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THE HORIZON EUROPE "BUILDCHAIN" PROJECT PRESENTATION: TRUSTWORTHY BUILDING LIFE-CYCLE KNOWLEDGE GRAPH FOR SUSTAINABILITY AND ENERGY EFFICIENCY

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Abstract

The aim of the project is to create a knowledge base as a tool for tracking all activities in the whole life cycle of buildings. As several EU directives address the sustainability, resilience, and energy efficiency of the building stock, it is mandatory to provide a market that allows the different actors to share their offers, including quality certificates and credentials, as well as to record and track all information, activities, and changes, and to use knowledge to improve sustainability.
Novel DBL-based applications will be tested in pilot projects focusing on historical buildings in critical condition and on different building classes. The project aims to increase the smartness and sustainability of the EU building stock, create new markets, and generate new value.

Keywords

Digital Building Logbook (DBL), Building Renovation Passport (BRP), Energy Performance Certificate (EPC), Building Information Model (BIM), Historical Building Information Model (HBIM), building indicators, digital data sources, survey, geomatics.

1. *Introduction*

The building stock accounts for more than 40% of the total energy consumption in the European Union. In addition to direct consumption, much energy is lost due to the fact that many building-related processes are repeated throughout the life cycle, information on geometry, building materials and their properties, test and operational measurements is lost or unused, not structured or organised, not updated, not shared between the different actors around the building stock. Collected information is currently scattered in an isolated manner across different databases and in the hands of different actors. Even if the collected data is accessible, there is a lack of systematic verification and quality control. This leads to unsustainable processes, wasted potential of this information, waste of resources, energy and time.

Especially in the shadow of current events, pandemic and energy crisis, climate change, reducing energy dependency and improving energy efficiency, climate resilience and sustainability is of high importance for Europe. Therefore, several European Union directives are related to improving the sustainability and energy efficiency of the building stock (European Union, 2018) (European Commission, 2021).

Another critical issue in Europe is the preservation of the historical and cultural value of the built environment. The turnover and replacement rate of the existing stock is low. It is estimated that about 85-95% of today's buildings will still be in use in 2050 (European Commission, 2020). The built heritage (buildings as well as their immediate surroundings, neighbourhoods) is a factor of identity of the European society, which makes it necessary to adapt any intervention to preserve its unique cultural value, while ensuring the decarbonisation of buildings.

The implementation of Digital Building Logbook (DBL), a common repository for all relevant building data, have the potential to overcome these obstacles and challenges, enabling better decision making throughout the building lifespan by digitizing building related information. An increasing interest in DBL among public authorities and business enterprises is observed in the last decade, which is reflected in the number of DBL initiatives that are being tested or are currently in development (Alonso et al., 2023; Carbonari et al., 2020; Gomez-Gil et al., 2023; Malinovec Puček et al., 2023; Volt et al., 2020).

A technical study is ongoing on behalf of the European Commission's with the aim to guide the Member States of the European Union (EU) in setting up and operationalising DBLs under a common EU Framework (DBL Study Team, 2023).

The Horizon Europe BUILDCHAIN project (HORIZON-CL4-2022-TWIN-TRANSITION-01-09 GA#101092052, https://buildchain-project.eu/) aims to exploit the potential of using Digital Building Logbooks (DBLs) for a smarter and more sustainable built environment in the European Union, building a Knowledge Base, that can be used to trace all activities related to the overall life-cycle of buildings.

2. *BUILDCHAIN concept*

The foundation concept of the project lies in integration of reliable, transparent and fully trackable data and knowledge (Fig. 1).

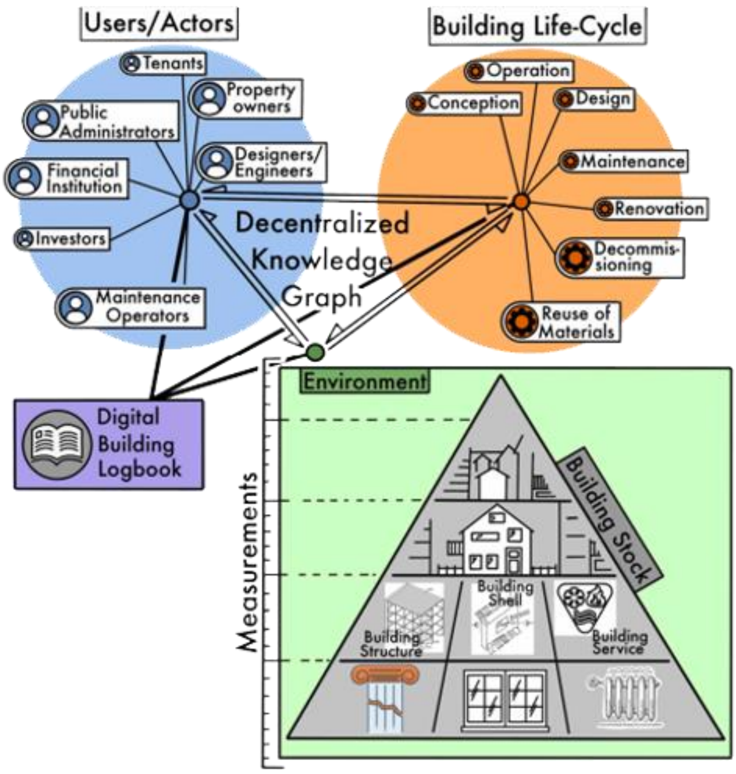

Fig. 1: Concept of the BUILDCHAIN system, showing interconnections between users, building life-cycle and built environment.

The creation of an affordable, reliable ecosystem around such high-quality data can significantly improve services and products provided in the specific field throughout the life cycle of buildings, e.g. adaptation and intervention strategies can be optimised for greater sustainability and resilience, according to the New European Bauhaus initiative. The proposed software and the subsequent economy can trigger the updating and re-qualification of the existing built environment to better adapt to new social trends and ever-changing environmental impacts, as provided by the Built4People project (Built4People Home - Built4People).

BUILDCHAIN is based on a State-of-the-Art (SoA) Decentralised Knowledge Graph (DKG) to design and develop its DBL solution for data and knowledge integration, as well as to incorporate new applications and functions to manage integrated information, efficiency, circularity, and transparency, and to improve the building stock while facilitating informed decision making and its validation (Dourlens-Quarantae et al., 2021).

The project will extend an existing DBL used by a municipality in Italy (Municipality of Florence) for the management and operational data of its buildings and integrate it with an already existing Decentralised Knowledge Graph (DKG) from TRACE, an open source blockchain-based solution, an OriginTrail protocol as an interoperable layer 2 sidechain (Gargaro, Del Giudice, & Ruffino, 2018).

This DKG software will incorporate building-specific ontologies to enable the logging (discoverability) and seamless updating (auditability) of all information related to the entire life-cycle of buildings.

Providing intelligent oracles that embed off-the-chain ontologies (e.g. compliance with standards, legacy databases, etc.) to interact with on-the-chain logged data will result in reliable data management and consistency, and also ensure high data quality. Embedding this feature in the DBL will allow the generation of a detailed knowledge base about the building life-cycle, which in turn will provide the various stakeholders, both private and public, with devices and interfaces that use the DKG to provide data, knowledge and building models, all available for publishing, tracking, sharing, tokenising and even trading in a free market economy.

The project will create a marketplace where actors such as designers, product and service providers, NGOs, public agencies and emerging businesses can share their offerings, including credentials and quality certificates, and enable the logging and tracking of every activity and change, as well as the use of knowledge to improve the energy performance and sustainability of the building stock.

In addition, DBL platform will be integrated with several new functionalities demonstrated on a dozen of use cases via easily accessible and publicly available APIs built on top of the DKG, including: management tools for standard building stock, Building Information Model (BIM)-based surveys and sensor fusion with Artificial Intelligence (AI), BIM-based tools for DBL data, optimisation tools for status monitoring of energy performance, the structural assessment of the buildings and their reliability against natural hazards, and structural monitoring tools based on digital twins and IoT sensor platform for early warning (Croce et al., 2021; Chiachío et al., 2022).

A summary of the twelve use cases and tools that will be developed in the BUILDCHAIN project is presented in Figure 2.

This level of integration of tools and information can effectively support decision making on adaptation and intervention strategies, optimise available funding for either single or multiple buildings, and ultimately support the transition from a linear to a circular economy in the building sector, resulting in a safer and more resilient building stock, also against natural hazards and future climate change impacts (European Commission, 2023). Focusing for example on Use Case 4, "*Earthquake and climate proof of building based on digital twinning*", DBLs can represent useful tools to facilitate the assessment process of built environment against

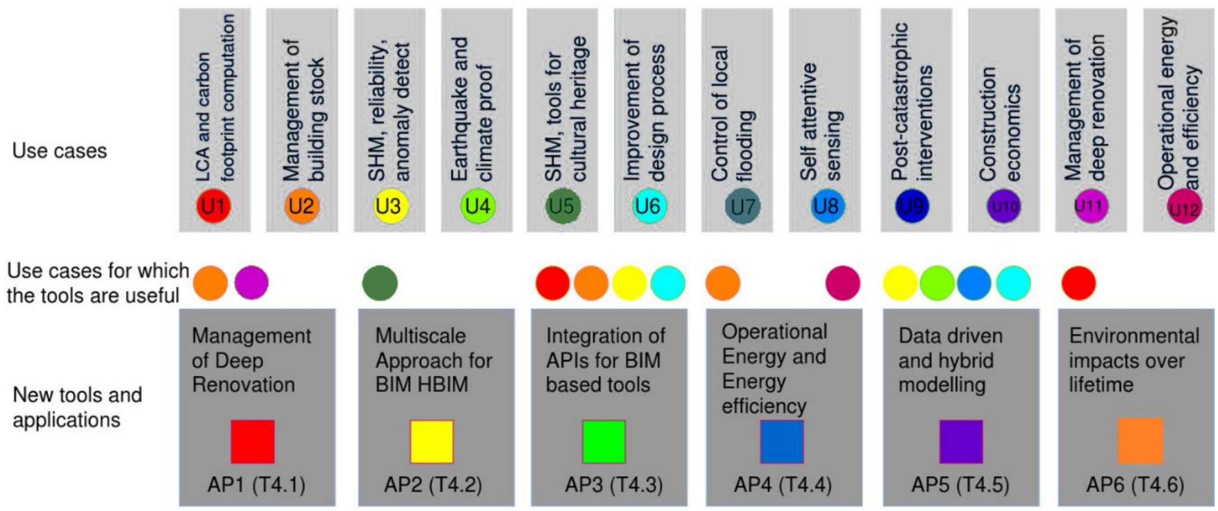

Fig. 2. Use cases and tools of the BUILDCHAIN project.

natural hazards, allowing the collection of the results in a systematic way and the evaluation at a higher scale than that of a single building, for example at a city level to define intervention priorities and adaptation strategies.

Different users and actors can benefit from this use case: policy makers could have access to data regarding climate and earthquake resilience in order to plan and promote intervention strategies at regional or national level; asset managers of a municipality or a big company will be able to assess data about earthquake and climate vulnerability of the managed buildings, planning intervention strategies for their adaptation, optimizing the allocation of available resources and complying with EU regulations; engineering professional can access to data about the building performance and design strengthening interventions complying with EU and National standards (Pöchtrager et al.).

In Figure 3, a UML diagram describing Use Case 4 is shown.

The use cases and APIs will be deployed and tested on large scale demonstrators as shown in Figure 4.

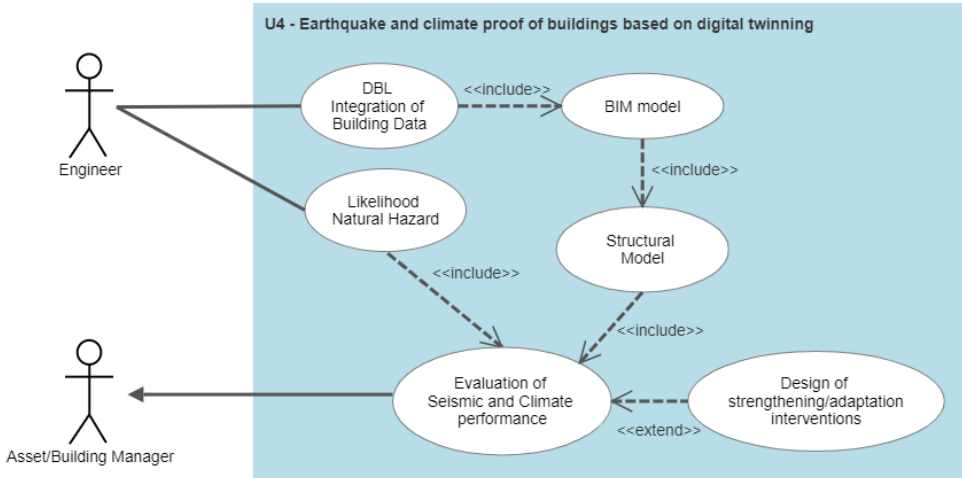

Fig. 3. UML diagram of Use Case 4.

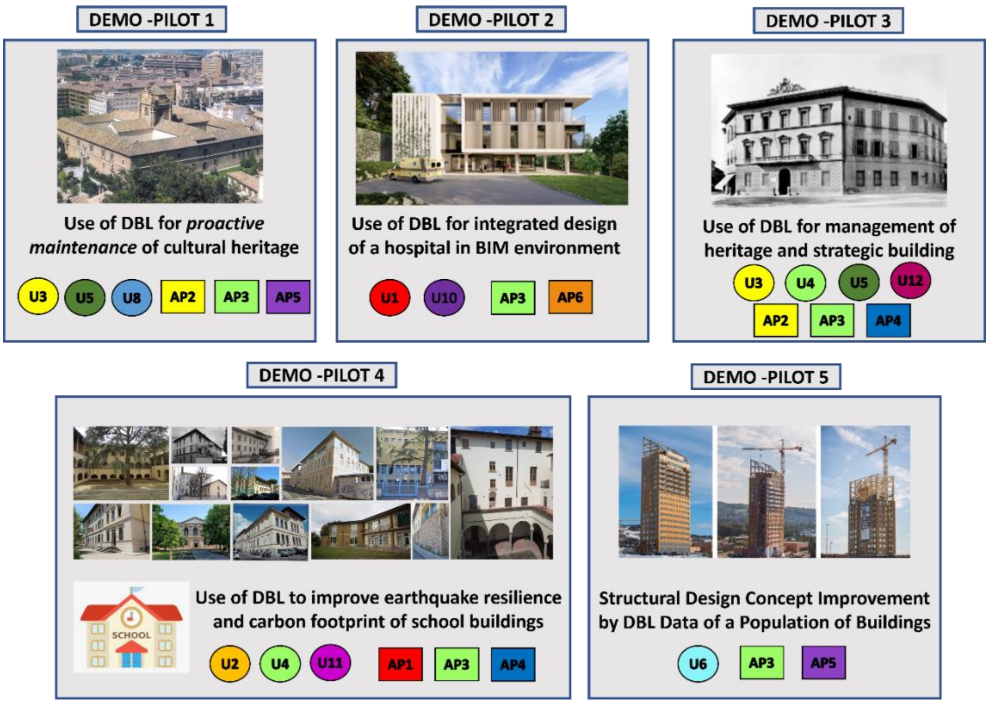

Fig. 4: Test pilots demonstrating the use of DBLs.

The five pilots will focus on:

- Proactive maintenance of cultural heritage (the "Hospital Real" in Granada, a XVI-century Renaissance building currently serving as the Rectorate of the University of Granada).
- Integrated design of a hospital in BIM environment (a new hospital in Slovenia).
- Management of heritage and strategic building ("Palazzo Poniatowsky-Guadagni" in Florence, XVIII century building, the head office of the local police). (Croce et al. 2023).
- Improvement of earthquake resilience and carbon footprint of a population of buildings based on DBL data. A large set of school buildings owned by the municipality of Florence will be investigated, for which data and structural models are available as a result of a previous research agreement between the Municipality and the University of Pisa research group (Croce, Landi, & Formichi, 2019; Croce et al., 2021).
- Structural design concept improvement by DBL data of similar buildings. In particular, modern tall timber buildings located in UK and Norway, as those described in (Blaž et al., 2022).

Overall, a very important aspect of the BUILDCHAIN project will be the scalability of the proposed platform (see Figure 5).

A multiscale approach will be followed in the design of the platform with the idea to integrate multi-level and multi-resolution BIM models, where the required level of detail will depend on the characteristics of the building (common or historical/heritage) and its relevance for the use cases. We will start from a rough model of the building at the urban scale, which can be used for city model purposes, like monitoring environmental impacts, climate parameters, distribution networks and planning interventions, and we can then increase the level of detail of the digital twin going to the local scale of the single building when we need to monitor for example the preservation of the architectural features of the building, the structural behaviour and the physical properties. (Bruno & De Fino, 2021).

Two specific Use Cases, "*U7 - Precipitation monitoring for active control of local flooding*" and "*U9 – Post-catastrophic interventions*", will be developed to demonstrate the benefits of DBLs at the urban scale. In fact, buildings and their DBLs

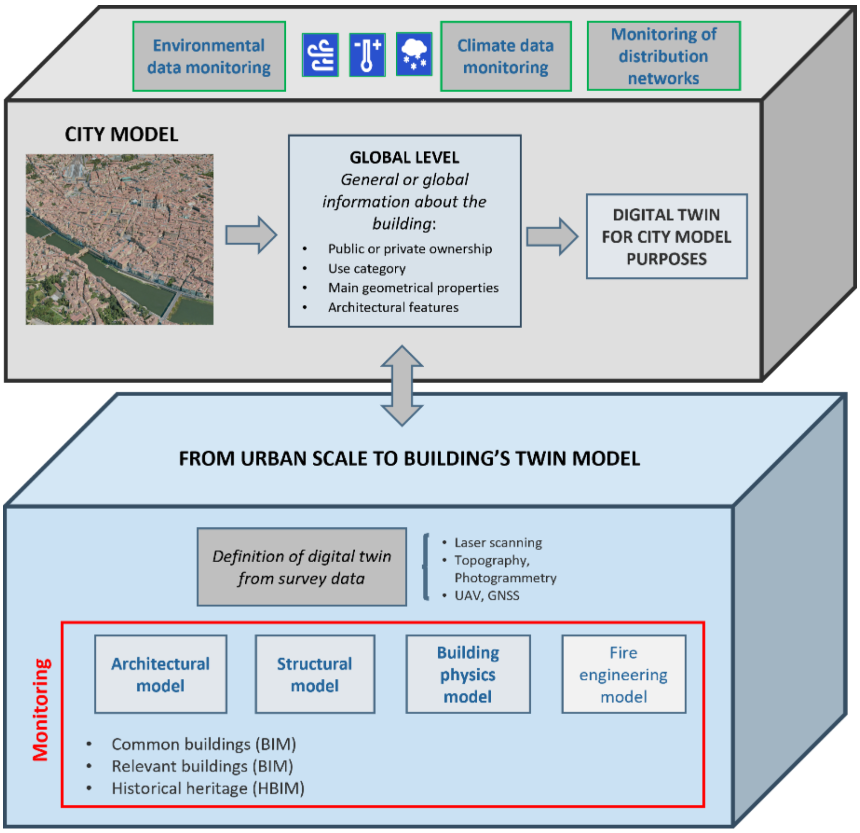

Fig. 5. A schematic graph showing the multi-scale approach for exploiting DBL data.

can represent the nodes of monitoring network of precipitations to evaluate flood risks, support policy of risk reduction, and develop stormwater management plan at City level (U7). Moreover, this monitoring network can be used also to support decision-makers in managing emergency phases after a catastrophic/extreme event controlling damage levels comparing the status of the buildings before and after the event by means of advanced survey techniques such as those based on UAVs. (Billi et al., 2023).

The system and the market envisioned by the project will encourage stakeholders, designers, developers, landowners, public authorities, investors, financial institutions, and operators to connect, interact and collaborate through the DBL, ultimately leading to the integration of the diverse expertise and interests involved (Fig. 1 and 2).

3. Project goals

As a whole, BUILDCHAIN has both scientific and technical goals. In order to set up, implement, monitor and exploit the project, the partners have defined the following six main objectives.

3.1 Improve the links between existing databases, tools and sources, new technologies for data collection.

The use of shared languages, interfaces and protocols will enable these services to provide the project with interoperability and data consistency (e.g. through shared European Manufacturing Data Spaces to ensure better accessibility to privately owned data, through industrial data platforms) and to create values through knowledge sharing, introducing a shared information model for the next generation of DBLs, fully exploiting existing standards and suggesting extensions for missing features.

3.2 Improve energy performance, cost effectiveness, circularity and climate resilience.

DBL data, construction/renovation materials with their intrinsic properties, facilities, transformation processes and operating features (e.g. energy consumption, number of occupants etc) will enable BUILDCHAIN to fully examine the current status of buildings and to suggest the best interventions or transformations as regards energy and costs to reduce carbon footprint.

These data include, as an example, management of spaces, facilities, and maintenance, along with maintenance/operating guidelines, warranty data, manufacture information and contacts, all of which ultimately leads to a highly detailed, BIM-based facility management. BIM data is then combined and augmented with real-world data (i.e. connections to management and control systems, creation and use of synthetic data), collected from multiple sources to generate a Digital Twin building enabling seamless monitoring along with costs and energy effectiveness as well as material reuse.

3.3 Improve safety, health and comfort of building occupants.

BUILDCHAIN will increase the levels of safety, health and comfort of the occupants through the incorporation of several data-driven modelling tools and functions that will optimize building energy consumption, thermal comfort and cost effectiveness, forecast major damages in both structural and non-structural building sections, and support operational decision making providing end-to-end simulations of "what-if" scenarios.

3.4 Improve management and renovation for large building stocks.

DBL data and the functions therein implemented will also play a role in boosting management of large building stocks, such as those owned by public administrations. DBL interconnection will allow for:

- monitoring and managing building maintenance;
- tracking, logging and reconciling the presence and/or validity of building certificates;
- monitoring, managing and optimizing energy consumption;
- supporting decision-making processes for renovation plans and optimizations based on the available financial resources.

3.5 Reliability, transparency and trackability of DBL data, including verification, certification and use of application-level proofs.

Advanced technologies such as blockchain show great potential in handling these issues, and their application should therefore be explored.

Decentralized Identities (DIDs) and Verifiable Credentials have recently been proposed as a standard to allow users to validate their rights, to make specific changes in DID documents etc. In DBLs, each building can be associated with a specific unique identifier (wallet number), along with any associated data and metadata. Use of DID methods may facilitate DBL interactions, such as accessing, editing or adding information. Besides, based on context-related observations, application-level proofs may also be used to validate features such as presence, location, quality certificates, ISO standards etc.

3.6 Improve collaboration and service quality of DBL-spawned economy

DBLs will allow for new data exchange commercial offerings around big data holders, such as municipal or governmental agencies, land registries, large construction businesses. For years, big data archives have been kept and maintained in isolated databases, gathering vast data quantities along the way. The availability to the public of these archives could spawn new economies: as an example, municipalities that have issued construction permits could retrieve several data, such as connectivity, heating fuel type, seismic resilience and so on. These data could be aggregated, e.g. by building type or neighbourhood, and marketed to specific vendors or used in different contexts, such as municipal policies, granting programs etc. These actions by the municipalities could be tokenized via a reward system or similar concurring in future cost reductions and increase of social welfare. In addition, DBLs allow for new offering of high-quality services in the supply chain of the building life cycle, i.e. design, building, renovation and recycle. As an example, DBLs allow for generation of a detailed BIM as regards its properties and condition, in order to provide specific renovation contracts ensuring the required effectiveness as energy performance, stock preservation, structural stability etc. Alternately, material present in old buildings could be best reused or recycled based on their condition as logged in the DBL. Beside the above goals, the project will promote and leverage BUILDCHAIN methodology and tools by testing and validating the developed solutions by means of a comprehensive set of smart pilot applications and scenarios (Fig. 3 and 4). In order to evaluate the achievements of the BUILDCHAIN solution, the Authors have devised an initial set of Key Performance Indicators (KPIs), which will be measured in the context of validation processes, mainly within the use-case scenarios.

4. The BUILDCHAIN consortium

To achieve the ambitious objectives of the highly multidisciplinary project BUILDCHAIN, a wide Consortium, coordinated by the University of Pisa, has been set-up relying on complementary skills, expertise, and experiences of the twelve partners reported in Table 1. The Consortium covers several disciplines including: civil engineering; architecture; structural engineering; building physics and energy efficiency; climate models; impact of climate change; preservation of cultural heritage; management of building stock; BIM technologies; business models; building economy; predictive modelling; AI solutions; physics based model updating; Big Data analysis; collaborative software engineering and design; cloud and fog computing concepts, architectures and solutions; blockchain related technologies and coding; building related ontology, assuring an adequate balance not only among academic and industrial partners, and public administrations, but also in terms of geographical coverage.

Tab. 1: The BUILDCHAIN Consortium.

No.	Partner	Country
1	University of Pisa (UNIPI)	Italy
2	Számítástechnikai es Automatizálási Kutatóintézet (SZTAKI)	Hungary
3	University of Granada (UGR)	Spain
4	Zavod za Gradbenistvo Slovenije (ZAG)	Slovenia
5	Unversity of Ljubliana (UL)	Slovenia
6	Athens Economics and Business University (AUEB-RC)	Greece
7	Prospeh, poslovne storitve in digitalne resitve (TRACE)	Slovenia
8	RINA Consulting (RINA-C)	Italy
9	CLIO S.r.l. (CLIO)	Italy
10	Municipality of Florence (FLORE)	Italy
11	Protim Ržišnik Perc (PRP)	Slovenia
12	BEXEL Consulting (BEXEL)	Serbia

5. Work plan and resources

The BUILDCHAIN project aims at the implementation of OriginTrail's DKG for technical activities categorizable into positioning, design, system development and validation.

The work plan, resulting from a focused, collaborative effort, defines both horizontal and vertical activities, as well as their mutual interactions, over a 36-months' time frame. Figure 6 shows the structure, timing and goals of each Work Package (WP) along with the information flow across WPs.

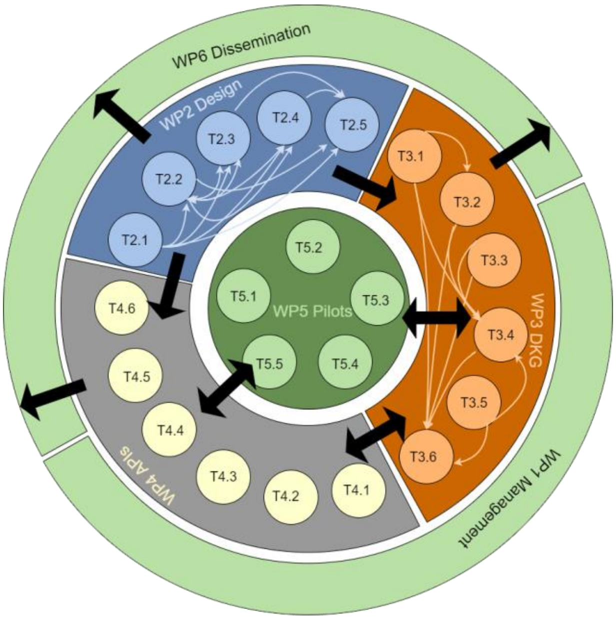

Fig. 6: Work Packages and Word Package interdependencies

The work plan is organized in six WPs, as follows (Tab. 2):

WP1 aims at ensuring timely achievement of high-quality results through technical and administrative coordination, as well as providing effective managing and financial coordination, ensuring compliance with the structures and procedures as defined in the proposal phase and in the contractual agreements.

WP2 is focused on the examination of the state of the art of existing DBL deployments and related DBL-based software and tools, along with surveying the requirements of interested parties and designing the novel BUILDCHAIN DBL system. As for design, the WP defines new use cases of the DBL as well as a Common Data Environment (CDE) for BIM-based data storage during the project, gathers common and novel data types to link to the DBL, for logging into or taking out of the system, along with events and triggers leading to generation of new data or activation of data sharing/exchanging, and lastly designs the BUILDCHAIN system ontology.

WP3 aims at providing a thorough solution for BUILDCHAIN both off- and on-chain data management, incorporating the DKG and developing methods to ensure interaction across entities, governance and guarantee of data quality, and finally a system promoting building sustainability and energy efficiency.

WP4 focuses on developing new DBL-based functions and tools to enhance its usability on different contexts, leveraging data for several engineering applications, including SHM and energy use optimization. Besides, BUILDCHAIN applications will be exploited in different phases of the buildings' life cycle, such as design and construction, as well as disposal and end-of-life assessments. Applications developed by WP4 will make use cases developed in WP2 feasible and will be implemented and tested in actual pilot projects within WP5.

WP5 aims at demonstrating the use of DBL as well as testing and validating BUILDCHAIN tools in several European pilot studies. These will provide stakeholders and citizens with samples of possible uses of the BUILDCHAIN tools to gather and update relevant building data, improving resource management, building decarbonisation, safety and health as well as supporting strategic decision-making for intervention and maintenance.

WP6 focuses on implementation of communication, dissemination, exploitation, standardisation, and training activities to generate and raise awareness about BUILDCHAIN, place it in its potential market and stimulate the growth of its community.

Tab. 2: Work Package description.

WP No	WP Title	Lead Partner
1	Project management and coordination	Università di Pisa
2	LogBook design	Szamitastechnikai es Automatizalasi Kutatointezet
3	DKG LogBook implementation	Univerza v Ljubljani
4	Technological Applications of DBLs	RINA Consulting
5	Built Environment Ecosystem Economy Pilots	Università di Pisa
6	Dissemination and exploitation	Universidad de Granada

Specific goals of WP6 include: providing the appropriate technical infrastructure to support awareness and community building efforts; creating suitable contents and communication materials to generate awareness in software industry and market; engaging in communicating with sector-specific media through websites, events and conferences, to establish BUILDCHAIN as a recognized tool for reliability, trust and developers' productivity; developing pragmatic exploitation plans, as well as marketing and intellectual property rights strategies targeting involved parties and market segments to ensure BUILDCHAIN's sustainability beyond the actual duration of the project.

Use cases as defined in WP2 are connected to WP5 via large-scale pilot projects (Fig. 4), with the assistance of the tools and APIs developed in WP4 (Fig. 2 and 4).

The first and the last work package provide common activities, ensuring management and coordination of collaborative phases (WP1) and positioning in the potential market as well as growth of the BUILDCHAIN project (WP6). These horizontal activities will be carried out throughout the entire duration of the project. The remaining WPs provide mainly vertical, technical activities, which will go on strictly for the time needed to develop and test the specific software components and demonstrate their use.

The project will articulate in five main phases, based on the predominant activity type:

i) set up;
ii) design and use cases;
iii) development and data collection;
iv) integration;
v) deployment, testing and validation.

6. *Early activities for the Palazzo Poniatowski-Guadagni demo pilot in Florence*

6.1 The building and its history

Palazzo Poniatowski-Guadagni is located on a site overlooking Porta al Prato in Florence and is characterised by a rather irregular shape, the result of several phases of construction. The first evidence of the existence of the building can be found in the maps of the city drawn up by Magnelli and Zocchi in 1783.

Later, a manor house was added, which became the property of Prince Stanislaus Poniatowski of Poland in 1832. In 1842 Prince Poniatowski's son bought the adjacent farmhouse and commissioned Giuseppe Poggi to restore the entire complex. The palace changed hands several times. In 1864 it was bought by Louisa Lee (1810-1886), wife of Marquis Donato Guadagni, hence the name Palazzo Poniatowski-Guadagni. In 1920 it was bought by the Municipality of Florence. In the years that followed, the use of the building changed several times (Fig. 7).

Fig. 7: Palazzo Poniatowski-Guadagni at the time when it was the when it was the seat of the Istituto Agricolo Italian Colonial Institute (photo by Schemboche, IAO photo library)

After the Second World War it became the headquarters of the Florence Municipal Police, which is still there today (Fig. 8).

Fig. 8: Today's Poniatowski-Guadagni Palazzo.

6.2 The first topographic surveys

The Palazzo is a three-storey building with a total height of 18 metres. The load-bearing structure is composed of stone masonry walls.

Three main blocks can be identified: a central body inclined towards the axis of Porta a Prato and two lateral wings oriented towards the converging avenues. Each floor measures approximately 860 m^2, with the exception of the first mezzanine, which measures about 320 m^2, and the attic, which measures about 210 m^2.

In the first few months of the project, a digital survey was carried out using laser scanners with the aim of developing a refined H-BIM of the demo pilot (Galera-Rodríguez, Angulo-Fornos, & Algarín-Comino, 2022). The building has a very articulated and complex structure. This type of geometry dictated the choice of survey method, which was to use a terrestrial laser scanner equipped with Slam technology. This type of instrument, using traditional inertial sensors and the new VIS (Visual Inertial System) technology, based on real-time photogrammetric processing that positions the instrument in space, makes it possible to pre-register the clouds during the survey. The specific instrument used is the Leica RTC360, which allows the coordinates of the points to be collected with an accuracy of approximately 2 mm at 10 m and the spherical image in HDR (High Dynamic Range), calibrated to 432 MP of 360° x 300° raw data, to be acquired at the same time.

The building evolves along three floors above ground, characterised by the presence of both spaces with a height equal to the level between floors and mezzanines that reduce the height of some of them (Fig. 9). (Martinez-Espejo Zaragoza, Caroti, & Piemonte (2021).

There are also basements with different access points that are not always connected.

The environments have different and often curvilinear plan geometries. Even in section, the rooms in several cases present a curvilinear shape of the ceilings. Figures 10 and 11 show some views of the point cloud of the relief of the main façade and the "piano nobile" of Palazzo Poniatowski-Guadagni.

Fig. 9: Laser scanning point cloud section of the Poniatowski-Guadagni Palace.

Fig. 10: Laser scanning point cloud of Poniatowski-Guadagni Palace main facade.

Fig. 11: Survey of a vaulted room with a frescoed niche on the main floor of the palace.

7. Conclusions

The present project proposal stems from the ever growing need to integrate high-quality data on buildings along their entire life cycle, from design to recycling. Currently, the inability to integrate data in the industry is a serious issue, preventing generation, analysis, sharing, and knowledge monetization on building sustainability and energy efficiency.

Each building has its own identity and life cycle. It is well known that several businesses interact during the life cycle of the building, thus generating a wealth of knowledge. DKG is currently the most advanced technology facilitating data integration according to interoperability principles, analysis, sharing, monetization (e.g. via cryptographic tokens such as TRAC) and generation of different tests of data quality. These include certificates owned by professionals willing to share or monetize BIM data, identities validated via the latest W3C frameworks such as DIDs and VCs, and generation of various proofs, such as for location, presence, standard compliance and so on.

Analysis of this knowledge integrated in a digital logbook for buildings can lead to enhancing products and services in practically all fields related to buildings, such as sustainability, energy performance and living comfort.

Assessing and ensuring safety of ageing structures and infrastructures is an open topic in Europe, as testified by recent catastrophic events, e.g. the collapse of the Morandi bridge (Genoa, Italy) in 2018. SHM, which provides observing and analysing behaviour of structures such as bridges or other buildings, can support informed decision-making in view of anticipating major unwelcome consequences. Increasing accessibility of monitoring gear entails the availability of these procedures for a wide range of buildings and structures. Constant improvements in Artificial Intelligence (AI) algorithms (rather used in process engineering) can provide support in the evaluation of "what-if" scenarios, explicability of monitored data and anomaly detection procedures.

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