

Green Energy and Technology

Consuelo Nava
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Climatic and Structural Safety in Multi-Hazard Regime of Cultural and Natural Heritage

Methodological Advances and Case
Study Applications

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Green Energy and Technology

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Preface

The protection of a Country's cultural heritage, both architectural and environmental, is a highly relevant political and scientific concern, given its profound implications for the social and cultural fabric of societies.

Safety assessment requires a comprehensive understanding of the various sources of risk (climatic, geomorphological, structural, etc.), demanding interdisciplinary approach to the problem. The topics involved are of considerable interest for the scientific community and constitute a knowledge base for any planning strategy, both for preventive actions (maintenance, building and site safety) and reactive interventions (emergency management, evacuation plans).

This book addresses the issue of climatic and structural safety in multi-hazard regime of cultural and natural heritage, drawing on the outcomes of a three-year technology transfer project, funded by the Italian National Recovery and Resilience Plan -PNRR T4Y PP 4.7.1. In particular, the project is entitled Open Platform *phigital space* (physical and digital) of the type *user-profiling* for the advanced and dynamic codesign of interventions on the built and ex novo.

The book is organized into two main parts collecting peer-reviewed papers from approximately twenty involved researchers and begins with a chapter detailing the methodologies adopted and the final goals of the project.

The first part of the book aims to deepen theoretical knowledge related to cultural heritage analysis, proposing advanced models for damage assessment on structures and their surrounding environments. These models also incorporate uncertainties related to material properties and consider different environmental stressors under three projected climate scenarios for the years 2030, 2050, and 2085.

The second part of the book features some chapters with a more applied focus. Thanks to some large-scale case studies, it proposes a digital platform to support all the meta-files relating to the security data collected. This platform, along with the creation of a Living Lab (physical platform), will provide a methodology for the transfer of digitalized data to different stakeholders: including institutions, professionals, and local communities.

The Editors sincerely thank all the senior and the young researches who have contributed by their outstanding contributions to the quality of this book.

October 2025

Consuelo Nava
Aurora Angela Pisano
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Theoretical and Methodological Approaches



The Exploitation Research, the Actions of the Laboratories, the Pilot

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Abstract. The scientific document presents the PNRR project – T4Y PP 4.7.1 entitled “Open platform “phigital space” (physical and digital) of the type “user profiling” (Call for tender for the presentation of proposals for the Strengthening of research structures and creation of R&D “innovation ecosystems”, set up of “territorial leaders in R&D”—to be funded under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2 Investment 1.4, funded from the European Union - NextGenerationEU. Proposal: Tech4You - Technologies for climate change adaptation and quality of life improvement. Spoke 4 - Technologies for resilient and accessible cultural and natural heritage: Goal 4.7: Protection and enhancement of natural and cultural heritage and identity of the inner territories. Pilot Project 4.7.1 - Open platform “phigital space” (physical and digital) of the type “user profiling” for the advanced and dynamic codesign of interventions on the built and ex novo.) for the advanced and dynamic codesign of interventions on the built and ex novo, carried out by the scientists and researchers of the dAeD and DICEAM departments of the Università Mediterranea degli Studi di Reggio Calabria. The frontier themes of information management and open knowledge for structural and environmental safety on cultural heritage contribute to the processes of “radical innovation” of the mission – spoke 4. The “mechanisms of the just transition”, to which respond through the adoption of KET’s, address the material and immaterial (physical and digital) management of the “data-information-resources” system, towards the production of models, methods, prototypes realized in “dynamic” regimes, such as “uncertain parameters” and “limit states” of the analysis and “predictive models of advanced design” for the adaptability to climate scenarios. The pilot project realizes a system-demonstrator, with the open platform “phigital space” of the type “user profiling” for the advanced and dynamic codesign of interventions on the built and ex novo. The experimentation and validation on n.2 case studies in n.2 historical identity settlements in the most fragile inland areas of Calabria (depopulation). The applied experimental activity, illustrated by the contributions of Session II, therefore has a digital information level that realises the transfer of information on a “user profile digital platform” and a physical information level with the creation of the Living Lab (physical platform) for the transfer to users (institutional, professional, community). This scenario realises what is called “open knowledge” in the PP objective.

Keywords: Climate change scenario · Living Lab · Agile Method · Digital Platform · Exploitation · Interdisciplinarity · Safety · Phigital · Open Knowledge · Frontier Research

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1 Introduction

1.1 Theoretical Background: The Exploitation Research ¹

The proposal Tech4You – Technologies for climate change adaptation and quality of life improvement, “(...) main concept is “climate affects you” and “you act on the climate” towards a sustainable and competitive Europe. Our R&I programme will enhance the scientific expertise of researchers and bring R&D results into use to build a resilient community and to strengthen SME competitiveness reducing the gap between research, market, and society. The effects of climate change require a multi-stakeholder involvement (research, businesses, society and government) in a joint action towards resilient communities. The scientific data show the global impact of climate change: Southern and central Europe are seeing more frequent heat waves, forest fires, floods and drought. (...) Tech4You recognises both the urgency and the last chance to take an action. Tech4You will inspire a new generation of researchers showing that using knowledge to develop innovative solutions is the response to the “last call” for a green transition towards a sustainable, inclusive and fair future. Tech4You will address climate change from 5 perspectives: natural risk, energy, food, culture, and healthy communities talking about the specific objectives (SO) described below:

(...)

SO4 – Adaptation of cultural heritage: Tech4You aims to mitigate the impact of extreme weather events on cultural heritage and to improve the accessibility for all leveraging on digital technologies (i.e.: robots, sensors, artificial intelligence, big data and augmented reality) (Spoke4); it wants to reinforce the local identity leveraging on the enhancement of the tangible and intangible cultural heritage and, on the other side, wants to enable the accessibility for all without any restriction for older people or disabled.

(...) The spokes 1-5 will be focused on the implementation of the research and innovation activities that are all addressed to bring the most promising technologies already developed by the research organizations to a higher TRL as close as possible to a marketable stage so that they could be quickly transferred to companies for being industrialized and commercialized. R&I activities will be strongly addressed to have pilot demonstration projects in which the involvement of the final users will be fundamental for the validation. The use of cascade funding will be also very important to expand the ecosystem by including a wide range of companies (particularly the many start-ups and spin-offs that are interested in the Tech4You topics).²

The T4Y proposal therefore presents itself as an innovative exploitation research project, aimed at improving the transfer of the most mature research carried out by teams of researchers, with social, economic and knowledge benefits for the regions involved (Calabria and Basilicata).

¹ This section of the paper draws on the studies by C. Nava, presented in the text ‘Emerging Technologies for Regenerative Design’. 5 theoretical questions on innovation and sustainability in frontier research (2023, edited by Aracne), in order to scientifically place the PP4.7.1 research proposal within the context of innovation and frontier research.

² The text outlines some key points of the T4Y proposal taken from the document. *Annex 1 – Project proposal (Article 10, paragraph 3 and Article 12 of the Call)*

In this direction, the theoretical framework of pilot project 4.7.1 “Open platform “phigital space” (physical and digital) of the type “user profiling”, which is maturing through the work of university laboratories and living labs in the field, can be traced back to frontier research, with its applied innovation aimed at advancing knowledge by “applying known solutions to investigated problems”, a path facilitated by the interdisciplinary skills of the research team.

Below are some references to theoretical studies that the author has examined in order to define the framework of “frontier research” in the field of “innovative knowledge processes”, in the case of “exploitation research” (Nava, 2023).

For a Definition and Classification of Frontier Research

Pasteur’s quadrant (Stokes, 1997, 2011) refers to the relationship between the relevance of advances in knowledge and their immediate application (Fig. 1), identifying the different operating conditions of frontier research. Experiencing these paths means questioning the conventional theory-method-project process, not so much in its necessary cognitive distinction, but in its operating condition and ability to report on the relationship between “pure applied research” and “pure basic research”, through the experimental phase of concept and inspiration, which also requires application. This phase becomes fundamental for all trajectories related to technology and technologies, referring to transformations in the built environment and innovation in processes and products, through new performative conditions of the project.

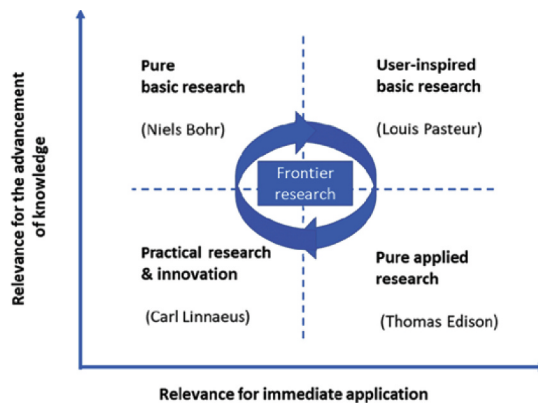


Fig. 1. Type of research in relation to the advancement of knowledge. Adapted from Stokes, (2011).

D. Holste, I. Roche, M. Hörlesberger, Marianne, D. Besagni, T. Scherngell, F. Claire, P. Cuxac, Pascal, E. Schiebel (2011), in their scientific paper “A Concept for Inferring “Frontier Research” in Research Project Proposals, investigate methods for recognising “frontier research” in research project proposals. This document discusses the issues sought in research project proposals submitted for peer review under the European Research Council (ERC) programme. The investigation has two aims: 1) to conceptualise and define, automatically extract and comparatively evaluate the attributes of frontier

research in proposals; and 2) to construct and compare the results of a statistical model with the review decision, in order to gain further insights and reflect on the influence of frontier research in the peer review process. To this end, indicators (including scientific “novelty”, “risk” and interdisciplinarity – see Table 1) were developed for all scientific disciplines in accordance with the European Council’s strategic definition of frontier research, using textual information from the proposal and other bibliometric data from applicants for research funding.

Table 1. Relationship between the definition of frontier research and corresponding indicators. (Source: definition: EC (2005); indicator: own data)

Indicators	Taxonomy (of frontier research)
Novelty	<p>“... is at the forefront of creating new knowledge and developing new insights. The people involved are responsible for fundamental discoveries and advances in theoretical and empirical understanding, occasionally achieving a breakthrough discovery that completely changes our knowledge of the world.”.</p>
Risk	<p>“...is an inherently risky endeavour. In the newest and most exciting areas of research, the approach or trajectory that may prove the most fruitful for the development of the field is often unclear. Researchers must be bold and take risks. Indeed, only researchers are generally able to identify the most promising opportunities. The task of funding agencies is limited to supporting the best researchers with the most interesting ideas, rather than trying to identify priorities.”.</p>
Pasteuresqueness	<p>“... may be interested in both gaining new knowledge about the world and generating knowledge that is potentially useful at the same time. Therefore, there is a much closer and more intimate link between science and the technology that derives from it, with few of the barriers that arise when basic research and applied research are conducted separately.”.</p>
Interdisciplinarity	<p>‘... pursues issues that transcend established disciplinary boundaries. It may involve multidisciplinary, interdisciplinary or transdisciplinary research that brings together researchers from different disciplines, with different theoretical and conceptual approaches, different techniques, methodologies and tools, and perhaps even different objectives and motivations.’</p>

Kim’s Matrix for Knowledge Innovation

For all experiences (project or research) involving disruptive innovation and therefore solutions based on emerging technologies, the “KIM matrix” is used to assess the transfer impact on external socio-technical contexts. This knowledge innovation matrix is divided into four quadrants: (1) Invention, (2) Improvement, (3) Adaptation and (4) Utilisation, based on two key dimensions: the maturity of the application domain (i.e.

opportunity, need, problem) and the maturity of knowledge (i.e. solution, artefact, theory) (see Figure 2).

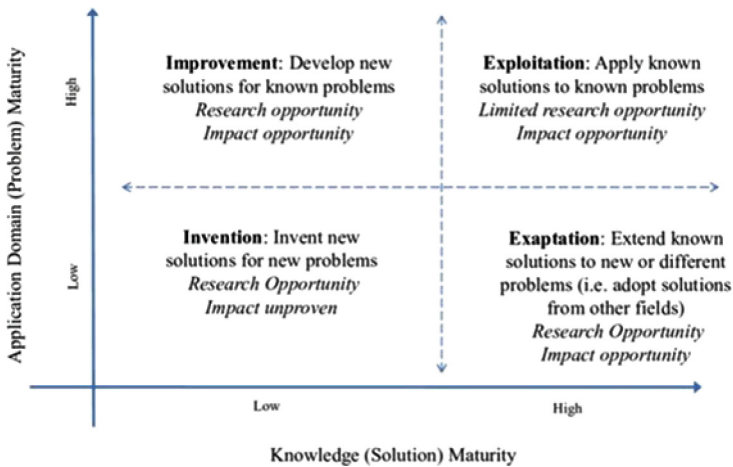


Fig. 2 Knowledge Innovation Matrix (KIM) with research opportunities and external impact results

Gregor S. and Hevner A. R. (2014), in “The Knowledge Innovation Matrix (KIM): A Clarifying Lens for Innovation”, propose different interpretations of the quadrants, breaking them down according to their various impacts on the sectors of innovation in which such experiences are practised.

They also demonstrate this evaluation strategy for the innovation sector in academia, where the focus is on rigorous knowledge production.

What is interesting about the KIM matrix, as it relates to this sector experience, are the definitions of the terms used in the quadrants, which are in some way capable of teaching us to recognise new values in frontier research, from the evaluation practice of innovative applications, as reported below:

Academic value proposition 1: in the *invention* quadrant:

- Research results will be significant, even if cases may be rare.
- Rigorous measurements of knowledge contributions are necessary to provide convincing evidence of new thinking.
- The impact on the real world is unproven and uncertain.

Academic value proposition 2: in both the *improvement and adaptation* quadrants:

- The research results will occur with relative frequency.
- Rigorous measurements of knowledge contributions are necessary to provide convincing evidence of new thinking.
- The impact on the real world can be substantial.

Academic value proposition 3: in the *utilisation* quadrant

- Research results will be negligible, both in terms of number of events and importance.

- (b) The impact of the research will be evident in the form of articles on technology transfer in specialised journals.

In this scientific scenario, it is clear that the case of PP4.7.1, all research related to enabling and emerging technologies capable of expressing hypotheses, options, models and reference visions for design and research that challenges environmental and climate issues finds its space for innovation in the “adaptation and improvement” quadrants, where strategies must be measured against tactics and actions. This is a task and responsibility for the world of applied science and advanced research, which is capable of connecting different issues and tools available. The application of resilience strategies requires such joint and transdisciplinary action in order to pursue the “adaptive capacity” (also required by all IPCC reports) that is necessary in the state of vulnerability in which we operate, not only physically, in a time of great transition and neutrality scenarios.

We will discover that, once again, the relationship between enabling technologies and emerging technologies is very close and relevant when it becomes capable of transferring innovation to two areas of action of resilience, intercepting the regenerative project as an expression of radical and/or transformative resilience (Nava, Melis 2021), for which some reflections and scientific discussions are provided below.

The “phigital space” platform, of “open profiling” type, aims to reach the TRL7, as a demonstrator of a generative system of data-information-resources, prototyped in an operational environment. The architecture of the digital platform on digital protocols, together with the transfer of data-information and use testing on selected case studies, in addition to private users, provides useful DSS to the PA sector or operating entities, to size interventions on cultural heritage. The platform will be able to work with a system of modules able to draw from data-input of different format and configuration, able to report the most useful information to the construction of scenario searched and allow with an interface of applications and simulations, the return of models and protocols attached on the requests made. The level of skills aimed at information management and open knowledge for structural and environmental safety on cultural heritage (settlements and historic buildings) in transition scenarios, are related to the field of geotechnics, structures and analysis of their vulnerability, adaptive technologies identified in the advanced design of dynamic and parametric type on scenarios of physical and climatic context of evolutionary type. Through the contribution for external research activities, the project plans to implement skills and services in the field of information-design, IoT, ICT and computer programming. So the platform “phigital space” further innovates the informative character, with reference to transition scenarios and the opening with the production of protocols on models and prototypes of material and immaterial type, useful for the enhancement of cultural heritage.

1.2 The proposal of Pilot Project (PP 4.7.1)³

1.2.1 Open Platform “Phigital Space” (Physical and Digital) of the Type “User Profiling” for the Advanced and Dynamic Codesign of Interventions on the Built and ex novo

The pilot project achieves a system demonstrator with the open platform “phigital space” of the “user profiling” type for advanced and dynamic co-design of interventions in existing or new buildings. 2 case studies/prototypes will be tested and validated in 2 historical settlements in the hinterland of Calabria (Grecanica area).

Prototype 1 – Municipality of Palizzi Marina – coastal area/natural heritage with a test area in the former slaughterhouse area (municipal area).

Prototype 2 – Municipality of Bova – promontory and historic centre/artistic-monumental heritage with the testing area of Palazzo Mesiani (municipal area).

The applied experimental activity, therefore has a digital information level that realises the transfer of information on a “user profiling platform” and a physical information level with the creation of the Living Lab (physical platform) for the transfer to users (institutional, professional, community). This scenario realises what is called “open knowledge” in the PP objective.

The focus of the application activity is to operate on the heritage of the cases identified in order to create prototypes from which to draw data, resources and information for the purpose of “managing information on issues of structural and environmental safety” (together) of (cultural and natural) heritage, through open knowledge systems (of physical transfer and with digital technologies for multiple user profiles), under climate change, in the 3 scenarios 2030, 2050, 2085 (IPCC 2018-19), with declination to the possibility of identifying an existing “asset” and a new one, as a field of application. It is recalled that T4Y intends to profile the improvement of the “Quality of environmental and life”.

1.2.2 The Executive Work Plan: 3 Milestones, 10 Actions

The project development period is set at 36 months (January 2023 – February 2026). The PP4.7.1 executive work plan is divided into three milestones that achieve the project objectives, progress on the technology readiness level (TRL4/TRL7) and propose three different levels of innovation, as described below.

Milestone 1

Formulation of work plan and detailed project strategy (TRL5) of the pilot project with two general objectives:

- a) realization of a system-demonstrator, with the open platform “phigital space” of the type “user profiling” for the advanced and dynamic codesign of interventions on the built and ex novo, in three physical-climatic scenarios 2030, 2050, 2085 (IPPC data information)

³ This section of the paper summarises, from paragraphs 1.2.1 to 1.2.4, the extract from the PP 4.7.1 proposal in the competitive phase and developed in the executive plan, drawn up by the author.

- b) the experimentation and validation on n.2 case studies in n.2 historical identity settlements in the most fragile inland areas of Calabria

Construction of the architecture of the digital platform on the digital protocols (pilot 30%) and construction of the input dataset, on the design of the pilot plants with the choice of case studies and information derived from the activities of analysis and study, with the interpretation of the first laboratory activities and the processing of integrated technologies (TRL6)

Project innovation: The technology transfer will be realized through the inclusion in the open platform “phigital space” of data “open profile” to serve different users

Milestone 2

Application of methodologies and experimentation on case studies and in situ laboratory; definition of contextualized data and definition of the platform information level and user accessibility profiles (pilot 80%). Identification of prototypes of systems and components on the testing cases of historical urban aggregate and building technologies of interest of the testing activities referred to in the actions of the PP, inserted in the scenarios elaborated in the action and architecture of the information of the output dataset. (TRL 6)

Product innovation: Actions that study models, methods instruct protocols containing recommendations for the proper implementation of technology and simplified criteria for the design of interventions. Action contributes to the technological development of a new generation of locally resonant metamaterial structural components with inherent vibration reduction capabilities that are entirely innovative and 100% patentable. Action contributes to a new method of advanced parametric design on climatic and technological scenarios.

Milestone 3

Operation of the platform on case studies and in situ simulation with different user profiles (pilot 100%). Interpretation and verification of output data testing the methodology used on different actions and the effectiveness of integrated technologies. (TRL7)

Process innovation: Exportability of the Platform as a DSS useful also to the Public Administration sector (municipalities), professional to size interventions on cultural heritage (from case studies exportable models); patenting of research outputs (pilot project) under supervision of dedicated office at University.

10 Actions

The project starts with activities whose methodology and technology is validated in the laboratory (TRL4), with the use of processes, systems and instrumentation that map, catalog and characterize data, information, procedures, tests (actions 1, 2, 3,4) and with some cases of realization of models and prototypes of small-scale systems or full-scale component (actions 5, 6,7, 8, 9, 10) tested in the relevant environment (TRL 5, TRL6, TRL7). In detail:

- with actions 1,2, through the inventory of building structural type and the capability to predict, by limit analysis theory, the collapse load and the failure mechanism of structural elements;

- with the action 3, through the use of RADP technology for the static and dynamic behavior of foundations;
- with action 4, through the use of dynamic analysis with uncertain parameters for structural bodies in brickworks;
- with action 5, through the development of tools for time-varying damage assessment on the structures of historic buildings, with models that consider the accumulation of damage;
- with actions 6, 7, through theoretical studies related to the dynamics of structural components in metamaterials with local resonance and devices with inerter;
- with actions 8,9, through methods and experimental projects on the themes of Advanced Sustainable Design (ASD) for Resilient Scenarios with bioclimatic approaches in urban and building design; through demonstrators, industrially validated and patented, on technologies applied to energy self-sufficient and circular buildings, of which prototypes have been made in scale with the techniques of additive manufacturing and industrial manufacturing.

The cognitive and experimental apparatus of the methodologies and technologies formulated and validated, as that related to the technologies and the realization of prototypes and systems is widely discussed and disseminated by the scientific products in national and international by the researchers of the team project and by research grants with the topics of pilot project. The expected result of the activities of departure, can only point to a system of interface between the products of the various actions and generate a new level of innovation of methodologies, technologies and the creation of prototypes in operational environments, assumable in a system “demonstrator” (action 10)

1.2.3 Description and Quantification of the Expected Results

The PP4.7.1 contributes to the value of T4Y research by establishing, during the proposal design phase, three levels of impact for achieving the objectives of transferring studies and applications to the territory and community involved.

The indicators refer to the extent of the effects that the research actions will have on the pilot project topics of interest to spoke 4.

The following are the operating systems for assessing impact: a. Economic Impact; b. Impact on Improving the Quality of Life; c. Technology Transfer.

a. Economic Impact (e.i.)

To e.i. in the project context. “The regeneration of a cultural asset can be a factor of sustainable development” (English Heritage, 2005). Reactivate assets, to the settlement and building, making them usable and safe from the structural and environmental point of view means to return “their value of use”, already “economic value” recovered and further “incentivized”.

To e.i. in the project activities. The sector related to the fruition of cultural heritage has been affected by the economy of knowledge and smart growth (H2020 and EU), “Producing culture is therefore a frontier economic activity in the era of the knowledge society and global markets and is increasingly complex, because it must adapt to goods and services very different in content and technology, as well as absolutely heterogeneous users” (Santagata et al. 2014).

Value from cost saving. The availability platform useful to instruct interventions can reduce by 20% the economic cost of investigations in the cognitive phase of preliminary technical feasibility.

Indicators

(to e.i. in the project context)

Quality indicators: Knowledge of the area and of its major structural fragilities allows for targeted and calibrated public/private interventions; allows also the possibility of investment over time and local economy activities based on the new attractiveness of the assets.

Quantity indicators: % of new interventions on the assets subject to experimentation; effectiveness (if) of transferable project results (processes and products) for attractiveness of funds for territorial investments on heritage.

(to e.i in the project activities)

Quality indicators: construction of new competencies based on the value of knowledge; investments in R&D; profitability of the initial know-how and the know-how acquired.

Quantity indicators: Investments in service providers and supplies; economies of scale for project management on a platform of integrated and interdisciplinary internal competencies (co-financing)

b. Impact on Improving the Quality of Life (environmental well-being, social and cultural development) of citizens.

The Calabrian territory has suffered significant losses of historical and cultural heritage due to its multiple fragilities (geomorphological, structural, climatic). The inland areas of Calabria are the most “sensitive” but also the most “identity”, the depopulation of villages, has increased the levels of fragility, decreased the care of heritage, together with the lack of primary services, strongly affecting the state of degradation and disruption of settlements and historic buildings. The protocols and models validated in the laboratory, on the geotechnical improvement of soils, on the integrated adaptation of the structures of historic buildings and the energy and environmental performance and durability of structures and artifacts in variable scenarios under different conditions, also restore ecological and social stability to the assets, aiming at new levels of reliability and comfort perceived by users and communities for their sense of belonging.

Indicators

The project aims to provide new levels of security and physical and digital accessibility to the spaces, in the different arrangements of use and over time. It reactivates the collective value of the settlement spaces and buildings, which for their guaranteed usability, increase the level of environmental and social well-being of the community and become real “attractors” for both possible promoters and users.

Quality indicators: level of usability and accessibility of assets; environmental and structural safety; flexible use of spaces; cultural interest in the open digital platform.

Quantity indicators: no. and duration of upgrading interventions on buildings and aggregates in the next 3 years; no. of months of accessibility and operation of upgraded

spaces in a year; no. and types of activities open to use in a year; demographic increase / repopulation index; no. of visitors to the assets; no. of users (various profiles) of the open digital platform.

c. **Technology Transfer**

The total impact is defined by 3 levels of “design driven innovation” to technology transfer:

Project innovation: The technology transfer will be realized through the inclusion in the open platform “phigital space” of data “open profile” to serve different users (Action 10)

Product innovation: Actions 1-2-3-4-5 that study models, methods instruct protocols containing recommendations for the proper implementation of technology and simplified criteria for the design of interventions. Action 6-7 contributes to the technological development of a new generation of locally resonant metamaterial structural components with inherent vibration reduction capabilities that are entirely innovative and 100% patentable. Action 8 contributes to a new method of advanced parametric design on climatic and technological scenarios.

Process innovation: Exportability of the Platform as a DSS useful also to the PA sector, professional to size interventions on cultural heritage (from case studies exportable models) (Action 8,9)

1.2.4 Goal Output and Goal Results the PP4.7.1

The frontier themes of information management and open knowledge for structural and environmental safety on cultural heritage contribute to the process-es of “radical innovation” of the mission – spoke 4, goal 7. The “mechanisms of the just transition”, to which respond through the adoption of KET’s, address the material and immaterial (physical and digital) management of the “data-information-resources” system, towards the production of models, methods, prototypes realized in “dynamic” regimes, such as “uncertain parameters” and “limit states” of the analysis and “predictive models of advanced design” for the adaptability to climate scenarios.

The **goal outputs** aim to bring the following technologies and systems up to TRL5 @M12 and TRL7 @M36:

- 1) A database of structural typologies for the historical buildings in the in-land settlement of Calabria selected as case studies; (nr.1 database with no 2 modules for 3 scenarios)
- 2) Direct methods numerical analysis for the prediction of mechanisms and collapse load of historical buildings falling in fragile territories; (no 1 method for 2 cases to 3 scenarios)
- 3) Advanced solutions in the design and implementation of ground improvements in fragile areas of settlement of historic heritage buildings; (no 2 series for 3 scenarios)
- 4) Dynamic modeling of historic brickworks; (no 2 models for 3 scenarios)
- 5) Time-varying vulnerability assessment tools and advanced protocols for cataloging existing historic buildings on identity structural types; (no 2 protocols for 3 scenarios)

- 6) Digital active control devices, based on the concept of inerter, for the protection and security of monumental heritage assets; (no.1 series for 3 scenarios)
- 7) Structural components in locally resonant metamaterials for structural and environmental safety of historic buildings; (no.2 series x 3 scenarios)
- 8) Atlas of predictive models and adaptive technologies on climate scenarios and reliability (technological and material) of the artifacts of historical heritage buildings (no 3 scenarios for 2 cases);
- 9) Enabling Technologies and Additive Manufacturing (3D printing) of prototypes of systems and components on testing cases (at settlement and building scale).(no. 8 prototypes)
- 10) Digital Platform User profiling Architecture and data implementation, information and models – Demonstrator

The following **results are expected** for the goal:

1. Promote the knowledge economy by means of the reactivation the use- value of heritage.

Contribute to the impact on the local economy of the cultural heritage identity, through innovative processes of reactivation, regeneration and securing of settlements and historic buildings, including in the economy of open knowledge and smart growth all the stakeholders of different profiles: researchers and professionals, users-prosumers, companies, public municipalities.

2. Realize a dual-interface (phigital) demonstrator of an “open knowledge” physical platform (physical-space)

Connect different skills, methodologies and validated technologies in environments relevant to the topics of interest and the techno-scientific fields of investigation, according to the model of co-design, open to the exchange of information and elaborations, among researchers of the team, IR and external companies. Use the transition scenarios as the “common space” to refer to in their experiments and advanced design techniques, as the module of translation of the different results, in models and configurations of morphologies, technologies, architectures and structures of historical heritage assets (settlements and buildings).

3. Realize a dual-interface demonstrator (phigital) of a digital platform “user profiling” (digital-space)

Demonstrate, with an open digital platform of the type “user profile”, the possibility of drawing from data-input of different formats and configurations in order to report the most useful information to the construction of the scenario sought and, through an interface of applications and simulations, be able to return a response to the requests made.

The implementation, populating and use-testing of data-information-models, extracted from the products of actions, allow the possibility of integrating digital outputs, in dedicated protocols to support design choices and intervention (evolved DSS and validation phase with case studies).

2 Methodology: Laboratories and Living Lab ⁴

2.1 Ecophigital Map

The work carried out by the team in order to achieve the objectives expressed in Milestone 1, took place in terms of methodological and desk research work and with a first start in the field, already in the first semester, through all the activities competing with the final objectives of the PP: and with reference to the adopted methodology of the TRL and the impacts to be produced at the end of the project. In order to integrate all the activities and actions aimed at the production of the deliverables, pursuing the PP's own objectives, a cognitive-applicative map was formulated (Ecophigital MAP), to read the research process and control the organisational logic of the industrial research and experimental development, with which the team operationally produces “the exploitation research”, according to the objectives required by the spoke and the HUB (Fig. 3).

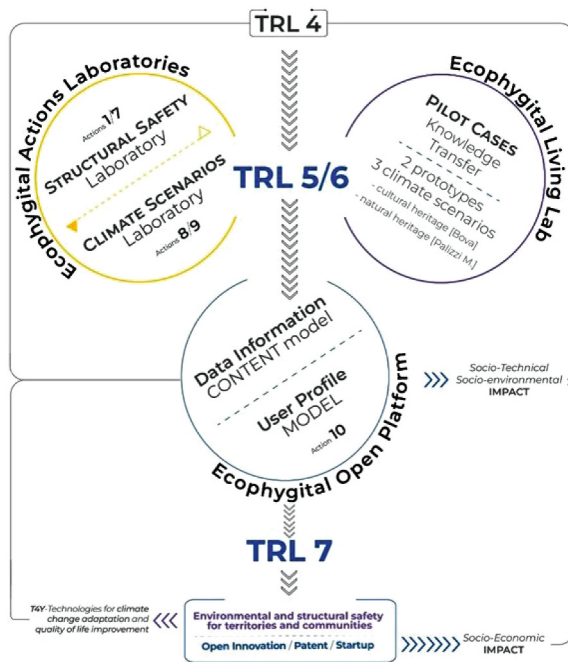


Fig. 3 . Ecophigital map for PP 4.7.1 (Diagram Method by C.Nava -Graphic Elaboration by G.Mangano (2024))

From the Ecophigital MAP, the three research dimensions/spaces of the PP emerge:

⁴ The section of the paper that describes the methodology refers to the implementation of the programme involving the activities and deliverables achieved in Milestone I and part of Milestone II, with the contribution of researchers who worked in teams and achieved the objectives in university laboratories and by participating in the living lab set up for the various actions.

- (1) *Ecophigital Actions Laboratories*: which expresses all the activities related to the actions, organised and carried out by 2 thematic/disciplinary Laboratories – SSL Structural Safety Laboratory (for actions 1/7) and – CSL Climate Scenarios Laboratory (for actions 8/9).

The activities carried out by the laboratories with the heads of the actions and the working group, are realised through the provision of instrumental resources (soft and equipment) which are already in the possession of the research groups and which are foreseen to be upgraded with the T4Y project's expenditure plan. Figure 4



Fig. 4. Meeting and dissemination activities in university laboratories

- (2) *Ecophigital Living lab*: this refers to the transfer of the research actions and activities to the knowledge levels for the applied experimentation on the 2 pilot cases selected (Bova municipality and Palizzi Marina municipality – municipalities of the internal areas of the Grecanica Area of the Metropolitan City of Reggio Calabria, , studied on the 3 climate scenarios (2030, 2050, 2085), as prototypes to be used for the acquisition of the data and information that will populate the data-information of the digital user profiling platform (Figure 5) (Lucanto D, Nava C, Mangano G; (2024).

the Digital Platform is constructed; then the structure of the inter-face for user profiling operations.

On this tool, in order to guide and instruct all the actions of the project towards the construction of the aforementioned platform a first preliminary document has already been advanced, (sect.2).

TRL Method

Ecophigital Open Platform realises TRL 7, as a demonstrator model in an operational environment, particularly aimed at meeting the transfer objectives of PP, such as environmental and structural safety for territories and communities and for the HUB's objectives on Open Innovation, Start UP, Patent and Start up.

Impact Value

Ecophigital Open Platform (3), adds to the values the final levels of socio-technical and socio-environmental impact, new value for the expected socio-economic impact of technology transfer to territories and communities for quality of life and security in climate change scenarios.

2.2 Selection of Prototype Cases

This section explains the reasons behind the selection of the two prototype cases for the experiment, which involved the team working with university laboratories and on site with the Living Lab.⁵

The topic referred to in spoke 4 refers to the care and enhancement of “cultural and natural heritage”, which the European Landscape Convention already defines as “protected assets”, referring to “architectural and environmental assets”.⁶

This category includes immovable property and parts of the built environment, complex buildings also considered in relation to their surroundings and their characteristic and traditional appearance; areas with unique characteristics and landscape, geological, natural and environmental value, such as parks and reserves, panoramic views and view-points, coastal areas, areas surrounding lakes, rivers and watercourses, mountain peaks, volcanoes, glaciers, woods and forests’ (Treccani glossary).

The PP 4.7.1 team identifies the Grecanica Area of the Metropolitan City of Reggio Calabria as a territory and community with a strong cultural and natural identity, recognised by UNESCO as intangible heritage and recognised for the identity of the Greek minority of Calabria.⁷

The following case studies have therefore been identified:

⁵ G. Mangano wrote about the Living Lab method and implementation in “The Living Lab project and community engagement in the pilot project 4.7.1”

⁶ “property protect” Legislative Decree No. 42 of 22 January 2004, ‘Code of Cultural Heritage and Landscape, pursuant to Article 10 of Law No. 137 of 6 July 2002’ and by the European Landscape Convention, 2000.

⁷ GRECANICA AREA – Cultural heritage - *Grecanica Area/ SNAI and SRAI Pilot Area _ National and Regional Strategy for Internal Areas*The administrative Grecanica area consists of 16 municipalities: Motta S. G., Montebello Jonico, San Lorenzo, Cardeto, Bagaladi, Roghudi, Roccaforte del Greco, Condofuri, Bova Marina, **Bova, Palizzi**, Staiti, Brancaleone, Samo, Africo

Prototype 1 – Municipality of Palizzi Marina – coastal territory/natural asset with testing area at the former slaughterhouse (municipal area) (Fig. 6)

Prototype 2 – Municipality of Bova – Promontory territory and historic centre/artistic and monumental asset with testing area at Palazzo Mesiani (municipal area) (Fig. 7)



Fig. 6 . Settlement map of the municipality of Palizzi



Fig. 7 . Settlement map of the municipality of Bova and Mesiani Palace

The investigation of prototype cases.

and finally, Reggio Calabria. However, the Greek-speaking island, i.e. the area where the Greek language is still spoken, can be narrowed down to the municipalities of Bova, Bova Marina, Roghudi, Ghorio di Roghudi, Galliciano, with traces also preserved in municipalities or parts of them such as Roccaforte del Greco and its Ghorio, Arangea and San Giorgio Extra di Reggio Calabria.

1. The “scale” knowledge levels for information and context areas may differ in the two prototype cases:

Prototype 1 – Municipality of Palizzi Marina – coastal area/natural asset

LT_ territorial level with reference to the Ionian coast of the Grecanico area

LSA_ environmental system level: coastal strip in the section up to 300 metres from the coastline, including the EX Mattatoio testing area (water/sea system, soil, vegetation, buildings, etc.)

Prototype 2 – Municipality of Bova – Promontory territory and historic centre/artistic and monumental heritage with Palazzo Mesiani testing area (municipal area)

LUCs_ urban level/historic centre (exposed fronts, related areas, roof area, soil, networks, etc.)

LAgM_ aggregate level of buildings/heritage and structures Palazzo Mesiani (masonry structures, roofs, etc.)

2. The knowledge activity on prototype cases will use
 - a. A level of indirect information and study (bibliographies, studies, research, data, etc.)
 - b. Direct information through survey activities of a practical/instrumental nature – on cases, with equipment, mobile labs, etc. of a Technical-interpretative nature – with scenarios and simulation models, tests, etc.

Therefore these activities will implement the “open construction site” phase in the first year of research (M1) on which to work for the deliverables/M1, the LIVING LAB development area.

The data, information, studies, etc. will be subject to in-depth analysis and study for the preparation of material useful for transfer to the digital platform and for activities related to dissemination to users in the area and dissemination of scientific research products.

2.2.1 The Prototypes and the ‘Data-Information-Resources’ System

The focus of the application activity is to work on the identified cases to create prototypes from which to draw data, resources and information for the purpose of “managing information on structural and environmental safety” issues (together) of cultural and natural heritage, through open knowledge systems (physical transfer and digital technologies for multiple user profiles), in the context of climate change, in the three scenarios 2030, 2050 and 2085 (IPCC 2018–19), with the possibility of identifying an existing “asset” and a new one as a field of application. It should be noted that, as reported by T4Y, the aim is to outline a profile for improving the “quality of the environment and life”.

This means that:

- The case studies are producers of methodologies, models, measures, etc. and therefore should be considered as such and are not the subject of experimentation, but rather the field of application for experimentation and integration into the demonstration case (the platform).
- The intention is to work on the concept of “risk” associated with related and interfering issues between structural safety (not only vulnerability and seismic risk, etc.) and

environmental safety (climate, biodiversity, etc. etc.), where climate change scenarios are the contextual and scientific systems from which to start and to which to refer, and in the specificity of the climate data set that will be produced on the case studies (see action 8).

- The work has been done on defining this multi-level risk, after conducting the initial exploratory phases of the action, and that we will do so with a co-design approach (as envisaged in the project).
- The activities have produced methodologies and results that have identified any differences, characteristics, etc. related to the three scenarios and across multiple models.
- In all experimental activities relating to deliverables, the aim was to produce “information useful for the integrated procedure with the platform”, which therefore requires a specific programme for the prototypes.
- Not all actions produced activities on both prototype cases, specifically on the Bova prototype (actions 1, 2, 4, 5, 6, 7), on the Palizzi prototype (3, 8, 9), and on both prototypes (action 10).
- The activity had a digital information level that dealt with the transfer of information to the user profiling platform (digital platform) and a physical information level with the activities of the Living Lab (physical platform) for transfer to users (institutional, professional, community). That this scenario achieves what is referred to in the PP objective as “open knowledge”.

3 Discussion– The Pilot Demonstrator *Ecophigital Platform*

3.1 Level of Innovation of the Demonstrator and User Profiles

The digital user profiling platform, with its highly transferable “open” and “interoperable” content, is the product of the pilot project, the Demonstrator, which has been awarded TRL 7 technological maturity level. The level of technological maturity achieved by the activities related to the actions/deliverables (the different TRLs) must be capable of “informing” the knowledge levels on information, content and interoperability of the platform, related to the themes of “structural and environmental safety” for heritage.

In summary and specifically, not only have advanced results been achieved from a scientific point of view, but the real challenge has been to make them “readable and interoperable” for multiple user profiles (Fig. 8).

The platform takes on different values for “open knowledge”, responding as:

- A highly communicative and effective system for users/citizens, communicating levels of information on topics and simulations and models to help them understand the phenomenon of risks, but also possible “safety” scenarios with integrated visions of quality of life, the future, etc.
- A support system for users/technicians, to understand the scenarios, models, measures and methodologies that can be adopted in studies and activities on topics of research interest, illustrating simplified processes to identify feasible paths for interventions on heritage and its assets.

- A user/public body support system to understand, with regard to the studies and methodologies conducted and the work carried out with the Living Lab, scenarios of change in contexts, possible resources and opportunities for “safe” territorial investments.

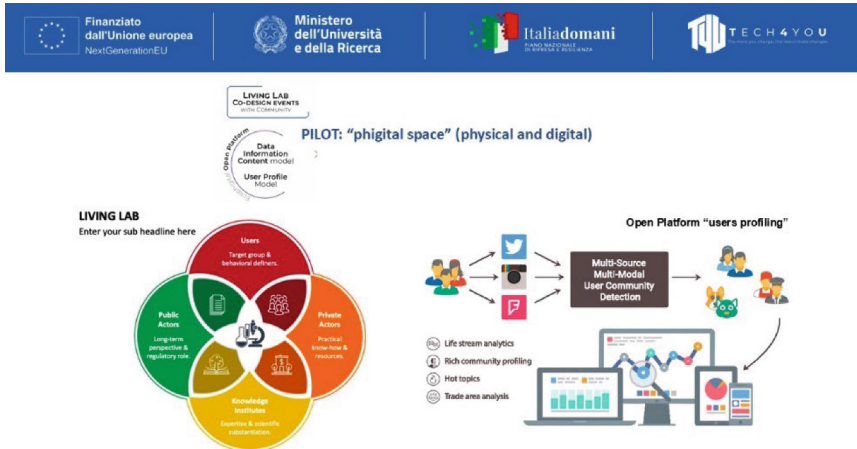


Fig. 8 . Structure and contents of the ‘phigital space’: platform and living lab

All activities and Pilot results with products to be included in the platform have a “filter” that selects according to access to the three types of users for the level of information most “dedicated” to them.

3.1.1 Integrated Procedure Between Actions/Activities and Platform

The platform has a communicative interface and content that is updated with the transfer of results and the outcome of actions. It is open because it has levels of interactivity and interoperability programmed by IT developers (Tab. 2).

Table 2. Content structure outline for the platform, useful for populating information.

AREA	Section 1 Contents	Section 2 Contents	Section 3 Contents
INFORMATION AREA	How to use the demonstration platform Guidelines and the 3 user profile filters	Presentation of TOPICS on structural and environmental safety and CC Texts, data, images, references	Presentation of prototype cases Dossiers, photos, videos, graphic tables, reference links

(continued)

Table 2. (continued)

AREA	Section 1 Contents	Section 2 Contents	Section 3 Contents
CONTENT AREA	Definitions and descriptions of RISK TYPES (references to the 2 prototype cases) data, texts, graphics Interoperability with access to other databases, platforms, etc.	MEASURES AND INTERVENTIONS Data, texts, graphics, models, simulations Interoperability with access to other databases, platforms, etc.	METHODOLOGIES USED WITH REFERENCE TO SECTION 1.2 Data, texts, graphics, processes, workflows, references, examples Interoperability with access to other databases, platforms, etc.
INTERACTIVITY AND INTEROPERABILITY AREA	Interactivity Section dedicated to the filters of the 3 user profiles Platform testing activities planned in the PP	Interactivity Presentation of protocols to assist specific cases Platform testing activities planned in the PP	LIVING LAB Physical and digital activities With open consultation Platform testing activities planned in the PP

3.1.2 Platform Population Activities _WOP (Workflow of Platform) Document

The platform has a descriptive-demonstrative (non-processing) purpose, but interoperable only on models, data, hypertextually traceable information on the sections populated by the work of the PP actions for different profiles (user, scholar, institution) (Tab. 3)

1. With reference to what has been described for the activities in the university laboratory and in situ (LL Programme and Agenda document), correspond to these activities “products” transferable to the platform as indicated in the sections and areas.
2. Briefly describe only “specifying the product” in the type (data, texts etc...) and also in its “definition” (e.g. climate scenario models etc.).
3. Report products according to A and B and on several products use A1, A2.
4. More extended and referenced descriptions with explanations and sources will concern the document attached to the workflow.

Table 3. Workflow matrix for information provided by actions

PERIOD	UNIVERSITY LABORATORY ACTIVITIES	LABORATORY ACTIVITIES IN SITU (c/o municipalities)	OPEN PLATFORM – sect 1	OPENPLATFORM – Sect 2	OPENAPLATFORM – sect 3
	Report on Corresponding Deliverable/indicate site (Palazzo Bova, Costa Palizzi)	Report on Corresponding Deliverable/indicate site (Palazzo Bova, Costa Palizzi)	(content area) Definitions and descriptions of RISK TYPES (references to the 2 case-prototypes) data, text, graphics Interoperability with access to other databases, platforms, etc.	(information area) A- Presentation of the Themes on structural and environmental safety and CC Texts, data, images, references (content area) B-MEASUREMENTS AND INTERVENTIONS Data, texts, graphics, models, simulations Interoperability with access to other databases, platforms, etc.	(information area) A- Contribution to the Presentation of Prototype Cases (Dossiers, photos, videos, graphic tables, reference links) (content area) A- METHODOLOGIES USED WITH REFERENCE TO SECTION 1,2 Data, text, graphics, processes, workflows, references, examples Interoperability with access to other databases, platforms, etc.
<i>IM period</i>	<i>document</i>	<i>document</i>		A- B-	A- B-

Attach more extensive descriptive .doc document Workflow activities, as expressed in the matrix (Fig. 9), indicating:

1. Period of the activities and explanation if in LAB or SITU
2. Section and Area of reference
3. Content and more extensive description of the product/activity, with possible references to data type and sources used
4. Type of data to be allocated to the interface by User profile also multi-use_ indicating if (citizen/student/body)
5. Interoperability of the data/information- indicating if connected to other types of products/data expressed in other activities (Fig. 10)

4 Conclusion

The PP4.7.1 pilot project carried out activities related to a three-year exploitation research programme, with great rigour in achieving the objectives and with reference to the activities of the 10 project actions. The experience gained by the team of senior and junior researchers highlighted a number of important conditions for the success of the competitive proposal and identified some critical issues during the course of the activities. Both conditions may serve as a reference for possible future research trends. Some points for discussion are presented below.

Barriers:

- At the start of the programme, a lack of communication between HUB T4Y and Spoke 4 impacted the progress of PP4.7.1.
- The availability of the budget for purchasing equipment for the laboratories was delayed in relation to the activity plan for the second milestone.
- Poor knowledge of the PNRR T4Y programme pilot projects for possible discussions on topics of common interest or similar research trajectories.
- Bureaucratic complexity of the procedural activities required.

Values:

- Excellent level of interdisciplinary exchange between researchers in carrying out studies and laboratory activities.
- Excellent and effective operational agenda for the team to exchange information and test the objectives achieved in an “agile process” (over 15 meetings in total, 4 Living Labs with municipalities).
- Good impact and balance between researchers from different departments and new recruits (9 researchers, 3 PhD students, 4 research fellows, 1 scholarship, 1 SME, 5 consultants, 2 BAC), with a good gender balance (9 F; 7 M).
- Good dialogue with the municipalities of the selected prototype cases.
- Excellent level of innovation for scientific activities aimed at open knowledge (new methodologies and collaboration between researchers).
- Excellent production of intermediate documents useful for semi-annual scientific reporting (draft paper for actions and report for pilot project).
- Excellent results obtained in audits with reviewers (2).
- Excellent production of digital and physical prototypes.
- Creation of a user profiling platform as a space for transferring data and information produced by the joint activities of the laboratories (WOP process).
- Good dissemination of intermediate products at international conferences and in scientific publications (papers).
- Achievement of measurable objectives with impact assessment as required by the proposal (paragraphs 1.2.3 and 1.2.4).

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