Biobased mortars in the Mediterranean context: the contribution of the CUBÂTI project within cross-border cooperation

Federica Fernandez[1,2*], *Khitem* Mensi[3], *Tiziana* Campisi[1], *Simona* Colajanni[1], *Antonella* Mamì[1], *Elvira* Nicolini[1], *Manfredi* Saeli[1] and *Maria Luisa* Germanà[1]

[1]Department of Architecture, University of Palermo, 90129 Viale Delle Scienze Ed.14, Palermo, Italy
[2]Euro-Mediterranean Institute of Science and Technology, 90139 Via Michele Miraglia n.20, Palermo, Italy
[3]Centre International des Technologies de l'Environnement, Boulevard du Leader Yasser Arafat, Tunis, Tunisia

Abstract. The Mediterranean context is a transition zone between the temperate and tropical belts, developing in some regions between 20° and 40° North and South latitude. Typical flora of the Mediterranean bush includes holm oak, cork oak, heather, myrtle, rosemary, laurel, oleander, orange, prickly pear, caper, and pistachio. The research carried out as part of the cross-border cooperation project CUBÂTI "Culture du bâti de qualité: recherche, innovation et entreprise pour la durabilité," funded by the Italy-Tunisie Programme 2014-2020, identified some of these plant species, linked to production waste from the agro-food sector of Sicily and Tunisia, to experiment with new additives to be used as reinforcement in plaster mortars. Furthermore, with the objective of improving circular processes and reducing the use of natural resources, we preferred to use local binders that are not resource-intensive, such as gypsum and clay. The activities were conducted through intense collaboration between research institutes and manufacturing companies to intensify technological transfer and raise awareness towards the use of more environmentally sustainable materials. The results obtained from the experimentation, which included durability tests of the developed materials, demonstrated that the controlled addition of plant fibres could be a sustainable way to improve some performances of plaster mortars.

1 Introduction

For the first time in the ENI (European Neighborhood Initiative) Italy-Tunisia program, CUBÂTI has turned the spotlight on the construction sector, an activity of considerable importance for the cross-border economy, sustainability, and quality of life. CUBÂTI focused on the concept of quality construction culture (baukultur) and on the common cross-

* Corresponding author: federica.fernandez@unipa.it

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border identity to strengthen the links between research, enterprise, and professionals. The project has created the conditions for a virtuous circle among production sectors of considerable importance and potential, usually separated, between Sicily and Tunisia: construction, agriculture, aquaculture, agro-industry, and cultural tourism.

The technology transfer activities involved the experimentation with mortars that included gypsum and clay as binders. The following aggregates of biological origin were tested: pistachio shells, orange peel, palm leaves, mussel shells, and prickly pear scraps.

The experimental protocols shared between the research partners made it possible to define an easily consultable and usable database, reproducible for future experiments.

These activities have resulted in demonstrative creations (small buildings in Tunisia, models, educational exhibitions), as well as scientific and informative publications.

2 The value of the cross-border cooperation

Cross-border cooperation and the rooting of the project in the common identity (heritage and environment) were the strengths of the project CUBÂTI, which guided the positive changes made. Numerous Sicilian and Tunisian companies, manufacturers of building materials and professionals were involved in workshops, seminars, fairs, with the support of a web exchange platform. Furthermore, thanks to the activation of the "PRIX CUBÂTI", with the cascade contributions tool, a certain number of entrepreneurs have been involved in a more continuous way, have contributed to the implementation of numerous activities, and have started cross-border cooperation projects and agreements among themselves very promising for future businesses. Finally, the dissemination activities of the project, with the numerous Open Labs and workshops, have aroused the interest and enthusiasm of young people for sustainable construction, sowing the seeds for further development of the subject.

In accordance with the motto "Common challenges, shared goals" [1], the project was based on a transnational vision of problems and solutions.

The lever on which we chose to act is that of local identities: an immense architectural heritage with deep common roots, to be preserved and enhanced; a similar environmental context in terms of climate, vulnerability, geological configuration and above all the presence of the Mediterranean Sea, a deep relationship between the populations of the two coastal areas since ancient times and today often a place of desperate transit. These identities and geographical contiguity of Sicily and Tunisia have allowed synergies between parallel activities, making the results adaptable on both sides and amplifying their effects. The common cross-border identity has guided the various activities linked to strengthening the links between the world of research and the production reality in the field of sustainable construction.

The common need to strengthen technological transfer from research to production is even stronger for traditional building materials, which use local and largely renewable resources, and therefore constitute a fundamental form of sustainability.

Furthermore, the CUBÂTI project has produced lasting tangible and intangible effects, including two university Technotheques which were created at the Department of Architecture of University of Palermo and the ENAU (École Nationale d'Architecture et d'Urbanisme) of Tunis. The technotheques present some of the realisations (examples of experiments and models) and the materials tested during the project implementation and today are used to welcome students and young people during the numerous orientation activities intended for schools and the general public (such as Open Days and "Sharper. The European Researchers' Night").

3 Biobased mortars for sustainable construction

The worldwide industrial activity yearly generates an enormous quantity of waste, whose treatment and disposal produce several difficulties [2]. Therefore, a shrewd waste management strategy can lead to financial savings, reduction in environmental impact, and improved Circular Economy (CE) [3], thus providing a valid alternative to the usual disposal in landfills [4]. The objective of CE is to reduce the environmental impact caused by human activities by encouraging product reuse and recycling, thereby limiting the waste of resources and constituting a powerful connector between the use of resources, waste management, and emissions [5].

Among the various industrial sectors, construction is one of the largest and is globally considered highly unsustainable due to the massive exploitation of non-renewable raw materials and energy emissions, while also generating huge amounts of greenhouse gases and waste [6, 7]. For instance, in the European Union (EU) alone, buildings are responsible for approximately 40% of energy consumption and about 36% of greenhouse gas emissions. However, construction activities are continuously rising, especially in developing countries, and it is estimated that global consumption of materials will nearly double by 2060, with one-third of that demand coming from the construction sector [8].

Given these facts, a fascinating strategy to mitigate buildings' environmental impact is considering ecological sustainability as an essential condition of building design and construction. Sustainable building is one of the most emerging sectors of the green economy and is extremely active in research and innovation within the new CE scenario and in the decarbonisation of energy models aimed at mitigating the increasing problem of climate change [9]. In other words, sustainable building aims to reduce the consumption of non-renewable energies and significantly mitigate, with biocompatible materials, the effects of architectural structures on people's health and the surrounding ecosystems.

Accordingly, if the future of the construction sector lies in enhanced sustainability, then there is a strong need for change, especially considering that construction is still permeated by a significant number of harmful factors such as the use of materials with high environmental impact, non-reversible constructive solutions, and low-efficiency processes and materials [10].

The use of waste materials could provide a different approach in construction, allowing a series of advantages compared to traditional materials, essentially showing a lower CO2 content, reducing health risks and costs, and improving CE. Moreover, waste disposal, decontamination, or deactivation still present huge problems that cannot be underestimated both in economic and environmental terms. These issues could also be mitigated through a more widespread use of construction bio-materials [11].

Some statistics show that around 2.6 billion tons of waste are produced in the EU yearly; of this, around 43.4 million tons are of natural origin. To date, only a small part of the produced organic waste is effectively recycled, while realistically, it could yield excellent results in the manufacture of construction products of an almost exclusively biological nature [12]. The most interesting aspect is that, according to approximations and modeling, the commercial value of organic waste treated for construction purposes would be five times higher than the value obtained through normal disposal processes. This is also possible due to real energy recovery that would implement production cycles with greater effectiveness, resulting in greater sustainability of products or materials. Furthermore, organic waste reuse leads to products with a reduced environmental impact.

The integration of waste materials would give a material the necessary features to satisfy the requirements for the certification of the Minimum Environmental Criteria (MEC), which aims to encourage the construction/renovation of low-impact buildings, both new and existing, through sustainable material use, in line with CE principles [13]. Finally, the possibility of using bio-materials in construction is a highly valuable opportunity in terms of potential benefits. In fact, due to their renewable nature, this novel category of materials could actively absorb CO2, and its subsequent long-term immobilization exerts a positive impact on the Earth's climate [14].

The following Fig. 2 shows the scientific publication trend dealing with biobased materials in the last two decades. Both graphs are derived from the Scopus database using the keywords “biobased materials.” In particular, figure 2-left also uses the keywords “construction” and “waste” to analyze the interest of the scientific community towards such topics. Figure 2-right also reports the keywords “mortar” and “mortar + waste” to focus the interest on this specific issue. From the analysis, it can be observed that a considerable number of papers were published over the last two decades and that the interest of the scientific community is continuously increasing, also in light of the topics of CE and sustainability. Moreover, in recent years, there is a growing attention towards topics more related to construction and construction materials, such as mortar with a biobased connotation.

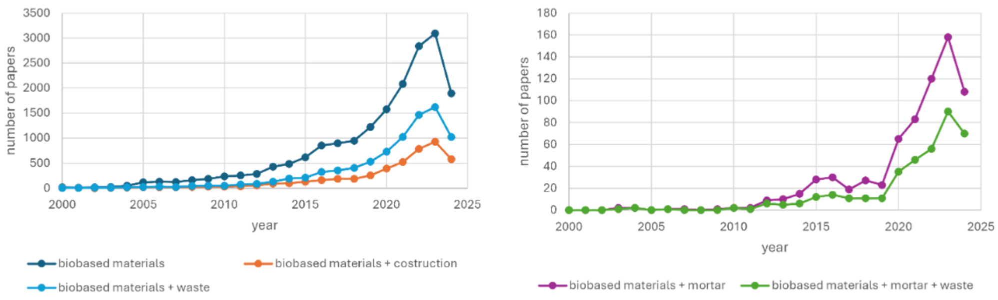

Fig. 1 Papers number trend published on Scopus, years 2000-2024. Keywords: “biobased materials”, “biobased materials + waste” and “biobased materials + construction” (left); “biobased materials + mortar” and “biobased materials + mortar + waste” (right).

In general, territorial dynamics play an important role in the implementation of the circular economy, oriented towards the recovery and minimization of waste, and must be associated with experimental studies on the characteristics and quality of local materials [15]. In particular, the cultural premises of this study refer to the shared identity between Sicily and Tunisia, as highlighted by a recent strategic cross-border cooperation project [16, 17]. In fact, the present experimental research has focused on materials that are easy to find in these areas, applying a replicable method to other regions in the Mediterranean area.

4 Testing of CUBÂTI biobased mortars

The experimental part of the project was conducted with the collaboration of four institutes: the Department of Architecture of the University of Palermo, I.E.ME.S.T. (Euro-Mediterranean Institute of Science and Technology) of Palermo, and C.I.T.E.T. (Centre International des Technologies de l’Environnement) of Tunis. These institutes cooperated through an intense exchange of know-how, utilizing all the instruments available in their various laboratories (Fig. 3).

Fig. 2 Joint testing activities in CITET Lab during the project implementation.

In an initial phase, geomaterials with considerable potential in Sicily and Tunisia were selected, some of which had already been developed in previous research [18] without a real technological transfer, aimed at standardized production. Attention was therefore paid to gypsum and clay, two materials from the common building tradition with which plasters are still made, the production of which has a low environmental impact.

After selecting the basic materials, involving the manufacturing companies, the biobased additives were identified, with the aim of increasing the performance of the plaster mortars, such as mechanical resistance and thermal insulation. Some waste materials were chosen from the agro-food sector (orange peels, pistachio shells), from aquaculture (mussel shells), widely present both in Sicily and Tunisia, as well as palm leaves and prickly pear blades, as common low-cost and easy-to-find materials in both territories. The individual materials were treated and ground in order to reach adequate grain sizes, and clay and gypsum were added in variable quantities, in order to obtain mixtures with good workability and adhesion capacity to the support with which numerous samples were made (Fig. 4).

Fig. 3 The different mix design produced in the frame of the project implementation.

After suitable curing, the produced samples were then tested in the UNIPA, IEMEST, and CITET laboratories to evaluate different types of technical performance, such as workability, density, mechanical resistance, thermal insulation, and durability. For each mix design, the mixes that presented the best performance in terms of mechanical resistance and conductivity were identified from the results of the first test cycle. In a subsequent phase, aging cycles were carried out in parallel on these mixes to identify the samples that showed better maintenance of performance over time (Fig. 5).

The durability aspect is a key issue for gypsum, clay [19], and biobased materials, as they are highly perishable and change when exposed to extreme environmental conditions, such as high humidity, high temperatures, or low temperatures. As there is no specific regulation for wet-dry cycles to be applied on mortars, standard UNE-EN 14066 [20, 21] was adapted, also considering the climatic conditions of the two countries (Mediterranean climate). The tests began when the test specimens were 28 days old. An aging protocol was identified to which the samples were subjected, based on thermo-hygrometric stress, alternating dry-high humidity cycles (90%) and low temperatures (-7°C) - high temperatures (60°C). After the first wet-dry cycles, some samples with orange peels showed the presence of biological activity and were eliminated.

Table 1. Ageing cycle protocol.

Phase	Ageing	Conditions	Duration
Phase 1	climatic chamber	humidity 99%	7 days
Phase 2	drying in oven	40 °C	4 hours
Phase 3	stabilization	environmental T	20 hours
Phase 4	frost	-7 °C	2 hours
Phase 5	Oven	60 °C	2 hours

Fig. 4 Mortar samples after ageing cycles in the CUBÂTI climate chamber.

In general, aging has not caused variations in the mechanical compressive strength of the various mix designs, which have maintained good mechanical resistance values. This demonstrates that the thermal stresses induced by aging do not cause material loss, decohesion, or intergranular desegregation, which could have reduced the mechanical performance in terms of compression [11].

At the end of the testing, it was found that, regarding the thermal conductivity tests, the best results were obtained with the gypsum-prickly pear pads mix, which showed a lambda value of approximately 0.1 W/mK. This confirms that the biobased mix designs contribute to the reduction of thermal conductivity, also improving the thermal insulation performance of the plaster.

As for the mechanical compressive strength tests, the mortar that gave the best results was the one with gypsum and pistachio shells, with compressive strength values up to 6.69 MPa. This result, in particular, could be attributed to the greater compactness of the mortar due to the presence of sand (S), which combined well with the finely ground pistachio shells, Pf with dimensions of 0.5 - 2 mm and Ps < 0.5 mm [11].

5 Conclusions

Through the project activities, several biobased mortars with considerable potential were tested using very sustainable geomaterials (gypsum and raw earth) and treated waste linked to strategic sectors and components of a strong local identity shared between Sicily and Tunisia (agriculture and aquaculture), such as shells of dried fruit and mussel shells. Cross-border cooperation has made it easier to achieve results and plan activities based on the strengths of each country and the sharing of expertise between the two parties. The project was truly a virtual bridge to strengthen relationships and collaborations between partners and with stakeholders, which proved essential at a strategic and institutional level.

The topics addressed and the activities carried out within the project fit perfectly into the principles of the circular economy and sustainability, fundamental transversal themes for the contemporary world. Local and low-impact materials are essential for sustainable construction and also for the energy needs during their lifespan. The social impact, as well as the repercussions on the productive and entrepreneurial fabric, can be verified in the long term thanks to the promotion of the baukultur concept. In fact, by producing and transforming the built environment, construction affects the quality of life and the ecological footprint at both an individual and collective level.

An economic analysis of the cost-benefit aspects of using biobased mortars compared to traditional materials could also be considered in a follow-up phase of the project, starting with a Simple Cost Analysis (SCA), which is a straightforward way to estimate product production cost, to highlight the economic advantages of circular bio-based building solutions compared to conventional solutions [23]. It should be mentioned that SCA is not a comprehensive approach because it cannot consider all incurred costs over the entire life of products. Indeed, SCA analyses in the collected papers calculate only costs occurring in the production or construction phase of circular bio-based building solutions. Hence, the results may not be accurate and holistic. To address this issue, comprehensive methods like Life Cycle Costing (LCC), which is the sum of all expenses expended in support of a product from its conception and production through its operational phase to the end of its service life, should be applied.

The CUBÂTI project has thus contributed to consolidating the four pillars of sustainable development: economic, social, environmental, and cultural. In particular, the research activities carried out demonstrate that the use of waste materials not only contributes to circular economy policies but can also increase the performance of traditional mortars, reducing the need for synthetic products.

References

1. M. L. Germanà, Défis communs et objectifs partagés pour les sites archéologiques, entre la Sicile et la Tunisie _ Sfide comuni e obiettivi condivisi per i siti archeologici, tra Sicilia e Tunisia, in A. Ferjaoui, M. L. Germanà (Eds), Architecture domestique punique, hellénistique et romaine. Sauvegarde et mise en valeur _ Architettura domestica punica, ellenistica e romana. Salvaguardia e valorizzazione, pp. 9-12 (ETS Pisa, 2014).
2. European Environmental Agency, Managing Municipal Solid Waste—A Review of Achievements in 32 European Countries; EEA Report No. 2/2013, (Publications Office of the European Union, Luxembourg, 2013).
3. European Parliament, UE Council, Directive 2008/98/EC on waste, 19 November 2008.
4. P. Ghisellini, C. Cialani, S. Ulgiati, A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production **114** pp. 11-32, (2016).
5. L.R. Luttenberger, Waste management challenges in transition to circular economy – Case of Croatia, Journal of Cleaner Production **256**, 120495, (2020).
6. M. Hirschnitz-Garbers, A.R. Tan, A. Gradmann, T. Srebotnjak, Key drivers for unsustainable resource use – categories, effects and policy pointers, Journal of Cleaner Production **132** pp. 13-31, (2016).
7. European Commission, Topics, Climate goals: making our energy system greener and more competitive, (2022). https://www.europarl.europa.eu/topics
8. D.L. Le, R. Salomone, Q.T. Nguyen, Circular bio-based building materials: A literature review of case studies and sustainability assessment methods. Building and Environment **244**, 110774, (2023).
9. F. Fernandez, et al., Development of eco-friendly and self-cleaning lime-pozzolan plasters for bio-construction and cultural heritage, Buildings, **10**, MDPI, (2020). https://doi.org/10.3390/buildings10100172
10. M. Bellomo, S. Colajanni, R. V. Margiotta, E. Nicolini, M. Saeli, A. Mamì, Almond shell reuse: a viable non-conventional aggregate for sustainable building materials. In proceedings of the ArchDesign'22 / IX. International Architectural Design Conference Proceedings, pp. 55-67. Istanbul: Özgür Öztürk Dakam Yayinlari (2022).
11. F. Fernandez, M. G. Insinga, R. Basile, F. Zagarella, R. Montagno, M. L. Germanà, Comparative Evaluation of Gypsum-Based Plasters with Pistachio Shells for Eco-sustainable Building. Sustainability, **16(9)**, 3695 (2024). https://doi.org/10.3390/su16093695
12. R. Leone, A. Calà, M.N. Capela, S. Colajanni, T. Campisi, M. Saeli, Recycling mussel shells as secondary sources in green construction materials: a preliminary assessment, Sustainability **15**, 3547 (2023). DOI: https://doi.org/10.3390/su15043547
13. M. Saeli, V.S.Batra, R.K.Singh, D.M.Tobaldi, J.A. Labrincha, The coffee-house: Upcycling spent coffee grounds for the production of green geopolymeric architectural energy-saving products. Energy and Buildings **286**, 112956, (2023).
14. F. Pittau, F. Krause, G. Lumia, G. Habert, Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls. Building and. Environment, vol. **129**, pp. 117–129, (2018).

15. L. Pani, L. Francesconi, J. Rombi, S. Naitza, G. Balletto, Recycled Aggregates Mechanical properties and environmental sustainability, in Proceedings of the INPUT Academy Conference, Cagliari Italy, October (2019).
16. M. L. Germanà, M. Saeli, A. D'Amore (Eds.) Réalisations en matière de transfert de technologie dans le cadre du projet CUBÂTI - Realizzazioni di trasferimento tecnologico nel progetto CUBÂTI - Technology transfer achievements in the CUBÂTI project, (New Digital Frontiers srl Palermo, 2024).
17. M. L. Germanà, F. Kharrat, Circular building production in the South Mediterranean area: the experience of CUBÂTI Project, in Sayigh A., Trombadore A., Sala M. Eds, Springer, in Proceedings of the International Conference "GETTING TO ZERO. Beyond energy transition towards carbon-neutral Mediterranean cities", Firenze (IT), 14-16/02 (2024).
18. M. L. Germanà, Earth as a building material between past and future _ Terra cruda nelle costruzioni fra passato e futuro, in S. Mecca, L. Briccoli Bati, M. C. Forlani, M. L. Germanà (Eds.), Earth/Lands. Earthen Architecture in Southern Italy _ Terra/Terre. Architetture in terra dell'Italia del Sud, pp. 37-39, (ETS Pisa, 2011).
19. M.L. Germanà, Perishability of earthen architecture, between built heritage and current production. In Proceedings of the Internationa Conference Padova 3-5 giugno 2021, Previato C; Bonetto J, (EDS), Terra, legno e materiali deperibili nell'architettura antica: 2. L'età romana. COSTRUIRE NEL MONDO ANTICO, vol. 6, p. 715-731, (Quasar, 2023).
20. CEN. EN 14066 Natural stone test methods - Determination of resistance to ageing by thermal shock, (2014).
21. C. Chastre, P. Faria, J. Neves, M. Ludovico-Marques, H. Biscaia, L. Nunes, Testing Durability on Construction Materials, in: C. Chastre, J. Neves, D. Ribeiro, M.G. Neves, P. Faria, P. (Eds), Advances on Testing and Experimentation in Civil Engineering. Springer Tracts in Civil Engineering, pp 29-51 (Springer, 2023).
22. D.G. Woodward, Life cycle costing—theory, information acquisition and application, International Journal of Project Management, 15 (6), pp. 335-344 (Elsevier, 1997).
23. D. L. Le, R. Salomone, Q. T. Nguyen, Circular bio-based building materials: A literature review of case studies and sustainability assessment methods, Building and Environment, vol. 244, (Elsevier, 2023).