance, degradation and end-of-life in severe operating environments is under development. It will serve as a tool for demonstrating advantages of using bio-based materials when compared to other traditional resources. The tool is dedicated for investors, architects, construction engineers, professional builders, suppliers and other relevant parties, including also final customers.

INVESTIGATED MATERIALS

New developments in the field of wood modification offer innovative products with enhanced properties of natural timbers. These include novel bio-based composite materials, as well as more effective and environmental-friendly protective treatments, e.g. thermal treatment, densification and chemical modifications. Similar revolutionary progress is observed with surface treatments including innovative coatings, impregnations or integration of nanotechnology developments in wood protection.
The samples investigated within the project represent all the above-mentioned groups. Performance of 120 selected façade materials provided by over 30 industrial and academic partners is recently evaluated. The experimental samples include different wood species from various provenances, thermally and chemically modified wood, composite panels, samples finished with silicone and silicate based coatings, nanocoatings, innovative paints and waxes, melamine treated wood, copper treated wood, bamboo cladding, reconstituted slate made with bio-resin and samples prepared according to traditional Japanese technique: shou-sugi-ban.

MULTI-SENSOR CHARACTERIZATION

A multi-sensor measurement chain, including both laboratory and on-site techniques, for the acquisition of properties at different scales (molecular, microscopic, macroscopic) is established at CNR-IVALSA. Routine material characterization includes:

- Photogrammetry

- VIS, near and mid infrared spectroscopies and hyperspectral imaging
- IR thermography
- Surface characterization (color, gloss, wettability, roughness)

Investigated bio-materials are characterized before, during and after degradation by biotic and a-biotic agents in order to provide experimental data to be used for better understanding the bio-materials performance/degradation as a function of time. Obtained data are currently utilized for development of numerical models.

WEATHERING TESTS

Weathering is the general term used to define the degradation of materials exposed to the weather condition. The rate of weathering varies within tree species, function of product, technical/design solution, finishing technology applied but most of all on the specific climatic conditions. Three different approaches are used for controlled samples degradation:

Natural weathering of bio-materials on the vertical stands

Dedicated stands are installed at CNR-IVALSA (San Michele All'Adige, ITALY). Experimental samples are exposed to four cardinal directions for different weathering doses/periods and characterized with laboratory instruments. Weathering stands simulating façade installation are presented in Figure 1. A sequence of images corresponding to the monthly changes of samples appearance is shown in Figure 2.

Figure 1: Facades materials exposed to natural weathering

Natural weathering on the robotized stand

The stand, recently under development, will assure optimal exposure to South by varying inclination from 23° to 70° following the sun position. All samples are automatically characterized weekly with a multi sensor scanner installed on the stand. The robotized stand will host digital camera, VIS and NIR spectrometers as well as a gloss meter. Moisture and temperature on the back (unexposed) side of samples will be continuously monitored. Three replicates per bio-material will be installed in order to assure statistical reliability of results.

Figure 2: Facades materials at the beginning of weathering test, and their appearance with the progress of weathering (up to 5 months).

Artificial weathering tests with SUN-test and QUV

Weathering campaign by using state-of-the-art artificial weathering instruments was conducted in order to compare performance of investigated materials. In addition, samples prepared from Norway spruce wood (*Picea abies* L. Karst.) within Round Robin test (COST FP1006) served as supplementary set to validate obtained results. In that case, 21 sets of twin samples were exposed for the duration of 12 months, facing the South in 17 locations in Europe. Samples were collected monthly, characterized afterward in the laboratory with multi-sensor approach.

END-OF-LIFE OF INVESTIGATED MATERIALS

The best solution from the environmental point of view will be identified for all investigated bio-materials. Suitability of the state-of-the-art methods currently used (such as combustion, pelletizing, digestion, land filling, and fermentation) are investigated for every material (Figure 3).

Figure 3: Facades materials during degradation in soil – simulation of landfilling

An additional set of intensive experimental trials is performed in order to develop alternative methods. It included exposition of the bio-materials to selected rot fungi and insects. A special focus was directed toward recycling systems for converting organic (bio-materials) wastes into high protein content feed supplements. This approach follows directly demands of FAO. Efficiency of selected insects for biomass transformation of wasted biomaterials is therefore investigated (Figure 4).

Figure 4: Facades materials after 3 months of degradation with termites in laboratory tests rated according to 5 point scale EN 252 (adapted) (left: grade 2 – moderate attack, right – grade 4 –failure)

MULTISCALE MODELLING

The approach of materials/buildings monitoring by using multiple sensors simultaneously has become more frequent due to better representation of the real-life scenarios. In this case, fusion of different sources of information is a fundamental, but also challenging task. This is due to the complexity of the optimal sensor selection, measurement strategy, signal processing and interpretations of results (Sandak *et al.* 2016). The following aspects are explored within the project:

- selection and evaluation of the most suitable signal pre- and post-processing techniques/algorithms aimed to the extraction of most useful information from the raw data sets
- elaboration of "Data Fusion" procedures for the integration of the data obtained from different analytical techniques/sensors and from different degradation stages
- multivariate classification/grading of the investigated materials quality/functionality, with a special focus on aesthetical aspect
- development of numerical models simulating changes of bio-materials' properties as a function of the weathering doses and construction details
- design of a visualization software simulating aesthetical changes of the bio-materials due to natural weathering progress
- creation of the numerical tool for computation of the bio-materials' service life period, including maintenance/renovation scheduling.

DEVELOPMENT OF DEMONSTRATION TOOLS FOR ARCHITECTS/ENGINEERS/INVESTORS

The new knowledge and numerical models would become useless without confrontation with the target group of future users. Unfortunately, very few architects and civil engineers are correctly trained in the aspects of using wood/bio-materials in structures. Therefore, an intensive campaign for promoting wood and bio-materials is conducted in the frame of BIO4ever project. Dedicated software simulating bio-materials performance, degradation and end-of-life in severe operating environments is foreseen as a most important deliverable of the project. The concept for the software simulating changes of bio-materials (related to both functional performance and aesthetics) for the whole duration of their service life is presented in Figure 5.

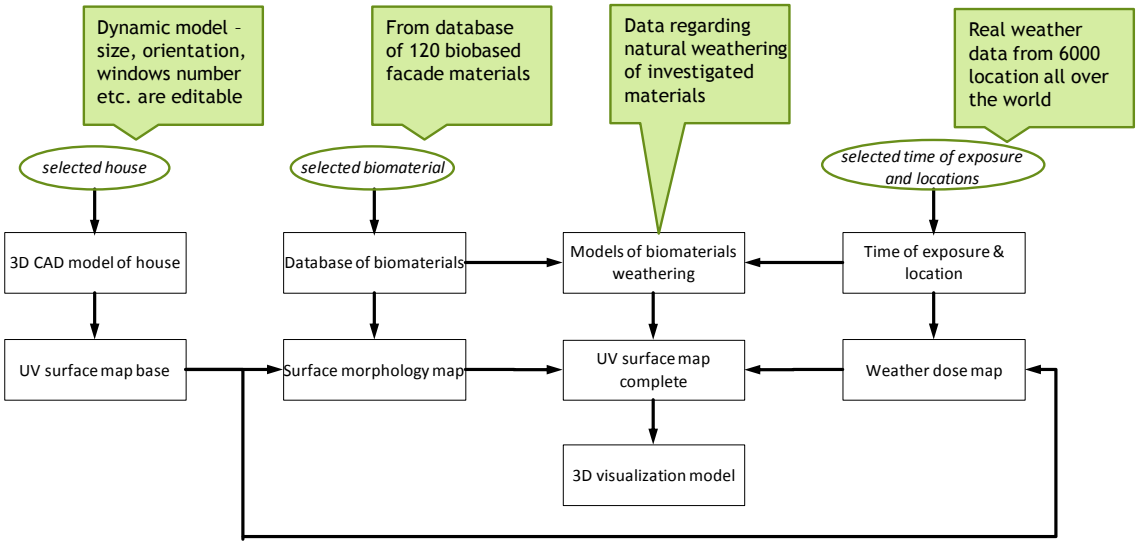

Figure 5: Flowchart of the data for 3D visualization of the building exposed to natural weathering

Time series of pictures are acquired during exposure of tested materials. These are subsequently used for interactive simulation of facades appearance. Customers will be able to choose a material from the database and simulate the building outlook at the brand new stage. In addition, numerical simulation will allow visualization of changes the appearance depending on the time of service, exposure direction, geographical location and with consideration of architectonical details of the structure. The print screen of the software prototype is presented in Figure 6.

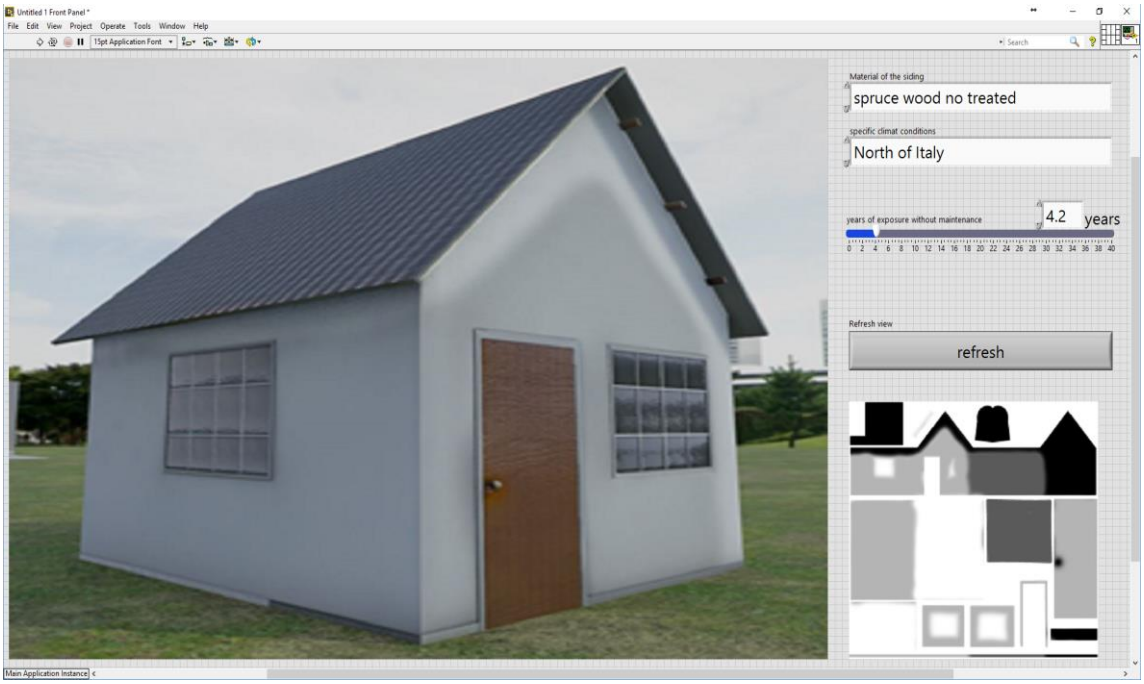

Figure 6: Print screen of demo software

CONCLUSIONS

The trend for rapid deployment of novel/advanced material solutions at reduced-costs through predictive design of materials and innovative production technologies is observed nowadays. It is extremely important for the bio-materials production sector to follow this trend and to continuously improve its offer. The development of really innovative and advanced products relies on the deep understanding of the material properties, structure, assembly, formulation and its performance along the service life. Comprehensive understanding of the physical/chemical properties and their connection with the material's structure will be obtained as a result of a combination of analytical/experimental methods and numerical modelling. Results of the BIO4ever project provide technical and scientific knowledge but also contribute to the public awareness, by demonstrating the environmental benefits to be gained from the knowledgeable use of bio-based materials in buildings.

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