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INFINITE
BUILDINGRENOVATION
Industrialised envelope solutions

D2.5

Novel methodology for the Social sustainability assessment

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About the project

Off-site prefabrication of multifunctional envelopes has been shown to be a technically viable approach to increase rate and quality of deep renovation of residential buildings. However, several barriers are still preventing a massive adoption of prefabricated solutions.

INFINITE aims at boosting the building renovation sector through the so-called "**Renovation4.0**" approach, which leverages on both digitalisation and industrialisation to offer **tailor-made solutions** with a high level of **design freedom**, **decrease retrofit costs and time** thanks to the optimisation of the value-chain and **foster the adoption of eco-compatible long-lasting products** and systems.

To do so, the INFINITE Project relies on three main pillars:

1. cross-fertilisation from digitalisation trends in other markets (i.e. Industry4.0),
2. exploitation of industrial capabilities and coupling with LC-thinking approach
3. experience gained from the 1st generation of multifunctional prefabricated envelopes

INFINITE promotes a life cycle approach that allows for comprehensive design, optimisation of the O&M and depletion of end-of-life residual value.

INFINITE partners cover the whole renovation value-chain. Together, they will develop a new generation of residential building renovation products and actions centred on the all-in-one industrialised Life-Cycle-based approach. Expected outputs include:

- a set of multi-user and **multidisciplinary design tools**,
- **process-optimised all-in-one industrialised eco envelope kits**,
- **adaptive control systems**,
- set of **demand- and industry-side matched business models** to show the Renovation4.0 market potential,
- a **structured framework of entities and knowledge** able to clearly and widely demonstrate the Renovation4.0 benefits.

INFINITE will unleash the potential of the renovation industry by increasing the market penetration of sustainable, high-quality and long-lasting building retrofitting products and methods. This will ultimately contribute to the decarbonisation of the European building stock.

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Executive Summary

The goal of the task is to develop a methodology that can be applied to evaluate the **socio-economic impacts and risks of building retrofitting in a user—centred perspective**. Building residents are directly impacted by retrofitting, but more actors are involved in the life cycle of building renovation. Therefore, **different stakeholders and both positive and negative effects** must be considered in a comprehensive analysis of the retrofit process. The methodology aims to provide a **step by step guidance** from the case study definition, to stakeholder and indicator selection and assessment possibilities. The idea is to provide generic guidelines for the social assessment of building renovation that can be easily adapted to the different cases and needs of practitioners. The framework is tested and validated with the INFINITE industrialized retrofitting case. The **three demo sites** in Slovenia, Italy and France were used for validating the methodology.

The methodological framework proposed for the social sustainability assessment of building retrofitting considers **16 steps**. The 16 steps are described in the deliverable, including the specific application of each step to the INFINITE project.

The first steps proposed in the methodology focus on how to **establish the scope of the analysis and define the building context and the indicators** for the social assessment. The remaining steps focus on **data collection, impact assessment and recommendations.**

The results highlight that social performance of industrialized retrofit solutions may be improved by the following aspects: On the one hand industrialization potentially has a positive impact on **Health and safety**. On the other hand, if technology assembly is moved from building sites to industrial plants, there may be a **lack of skilled workers** for off-site assembly of new and more complex solutions. Consequently, we highlight the importance of **training and visual guidelines** for workers. Further findings include an expected **reduction of disturbance** for residents due to less works that need to be performed on site, **employment** as a geographic challenge and maintenance cost as a potential hotspot as modern technologies arguably become harder to maintain. It is crucial to take on a **life cycle perspective** in order to avoid focusing on direct benefits and disregard burdens that may not be visible immediately or are shifted to the supply chain.

1. Introduction

The INFINITE project aims at providing sustainable solutions for industrialized building renovation. The developed technological solutions need to be sustainable from an environmental, economic and social point of view. Specifically, different societal stakeholders may be positively and negatively impacted by building renovation and its supply chains.

The social dimension is typically the most difficult to assess, due to a number of reasons:

- There can be a **wide range of societal stakeholders** impacted by the life cycle of the system under study, and not all life cycle stages affect the same stakeholders.
- **Social data are more difficult to collect** because stakeholders are less willing to disclose them and/or data are less conventionally measurable.
- In contrast to economic and environmental data, **social information can be qualitative, quantitative or semi-quantitative** and each piece equally contributes to the assessment.
- **Cause-effect relations** are in place among different stakeholders, impacts and risks which are not always easy to be captured and quantified.
- The methodology for social Life Cycle Assessment (s-LCA) is more recent and less consolidated than environmental LCA and Life Cycle Costing (LCC); furthermore, in many cases, it is useful to **combine social LCA with social sciences** (e.g. anthropological studies), but there are no clear guidelines on how this should be done.

As environmental and economic impacts have an effect on societal stakeholders, it appeared crucial having a dedicated task working on this topic in INFINITE, keeping in mind the limitations above, but also trying to overcome them with a proposal of a methodological framework for social sustainability assessment in building retrofitting.

2. Goal and structure

The goal of this study is to develop a **methodology** that can be applied to evaluate the **social** and **socio-economic impacts and risks of building retrofitting in a user—centred perspective**. Building residents are directly impacted by retrofitting, however, more actors are involved in the life cycle of building renovation. Therefore, different stakeholders and both positive and negative effects are considered for the analysis. The framework aims to provide a **step by step guidance** from the case study definition, to stakeholder and indicator selection and assessment possibilities. As for some methodological steps different alternatives may be available depending on the case study, different options are described. The idea is to provide generic guidelines for the social assessment of building renovation that can be easily adapted to the different cases and needs of practitioners. The framework is tested and validated with the INFINITE industrialized retrofitting case. The three demo sites in Slovenia, Italy and France were used for validating the methodology. However, it is possible that the level of detail of the social assessment differs depending on the project specificities, due to data availability and language barrier. The development and testing of the methodology in INFINITE are performed in an **iterative way**, given that **insights from local case studies lead to modify and adjust the methodology itself**.

After a brief overview on selected studies and project addressing social sustainability, the methodological framework is proposed and described. For each step of the methodology, a dedicated section provides a generic description and application of that step to the INFINITE case and demo sites (when applicable).

3. Review of studies addressing social sustainability

3.1 H2020 ITERAMS

The **H2020 ITERAMS** (Integrated Mineral Technologies for More Sustainable Raw Material Supply) project[1] (2017-2020) aimed at developing more sustainable mining technologies to close the water loop at mining sites, valorize waste and reduce environmental footprint. GreenDelta was responsible for the sustainability assessment in the project, covering environmental, economic and social aspects. For the latter, the goal was to understand 1) **how the novel ITERAMS technologies affect social impacts and local communities´ perception** about the mine operation (thus influencing mining acceptance and the so-called "Social License to Operate"); and 2) if there are any **differences between the technological impacts on social issues and what the communities perceive**. To achieve these goals, a methodology was developed, see Figure 1. The methodology is described in a Shortbook about the project [1] and has been presented in different events [2][3] an publications [4].

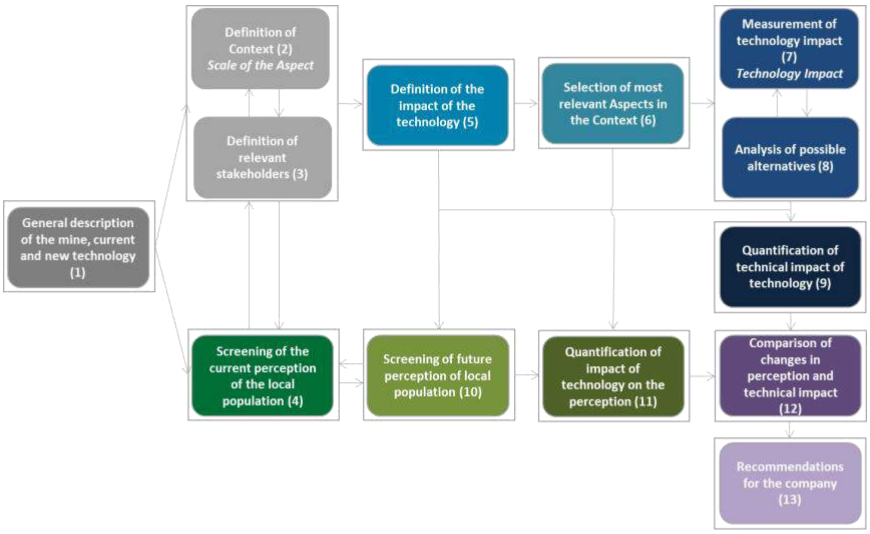


Figure 1: Methodology for social assessment of technological and perceived mining impacts in H2020 ITERAMS project

[1] H2020 ITERAMS http://www.iterams.eu/

The application of the developed methodology showed that for all selected social categories the **expected technical impact resulted higher than the expected perceived future impact** of ITERAMS technologies, showing that not all positive and negative impacts due to the main and ITERAMS are perceived by the local population. The main perceived social aspects are employment, region development, accommodation prices, status of water resources, working conditions (safety, working hours, salary), and inclusion in main decisions. It also emerged that **proper communication of benefits obtainable with ITERAMS is key for their perception**.

Although the sector under study in ITERAMS is different from the one in INFINITE, different links can be identified between the two projects in terms of goal and methodology to assess social impacts and technology perception. The methodology in ITERAMS is, therefore, seen as a starting point for the definition of the methodological steps for social assessment in INFINITE.

3.2 H2020 CULTURAL-E

The H2020 Cultural-E[2] project has developed an Atlas at the European level to map different variables that affect energy consumption of buildings, see Figure 2. These variables include cultural, climate, demographic, design parameters grouped in different categories. Specifically, one category is represented by **socio-economic factors**, including the following aspects:

- Population Density;
- Gross Domestic Product;
- Households Disposable Income;
- Households Electricity consumption;
- Households Gas consumption;
- Electricity prices;
- Gas prices.

The socio-economic factors identified in this project can be a included for the socio-economic assessment in INFINITE and the definition of related indicators to measure INFINITE technology impacts.

[2] H2020 CULTURAL-E https://www.cultural-e.eu/

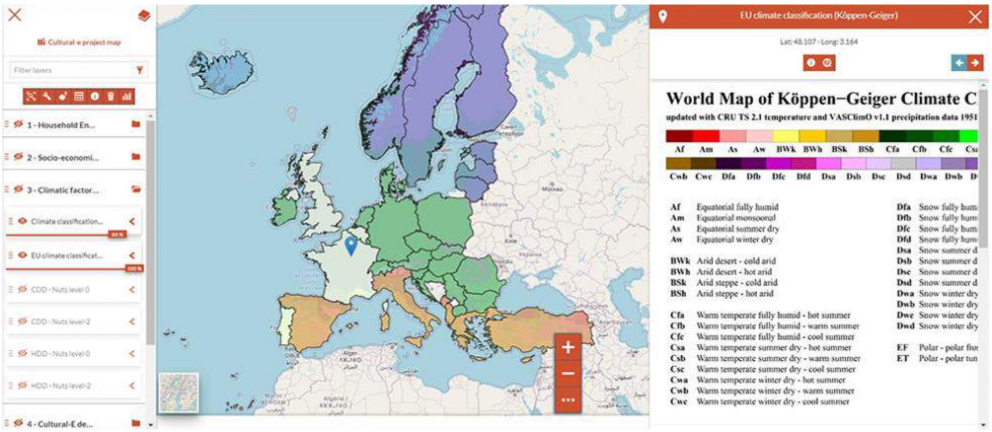


Figure 2: Tool screenshot from the Cultural-E website[2]

3.3 Socio-economic impact pathways in building retrofitting by M.I. Touceda

Very little literature is available concerning the assessment of social impacts in the life cycle of a building retrofit. In the majority of cases, **the focus is on building residents** (therefore only on the retrofitting and building operation stages). **No comprehensive guidelines on the assessment of the whole retrofit life cycle and involved stakeholders are available.** Touceda pointed out that the S-LCA Guidelines [5] focus mainly on the production phase, while the EN15643-3:2012 covers the use phase [6], see Figure 3.

Figure 3: Social aspects covered by S-LCA Guidelines and EN15643-3:2021, elaborated by Touceda [6]

Touceda's work is the only one that was found to provide a methodology to combine different impact pathways for different stakeholders in the building retrofit life cycle, see Figure 4.

Table 1 Summary of impact pathways proposed in this LCSA methodology

		Stakeholder	Topic	Impact assessment method	Damages	Areas
LCSA	e-LCA			ReCiPe	Species loss per year	Natural environment
				ReCiPe	Surplus cost	Natural resources
		Society	Emissions to environment	ReCiPe	Damages to health (DALY)*	Human health & social well-being
		Workers	Health & safety	WHO Global burden of disease SHDB		
		Households	Indoor air quality	Usetox method WHO inadequate housing		
			Adequate indoor T.	WHO inadequate housing		
		Workers/local community	Employment	Construction DB + I/O tables	Fair employment (wh)*	
			Fair working conditions	SHDB method		
		Households	Fuel poverty	"Low income- high costs"	Fuel poverty gap (€)	
		State	Investment & return Avoided costs	Adapted LCC methods	Contribution to growth (€)	

*Where *DALY* disability-adjusted life years; *wh* working hours; *WHO* the World Health organization; *SHDB* Social Hotspot Database

Figure 4: Impact pathways proposed in the methodology for life cycle sustainability assessment by Touceda [6]

Finally, Touceda proposed a number of aspects for the socio-economic inventory in building retrofitting [7], see an example in Figure 5. This represents a crucial starting point for the development of the methodology in INFINITE.

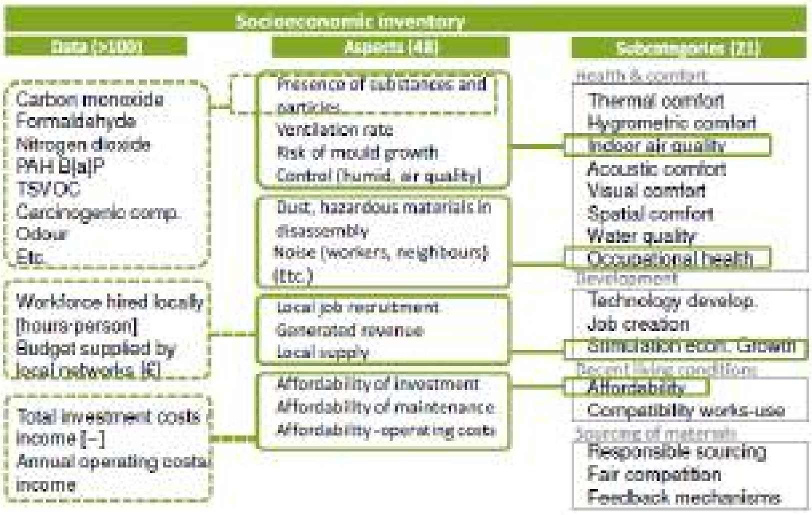


Figure 5: Socio-economic inventory for building retrofitting [7]

4. Methodological framework proposal

The **methodological framework** developed by GreenDelta for the social sustainability assessment of building retrofitting considers 16 steps, that are connected to one another, as displayed in Figure 6. The 16 steps are summarized as following and further described in the next sections of this chapter.

1. **Case definition**: description of the objective of the retrofitting project, the technologies that will be used and implemented for retrofitting and identification of one or more case studies.
2. **Brainstorming:** understanding the value that can be generated by the project for different stakeholders involved in the life cycle of building renovation; identification of possible variables, risks, stakeholders part of the retrofitting and analysis of the cause-effect relations among them.
3. **Social hotspot screening:** identification and analysis of the crucial aspects in the life cycle of retrofitting and for different actors involved. Hotspots can be defined as recurring issues or positive effects, and most contributing processes to social impacts.
4. **Stakeholder selection per life cycle stage**: definition of the societal stakeholders for which social impacts will be assessed, based on the goal of the project and social assessment study.
5. **Building context:** study of the socio-economic and social situation of the building case study and perception of the context by building residents.
6. **Description of possible retrofitting solutions**: description of the retrofitting technologies to be implemented in the project with a focus on possible benefits or negative effects on the building context and the selected stakeholders.
7. **Social indicators**: selection of social indicators for the assessment of social sustainability of the project. Indicators should be defined for the different life cycle stages and stakeholders in building retrofitting. Assessment scales of the indicators are to be developed, considering qualitative, quantitative and semi-quantitative nature of social indicators. Possibly, a benchmark for the different indicators can be identified.
8. **Baseline definition**: definition of a reference situation to which the social impacts and risks of retrofitting will be compared, for instance the building before renovation.
9. **Stakeholder dialogue**: engagement of different stakeholders, such as researchers, social scientists, technology providers, for the definition of social indicators meaningful for the assessment and data collection.
10. **Data collection:** typically the most time-consuming step dedicated to data gathering from different sources (primary data, literature) and for different stakeholders. Data are collected to assess the selected social indicators. Depending on the data availability, this step may result in the creation of social life cycle models in dedicated modelling software and databases.
11. **Assessment of positive and negative impacts of retrofitting:** evaluation of positive and negative effects of the building renovation, expressed for the different social indicators.

12. **Impact comparison with baseline:** comparison of the social impacts of retrofitting with the defined reference situation (baseline) to understand improvement or worsening of different social aspects.
13. **Changes in perceived context of building (by residents):** investigation of changes in residents´ perception about issues or positive aspects in the building if retrofitting technologies are implemented.
14. **Acceptance of novel technologies (by residents):** based on the current perception of problems and positive aspects and changes in this perception thanks to the retrofitting project, investigation of the foreseen reaction of residents to the retrofitting process and solutions.
15. **Conclusions and recommendations:** summary of results and their interpretation and provision of recommendations to improve the social sustainability performance of retrofitting and acceptance of novel technologies. When possible, it is recommended to perform this assessment at the early stage of the retrofit design process in order to orient the design with the results of the social assessment and favor a participative design approach.
16. **Monitoring over time:** monitoring the social impacts of building renovation during the retrofitting process and after the renovation to investigate if and how impacts change over time and possible improvement actions.

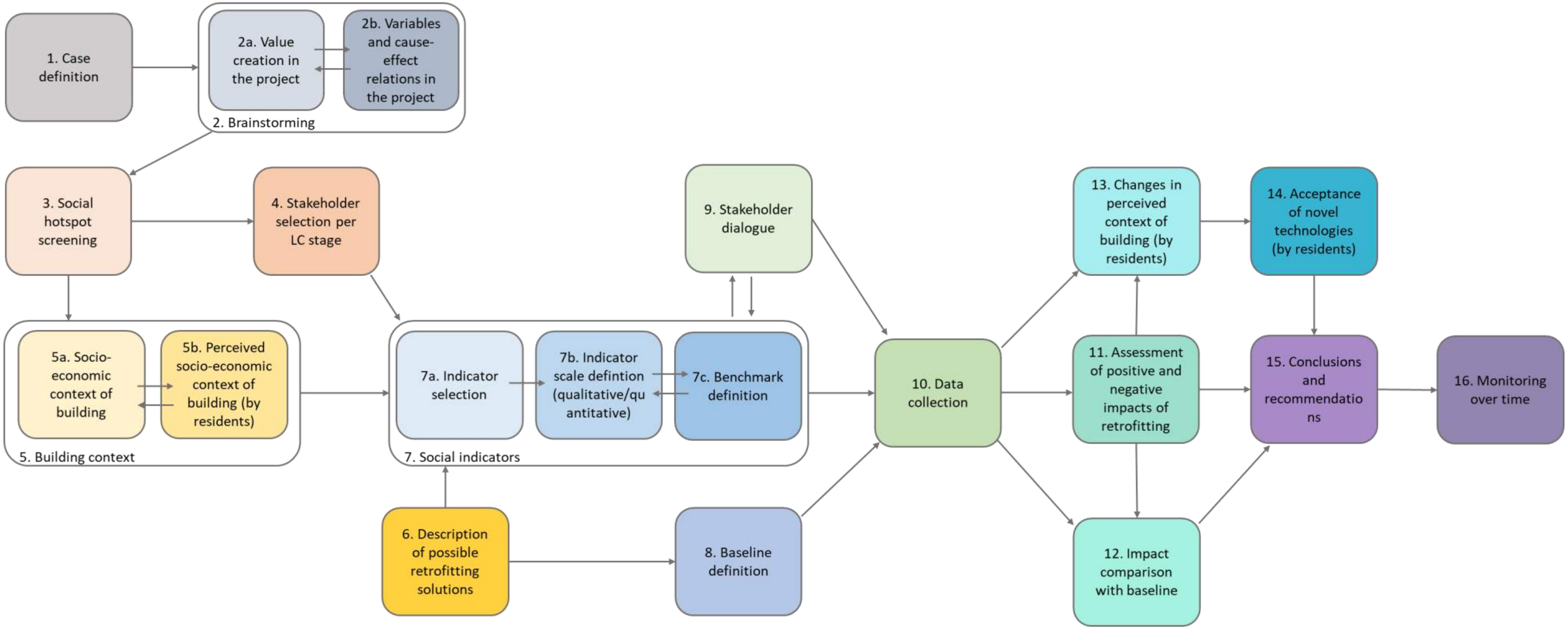
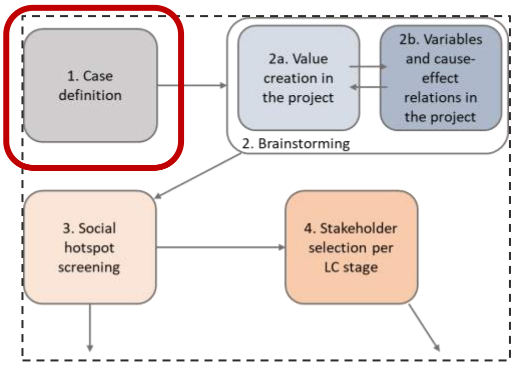


Figure 6: Methodology for social sustainability assessment in building retrofitting

4.1 Case definition



This represents the first step of the methodology and consists of describing the **goal and characteristics of the retrofitting project and related technologies**. The **case studies** where the renovation measures will be implemented should also be identified and described in this step. Finally, the case definition should also cover the scope of the project, including the life cycle stages and stakeholders on which the project focuses. This step orients the next phase of the methodology, namely brainstorming around the value, stakeholders and variables in the project.

4.1.1 Application in INFINITE

Goal of the project: INFINITE aims to shape how we design and perform retrofitting of buildings in the future: modular, industrialised and sustainable, with support of digital tools. The main goals of the project are:

- To **develop all-in-one industrialized envelope solutions** under a catalogue vision, lowering costs and improving flexibility and life cycle sustainability performance.
- To **develop a decision-support digital environment**; this will serve to ease the management of industrialized renovation processes over the whole value chain and for all stakeholders involved, from residents to building owners and AEC industry.
- To **engage stakeholders in the value chain of renovation process** to increase the acceptance of novel industrialized solutions.

Description of the project: INFINITE pursues an industrialized retrofitting approach, which at the same time includes benefits of digitalization, that is assumed to have a great potential for performing the upcoming renovations in the EU more efficiently and quickly. The developed solutions should be suitable for **mass production, decrease retrofit time and costs, and improve the sustainability performance considering the complete life cycle**. Different technologies are developed and combined to create different "**kits**" that can be installed at building sites. INFINITE kit solutions are selected for the renovation of **three buildings** in three different European countries, France, Italy and Slovenia.

Definition of retrofitting technologies: different results are expected for the development of the retrofitting technologies, namely:

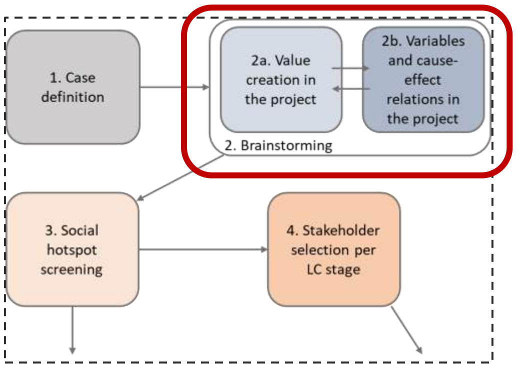
- R2.1: Passive eco-compatible green envelope kit, including green façade, green roof and grey-water treatment unit.
- R2.2: Energy and fresh air distribution envelope kit.
- R2.3: Integrated smart window kit.
- R2.4: Energy generation BIPV (Building Integrated Photovoltaic) kit.
- R2.5: Energy generation BIST (Building Integrated Solar Thermal) kit.
- In addition, it is also possible to consider the wooden-based façade and roof with passive cladding as a kit itself, the kit "0".

Case studies: **three** buildings are selected for the implementation of INFINITE renovation:

- Choisy le Roi (France). Number of residents: 60-70 (tbc); resident composition: families with children, couples, elderly, retired people.
- Greve in Chianti (Italy). Number of residents: 15; Resident composition: elderly, retired people.
- Ravne na Koroskem (Slovenia). Number of residents: 90. Resident composition: elderly, migrant workers, seasonal workers, temporary residents.

Scope of the project: INFINITE aims to demonstrate that industrialized retrofitting is sustainable and leads to benefits for residents in comparison to current building status without renovation and to traditional retrofitting. The developed technologies are likely to affect different stakeholders in the life cycle of building renovation. The life cycle stages involved in building renovation are: **raw material acquisition, manufacturing of the kits, transport and installation of the kits at the buildings, building operation and maintenance after retrofitting, end of life of the kits**. Workers, local communities, residents, technology providers and suppliers, building owners and managers appear to be directly or indirectly affected by the INFINITE project.

4.2 Understanding stakeholders, variables, impacts and risks in building retrofitting



Based on the project case description, a second step is necessary to brainstorm about the **values and costs** that are linked to the project as well as the identification of **cause-effect relations** among the variables and stakeholders potentially affected by and affecting the project. This step is a good chance for the different parties in the project to gather together and discuss about the implications of the project for different actors. This can be done with just pen and paper or also digital tools for visual collaboration, such as Miro [3] or vensim[4]. This step will lead to a brainstorming about both direct and more **hidden indirect effects** of the project.

4.2.1 Value creation ecosystem

As reported by Pardo-Bosch [8], the key question to mention in an initial brainstorming about the project is:

What are the activities needed to create value for the ultimate beneficiaries? Who are these ultimate beneficiaries? What actors/ stakeholders are necessary to develop these activities? What are the values captured?

An ecosystem for value creation consists of:

- **Stakeholders** directly or indirectly involved in the project life cycle under study;
- **Value** provided from one stakeholder to another;
- **Cost** paid from one stakeholder to another.

4.2.1.1 Application in INFINITE

A draft for value creation ecosystem for INFINITE is provided in Figure 7.

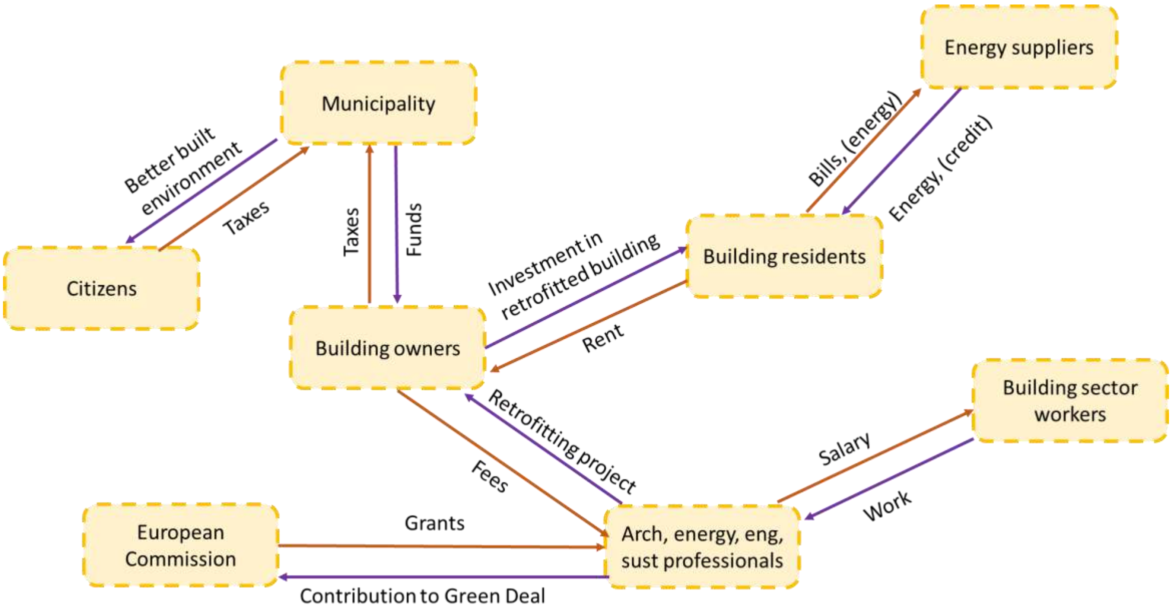


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Figure 7: value creation ecosystem for INFINITE

[3] https://miro.com/login/

[4] https://vensim.com/

Several stakeholders can be identified, ranging from the European Commission, municipality, citizens, energy suppliers to building owners and residents, workers and professionals in the construction sector. Specifically,

- The **European Commission** will provide funds to architects, energy, engineering and sustainability professionals from companies, research institutes and universities to work on retrofitting strategies that will contribute to achieve the EU climate objectives in the short- and long-term.
- **Architects, energy, engineering and sustainability professionals** will develop retrofitting solutions that will be purchased by the building owners, leading also to **employment** in the building sector to perform the retrofitting activities and manufacture the technologies.
- **Building owners** will pay taxes to the municipality because of the rent that they obtain from the residents and other taxes due to dwelling owning. The municipality may also provide some funds to support building retrofitting by building owners;
- **Building residents** will benefit from the owners´ investment in building renovation, e.g. in terms of improved thermal well-being, architectural quality, savings for energy bills.
- **Energy suppliers** will still receive energy bills from residents, but credits can be provided to them due to renewable energy generation and its provision to the grid.
- Finally, **all citizens** will benefit from a better and less polluted built environment, and pay taxes to municipalities that can be used to fund further retrofitting projects.

4.2.2 A causal loop diagram

Causal loop diagrams are often used in system dynamics to understand the system under study and relations within it [9][10]. To draft a causal loop diagram, the first step is to define the **variables** part of the system, the second step would be to think about the relation and connection between the variables. Following that, a direction of the causal relation should be added, either indicating “increase” (+) or decrease (-). Only direct relations are recommended to be reflected. Finally, the relations in the diagram can be analysed, for instance by considering one variable at a time as a starting point of the investigation. A causal loop diagram was created for the H2020 ITERAMS project and resulted as a valid and useful tool to orient the sustainability assessment and to further interpret the implications of the results of the assessment for different stakeholders[4].

4.2.2.1 Application in INFINITE

A causal loop diagram has been drafted with vensim[4] to represent variables and relations in the INFINITE project, see Figure 14. The starting point of the diagram is the **industrialized process and improved building envelope and systems**. Different elements can be distinguished in the diagram:

- **Variables:** parameters that have an influence on retrofitting operations. They are shown with a white background, see Figure 8.

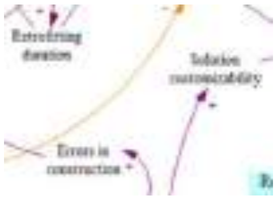


Figure 8: Variables in causal loop diagram

- **External conditions:** parameters that, depending on their presence or absence, influence building retrofitting. Furthermore, these parameters cannot be easily influenced, see Figure 9. They are shown with a light blue background.

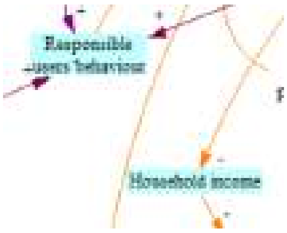


Figure 9: External conditions in causal loop diagram

- **State description**: these represent the core elements of the diagram that affect and can be affected by variables and external conditions. They are shown as framed white boxes, see Figure 10.

Figure 10: State description in causal loop diagram

- **Risks**: representing a consequence of an action occurs with a certain magnitude and probability. These are shown as hexagons, see Figure 11.

Figure 11: Risk in causal loop diagram

– **Impacts**: representing pressures on social stakeholders, such as workers, residents, etc, shown in boxes (see Figure 12) with different background colors depending on the stakeholders affected.

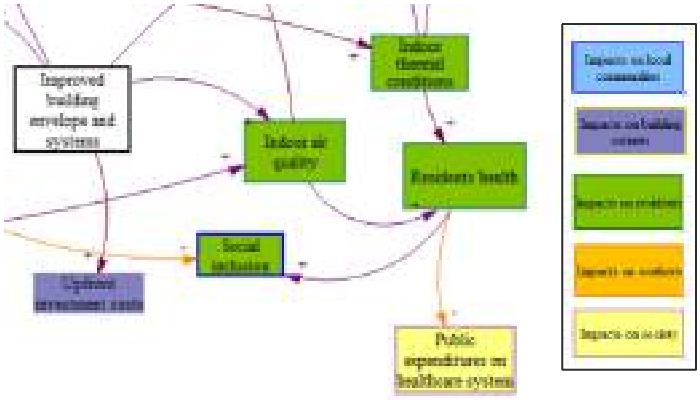


Figure 12: Impacts in causal loop diagram

– **Arrows:** a purple arrow with a "+" indicates that if aspect A increases, aspect B increases; an orange arrow with a "-" indicates that if aspect A increases, aspect B decreases. For instance, as shown in Figure 13, if building energy performance increases, the building value will increase (purple arrow with "+") and the risk of energy poverty will decrease (orange arrow with "-").

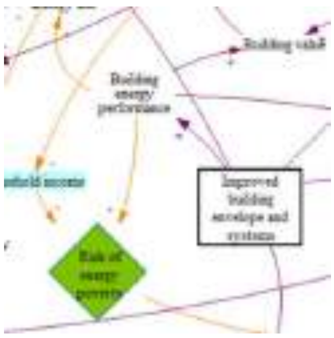


Figure 13: Arrows in causal loop diagram

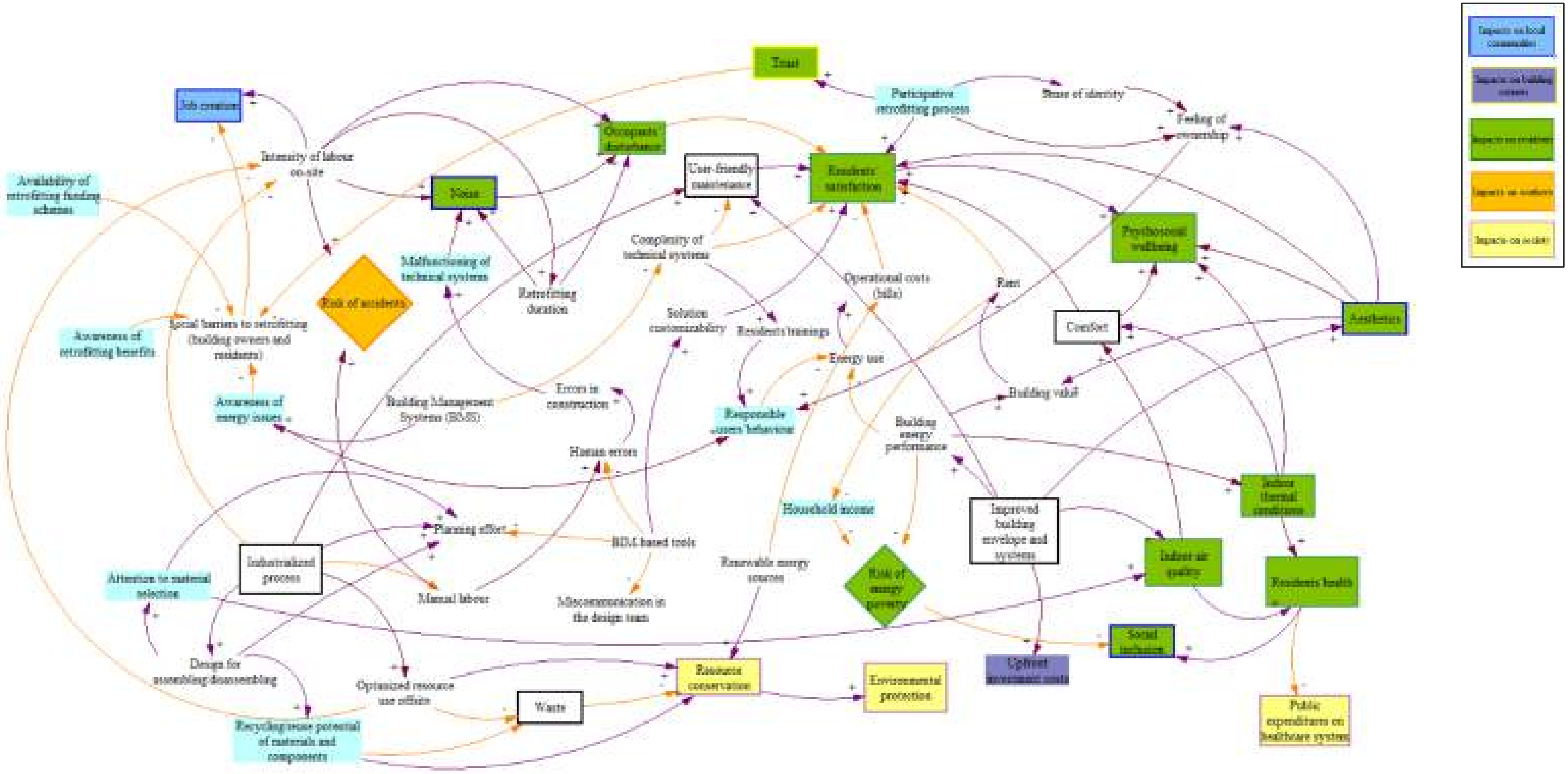


Figure 14: casual loop diagram for the INFINITE industrialized renovation

The diagram helps to investigate benefits and risks/impacts for the different actors involved. These assumed benefits and risks/impacts have to be further explored and assessed with the next steps of the analysis.

For instance, from the diagram it is possible to focus on the **residents' satisfaction** aspect and understand which variables are affecting it, see Figure 15. Indeed, **aesthetics, comfort, complexity of technical systems, bills, inclusion in retrofitting process, rent cost, renovation solution customizability and user-friendly maintenance** all potentially affect the satisfaction of the inhabitants. It appears important to consider these variables and relations when developing social indicators for the assessment.

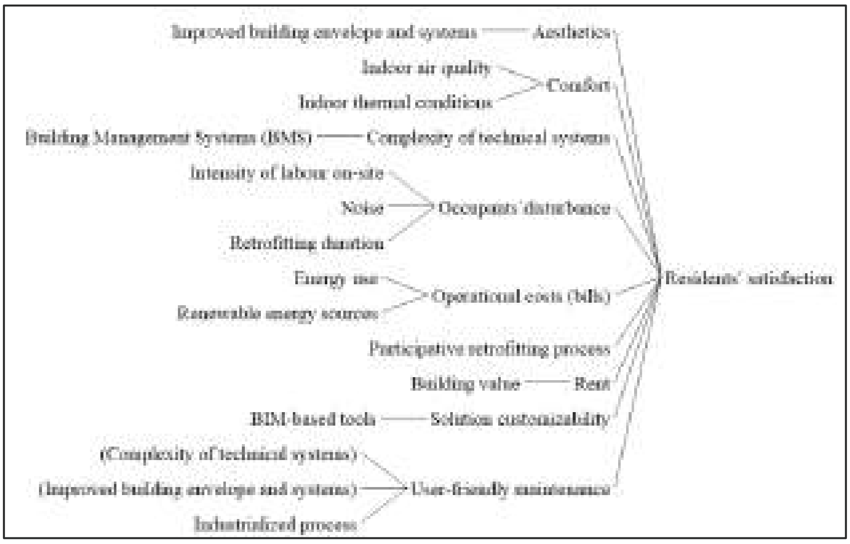


Figure 15: Residents' satisfaction as described in the causal loop diagram (brackets represent variables that already appeared)

Furthermore, residents´ satisfaction together with aesthetics, comfort and indoor thermal conditions are crucial aspects for **psychosocial well-being**, as it can be seen in Figure 16 extracted from the causal loop diagram.

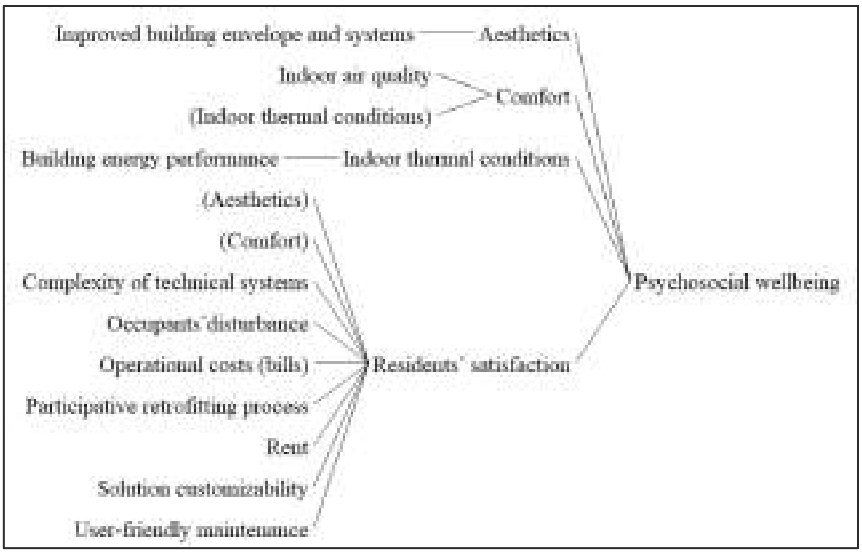
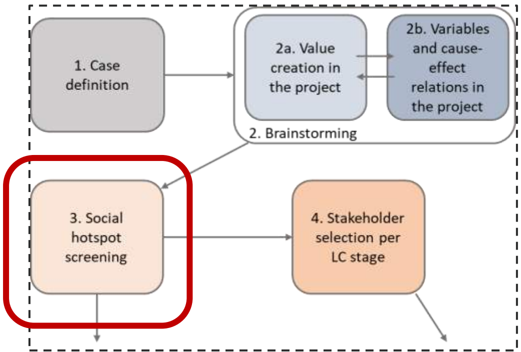


Figure 16: Psychosocial well-being as described in the causal loop diagram (brackets represent variables that already appeared)

4.3 Social and socio-economic hotspots screening in building retrofitting



This phase is dedicated to investigating the **potential social and socio-economic hotspots for the sector under study**. This screening should be performed based on the case definition and brainstorming of the previous steps. The goal is to preliminarily identify pressures (risks and impacts), issues and most contributing factors to social impacts before performing the actual full study. Having good insights with a preliminary study will be crucial for **resource and time optimization in the full study**. A preliminary hotspot screening is usually performed with generic data or few project-specific data at the beginning of a retrofit project. This allows to **prioritize the areas of interest for the following full study** and to have a better understanding of the potential impacts, risks and trade-offs that could be associated with the retrofitting project under study. Different approaches can be followed and combined for the hotspot screening, among others:

- Literature review;
- Analysis of previous retrofitting projects;

- Preliminary social LCA study with existing databases;
- Informative interviews with project partners and key stakeholders (for instance resident representatives and facility managers).

4.3.1 Application in INFINITE

Literature about retrofitting and, when available, about industrialised renovation and reports about previous project experiences were analyzed to identify recurring hotspots in the field. In addition, a preliminary social hotspot screening has been performed with the **PSILCA**[5] database. Interviews with project partners were also conducted and will be reported in the section 4.5 about building context to avoid repetitions.

4.3.1.1 Literature review

According to Pardo-Bosch [8], retrofitting has a vital role in the EU's efforts to reduce GHG emissions by 2050 since 40% of all energy consumption in the developed countries are attributed to buildings [11]–[13]. As a significant percentage of buildings across Europe face renovation soon, it is imperative to analyze the issues that can be addressed with retrofitting a building. However, also, it is crucial to identify **the social and economic barriers encountered**. This review highlights the most critical issues common to the different literature references investigated on the socio-economic implications of retrofitting building. This section is a summary based on the literature review of the following:

- Scientific papers – 31 in total;
- Reports – 4 in total;
- PhD dissertation, presentation, poster, standard (EN -15643-3), Building certification system (DGNB), EU project, 1 each;
- General overview on building certification systems (WELL, BREAM, LEED, DGNB).

Retrofitting is also a key component in achieving sustainable development, **promoting social inclusion, environmental protection, and financial viability** [8]. Some of the key benefits identified in various studies [6], [8], [14]–[18] are:

- Increased **residents' satisfaction** from improved aesthetics, better indoor environmental quality, thermal comfort, energy savings, reduced energy dependence.
- Reduced **public expenditure on health care systems** due to the positive effect on the health of residents.
- Improved **economic conditions** from job creation, business opportunities.
- **Psychosocial wellbeing** from improved living standards, reduced energy poverty, social inclusion, especially for residents with low income.
- One study on green walls also identified other benefits of energy reduction: insulation, evaporative cooling due to evapotranspiration, and vegetation shading [19]. However, the

[5] https://psilca.net/

study also points out the proper maintenance of green walls using recycled or reused materials, selecting low maintenance plants.

The **key issues** driving the need for retrofitting buildings are similar in most studies, highlighted as under:

- Low thermal insulation (opaque and transparent), poor indoor environmental quality, poor seismic and structural performance, low system efficiency and energy poverty [14], [17], [20]–[23].
- Adverse health issues such as inadequate natural light, moisture and mould, indoor noise [15].
- Several studies on retrofitting have identified some critical barriers for building retrofitting, which can be identified as the social or socio-economic hotspots for retrofitting projects.
- **Differences in the interests of building dwellers and building owners**, lack of consensus, or even lack of dialogue between stakeholders are a deterrent to retrofitting projects, as evident in several studies [13], [14], [16], [21].
- **Resident disturbance**, which could be caused by noise [15], [17], [21], [24], or retrofitting duration [14], [25].
- **Economic viability** is a primary concern for investors and owners due to high up-front investments and maintenance costs [8]. The authors suggest that owner engagement is crucial in overcoming this economic barrier. This barrier is often accompanied by the absence or overlapping of private and public retrofitting funding schemes, lack of financial incentives [13], [19], [25]. Consequently, low-income households cannot afford to retrofit as some studies suggest [6] [15], causing a higher risk of social inequality [26]. In the case of building owners, return on investment (ROI) is an essential factor, unfavourable ROI poses a hurdle [26].
- An **increase in the rent price** is not well perceived, as evident from many retrofitting studies [6], [13], [14]. Astmarrson et al. [13] recommend that the rent decreases again once the investment has paid off to the landlord, and the tenant gets the benefits of energy savings. Touceda et al. [6] also point out that increased property taxes, influenced by higher **building value post retrofitting**, is also a deterrent for landlords. Furthermore, studies indicate an increase in rent prices may result in increased social inequality[26]
- **Lack of awareness of energy issues and construction materials** poses a social hurdle, as suggested in a few studies [8], [25]. Along with a lack of awareness, the unavailability of commercial simulation models and challenging data interpretation was a barrier [19].
- **Behavioural barriers** that may result in differences in predicted and actual energy use from occupants may also deter building retrofitting [8], [20], [27], [28]. However, several studies used questionnaires to investigate user behavior [27], [28] and users' awareness of sustainability and energy efficiency. The authors suggest employing real-time usage data to bring about behavioral retrofitting [27].
- In terms of **industrialized retrofitting solutions**, as opposed to traditional ones, there is a perceived opinion of the quality of assembled components being inadequate, the process to be lacking infrastructure and a viable business model, and systems being complex. [14]. However, the authors make a case for industrialized retrofitting by highlighting the benefits,

such as higher accuracy (thanks to BIM, automated production line, standard products), shorter time (construction time shortened by 18%), safer conditions (fewer workers and for less time), efficient construction process, additional planning and measuring and monitoring efforts, less waste, less intrusiveness and disturbance for inhabitants.

- A few studies also identified **long and complex decision-making processes** (e.g. condominium), disturbance and relocation to be the main barriers [14], [21], [25]. Users´ **acceptance and trust in new technologies**, lack of solution customizability are also reported.
- Lack of understanding and support from inhabitants, low awareness of benefits, low political consciousness, lack of education and low confidence in construction professionals have been highlighted as barriers [13], [14], [19].

Other issues could be due to a **lack of correspondence between design and drawings and on-site construction** [28].

For overcoming the social and economic barriers in building retrofitting, studies suggest survey on users' behavior, developing questionnaires for users and building companies [16], [21], [27]–[29], bringing awareness on sustainability issues and energy efficiency [13], [27], comparing expectations with final results [18] as well as facilitate communication by actively involving stakeholders, identifying specific problems, needs, expectations [8], [14].

4.3.1.2 Preliminary social LCA screening

Given that the literature review mainly provided insights about the stakeholder category of residents and for the life cycle stages of building renovation and operation, it appeared important to investigate **potential hotspots in the supply chains of building renovation** and for other stakeholders. For this purpose, existing processes in the social LCA database PSILCA v.3[5] were selected and assessed. As specific processes representing retrofitting were not available in the database, **macro-sectors** were selected for the countries where the demo cases are located, specifically:

- Construction, Italy.
- Construction, Slovenia.
- Construction, France.

According to the economic sector classification by NACE rev.2 [30], the construction sector "includes general construction and specialised construction activities for buildings and civil engineering works. It includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site and also construction of a temporary nature". Social risks reported in the selected sector are not only referred to the retrofitting of buildings, but rather represent an average for the whole construction sectors in the selected countries. However, this preliminary investigation can **provide insights about the risks in the construction sector** that can be common to more specific building retrofitting processes, for instance in terms of **health and safety**. Furthermore, this screening gives the chance to understand **which generic social hotspots in construction sector can be improved if industrialized renovation is applied**.

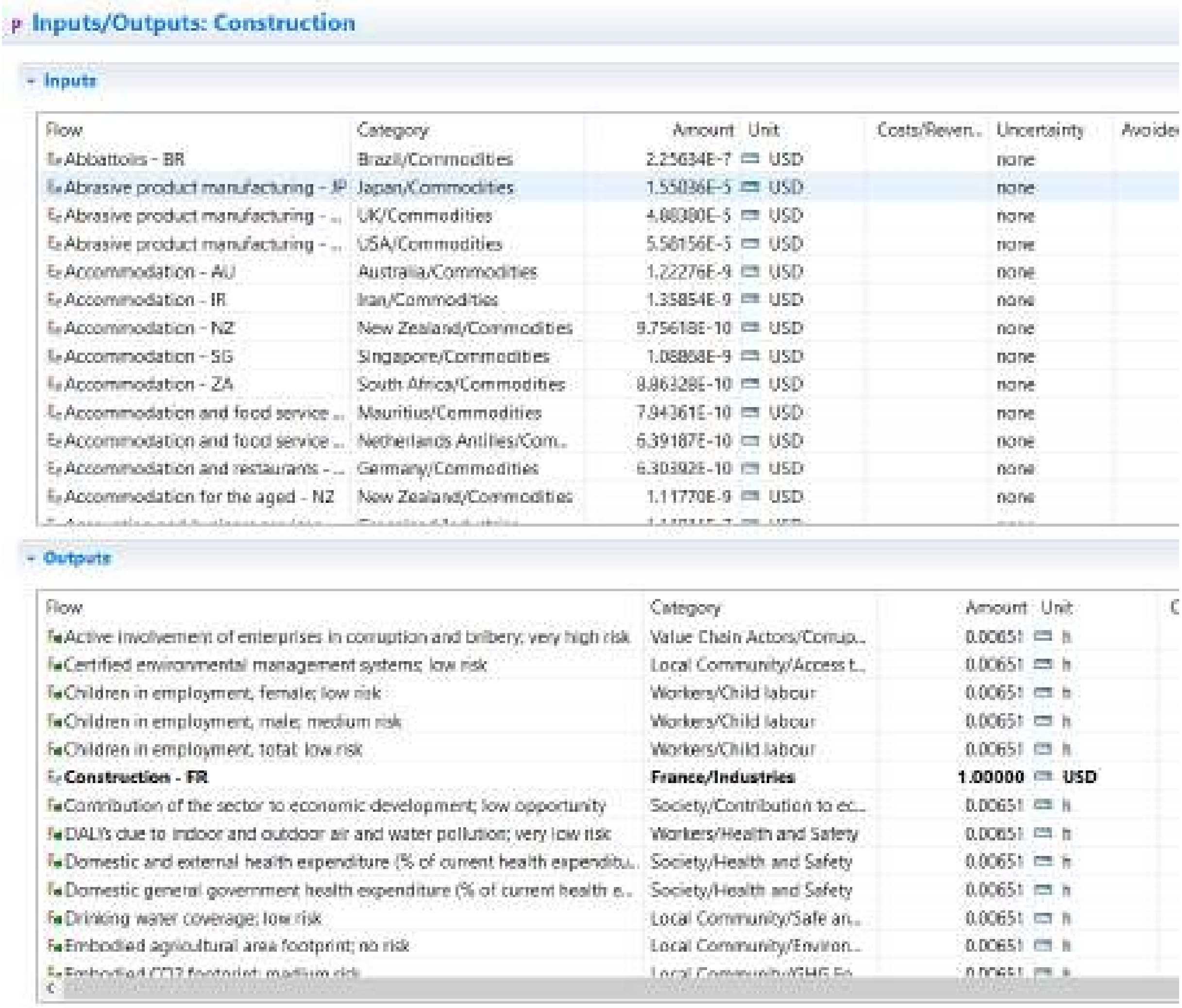
The only processes available in the PSILCA database that can be regarded closer to industrialized renovation are referred to USA and Australia. Although these countries are not in the scope of INFINITE, the following sectors are analyzed with the idea that generic conclusions about **prefabrication** social impacts can be made regardless of the country where they take place.

- Prefabricated wood building manufacturing, USA.
- Prefabricated building manufacturing, Australia.

Finally, also the process "Construction of residential buildings", Spain is analyzed, considering the specific focus of the sector in residential buildings and that one of the virtual demos is located in Spain.

The different sectors are first analyzed individually and then compared. Please note that the comparison of generic construction sectors for France, Italy and Slovenia against specific prefabricated and residential construction for USA, Australia and Spain, is not fully consistent. However, with the assumption that many social hotspots in construction can be similar in the subsector of residential building renovation, this comparison is considered acceptable for this preliminary analysis.

Social impacts are calculated for 1 USD produced by each sector and assessed with the impact assessment method provided in PSILCA 3, the Social Impacts Weighting Method [31]. Results are expressed in medium risk hours, i.e. amount of hours with a medium risk of occurrence for the selected social aspect. This unit of measurement for social indicators is typical for social LCA databases and is used to define the relative contribution of a process to the whole system under study. Social indicators in each process are quantified with **worker hours**, i.e. the amount of hours needed to produce the reference output, e.g. 1 USD in the construction sector. **The idea is that the longer the time needed to produce a product/service, the higher the worker hours, the higher the exposure to the risk described by the social indicator**. Each indicator, besides being quantified with worker hours, needs to be risk assessed. Different **risk levels** (from very high, high, medium, very low, low, no risk) can be assigned to an indicator by referencing the collected data against a risk scale provided in the PSILCA database. For instance, see the indicators on the output side of the French construction process in Figure 17: as an example, the indicator of "active involvement of enterprises in corruption and bribery" has been classified with "very high risk" and quantified with 0.00651 hours (the time needed to produce 1 USD of product/service from the French construction industry).



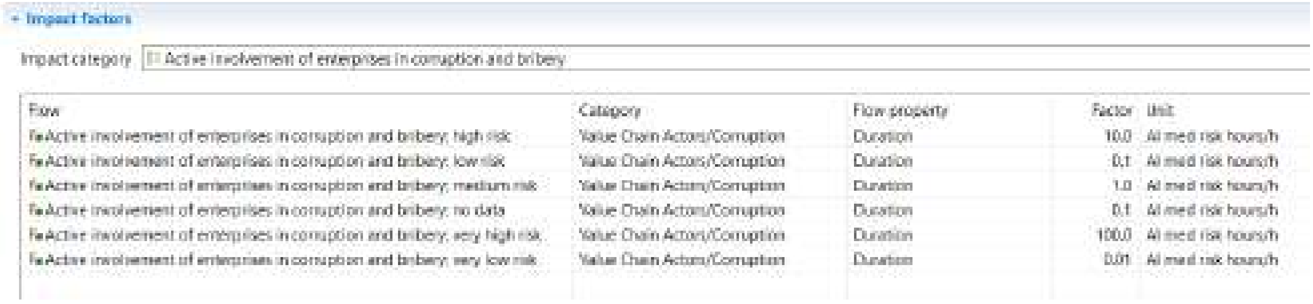
Flow	Category	Amount	Unit	Costs/Reven..	Uncertainty	Avoide
Abbattoirs - BR	Brazil/Commodities	2.25634E-7	USD		none	
Abrasive product manufacturing - JP	Japan/Commodities	1.55036E-5	USD		none	
Abrasive product manufacturing - ...	UK/Commodities	4.08380E-5	USD		none	
Abrasive product manufacturing - ...	USA/Commodities	5.58156E-5	USD		none	
Accommodation - AU	Australia/Commodities	1.22276E-9	USD		none	
Accommodation - IR	Iran/Commodities	1.35854E-9	USD		none	
Accommodation - NZ	New Zealand/Commodities	9.75618E-10	USD		none	
Accommodation - SG	Singapore/Commodities	1.08868E-9	USD		none	
Accommodation - ZA	South Africa/Commodities	8.86328E-10	USD		none	
Accommodation and food service ...	Mauritius/Commodities	7.94361E-10	USD		none	
Accommodation and food service ...	Netherlands Antilles/Com...	6.39187E-10	USD		none	
Accommodation and restaurants - ...	Germany/Commodities	6.30392E-10	USD		none	
Accommodation for the aged - NZ	New Zealand/Commodities	1.11770E-9	USD		none	

Flow	Category	Amount	Unit	C
Active involvement of enterprises in corruption and bribery; very high risk	Value Chain Actors/Corrup...	0.00651	h	
Certified environmental management systems; low risk	Local Community/Access t...	0.00651	h	
Children in employment, female; low risk	Workers/Child labour	0.00651	h	
Children in employment, male; medium risk	Workers/Child labour	0.00651	h	
Children in employment, total; low risk	Workers/Child labour	0.00651	h	
Construction - FR	**France/Industries**	**1.00000**	**USD**	
Contribution of the sector to economic development; low opportunity	Society/Contribution to ec...	0.00651	h	
DALYs due to indoor and outdoor air and water pollution; very low risk	Workers/Health and Safety	0.00651	h	
Domestic and external health expenditure (% of current health expendit...	Society/Health and Safety	0.00651	h	
Domestic general government health expenditure (% of current health e...	Society/Health and Safety	0.00651	h	
Drinking water coverage; low risk	Local Community/Safe an...	0.00651	h	
Embodied agricultural area footprint; no risk	Local Community/Environ...	0.00651	h	

Figure 17: Example of inputs and outputs for the French construction industry

Finally**, the higher the risk level, the higher the impact factor which will be used to multiply the worker hours of a process.** As for the case of the indicator of "active involvement of enterprises in corruption and bribery" which has been classified with "very high risk" in the French construction sector (see Figure 17), a factor of 100 will be used to multiply the worker hours (0.00651 h), thus obtaining 0.651 medium risk hours for the selected indicator in the French construction process. The "medium risk hours" unit is due to the choice of "medium risk" as reference unit for the scale, thus with an impact factor of 1, see Figure 18.

The same impact factor scale is applied to the other indicators. Total impacts for each indicator are calculated by summing up all results for each process in the life cycle, obtained by multiplying the worker hours by the impact factor corresponding to the indicator risk level, and scaled to the reference unit of the system (e.g. 1 USD from construction sector).



Impact factors

Impact category: Active involvement of enterprises in corruption and bribery

Flow	Category	Flow property	Factor	Unit
Active involvement of enterprises in corruption and bribery; high risk	Value Chain Actors/Corruption	Duration	10.0	AI med risk hours/h
Active involvement of enterprises in corruption and bribery; low risk	Value Chain Actors/Corruption	Duration	0.1	AI med risk hours/h
Active involvement of enterprises in corruption and bribery; medium risk	Value Chain Actors/Corruption	Duration	1.0	AI med risk hours/h
Active involvement of enterprises in corruption and bribery; no data	Value Chain Actors/Corruption	Duration	0.1	AI med risk hours/h
Active involvement of enterprises in corruption and bribery; very high risk	Value Chain Actors/Corruption	Duration	100.0	AI med risk hours/h
Active involvement of enterprises in corruption and bribery; very low risk	Value Chain Actors/Corruption	Duration	0.01	AI med risk hours/h

Figure 18: Example of impact assessment factors in PSILCA database

Different social indicators are assessed for four stakeholder categories:

- Workers;
- Value chain actors;
- Local community;
- Society.

As a first step, **high and very high risks** in the different sectors are identified, as shown in Figure 19. The main findings can be summarized as following:

- **Accidents and insufficient safety measures** are less significant in prefabrication activities in comparison the whole generic construction sector;
- **Resource use (biomass, water) and environmental impacts** (for instance CO2 emissions) are relevant aspects in general, regardless of prefabrication.
- **Country-specific issues** need to be investigated, such as wage aspects in Slovenia, risk of migrant workers´ discrimination in France, Spain and Slovenia, and corruption in Italy, France and Slovenia. Indeed, **it needs to be understood whether industrialization foreseen by INFINITE can have any positive and negative effect on these highlighted issues**.

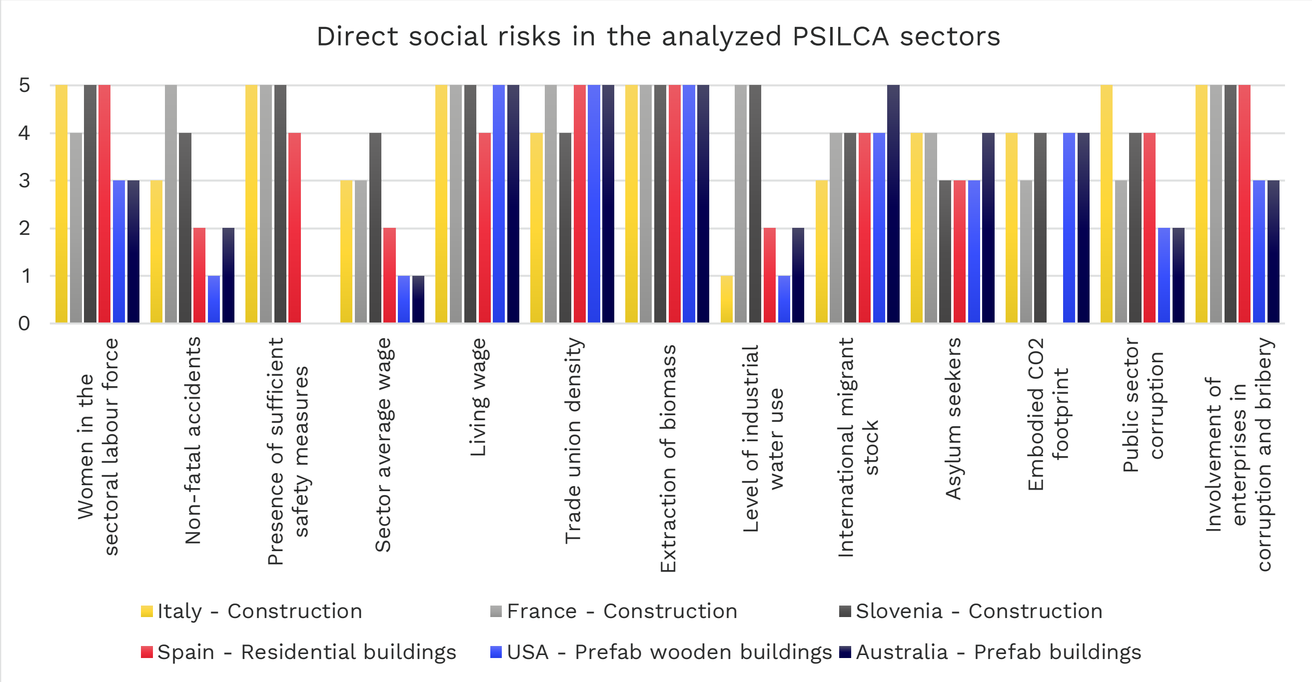


Figure 19: Direct social risks in the analyzed PSILCA sectors (0=no risk/no data; 1=very low risk; 2=low risk; 3=medium risk; 4=high risk; 5=very high risk)

If not only direct, but overall social impacts are assessed including the supply chains for the construction sectors in Italy, France and Slovenia, it is possible to identify common hotspots between the three countries:

- The construction sector itself is largely contributing to impacts regarding safety measures, lack of women in the labor force, involvement of enterprises in corruption, Greenhouse Gas emissions and non-fatal accidents.
- **Manufacturing of non-metallic mineral products** in the supply chains of the construction sector is responsible for impacts on industrial water depletion, absence of certified management systems, child labor and lack of fair salary.
- **Construction goods** used by the construction sector are linked to impacts on lack of fair salary and safety measures, accidents, risk of discrimination of migrant workers.
- Finally, business services needed for construction processes contribute to impacts with a certain share, for instance for lack of fair salary and risk of overtime.

The life cycle of the **Italian construction sector** shows a high contribution to the risk of workers not receiving a fair salary, consumption of biomass, involvement in corruption, lack of safety measures and women in the labour force, see Table 1. The country-specific aspect of public sector corruption also emerges as a hotspot in Italy, thus potentially affecting any economic activity in the country. It is interesting to note that **safety- and environmental-related issues are directly generated in the construction sector,** while the supply chains have a major contribution in other categories, such as promoting social responsibility; for instance, see Figure 8, where Italian business services show a risk of acting unsustainably in the supply chain; minor risks for the topic of social responsibility are also linked to **production of non-metal minerals in China**.

It should also be noted that the construction sector itself needs to buy construction goods for all its activities and processes. This applies to all construction sectors analyzed.

Table 1: Selected social impact category results for the construction sector in Italy (for 1 USD output of the sector)

Hotspots	Impact category	Upstream incl. Direct (medium risk hours)	Direct (medium risk hours)	Share direct/total
Manufacture of non-metallic mineral products, metal products (except machineries), business services, construction goods	**Fair Salary**	3.89	1.44	37%
same as fair salary	**Biomass consumption**	1.90	0.68	36%
same as fair salary	**Public sector corruption**	1.84	0.68	37%
construction goods, land transport	**Active involvement of enterprises in corruption and bribery**	0.90	0.68	75%
construction goods	**Safety measures**	0.80	0.68	85%
construction goods	**Women in the sectoral labour force**	0.77	0.68	88%
business services, non-metallic mineral products, land transport, wholesale trade and commission trade	**Promoting social responsibility**	0.67	0.00	0%
non-metallic mineral products, construction goods, business services, metal products (no machineries)	**Value added (total)**	0.63	0.01	1%
same as fair salary	**Trade unionism**	0.27	0.07	26%
Manufacture of non-metallic mineral products, construction goods, business services	**Industrial water depletion**	0.23	0.07	30%
same as industrial water depletion	**Migration flows**	0.21	0.07	33%
non-metallic mineral products, wood and products of wood, computer and related services	**Certified environmental management system**	0.20	0.00	0%
Construction goods, other non metallic products, coke and petroleum products and nuclear fuel	**GHG Footprints**	0.11	0.07	71%
same as fair salary	**Weekly hours of work per employee**	0.10	0.01	7%
same as fair salary	**Child Labour, male**	0.08	0.01	9%

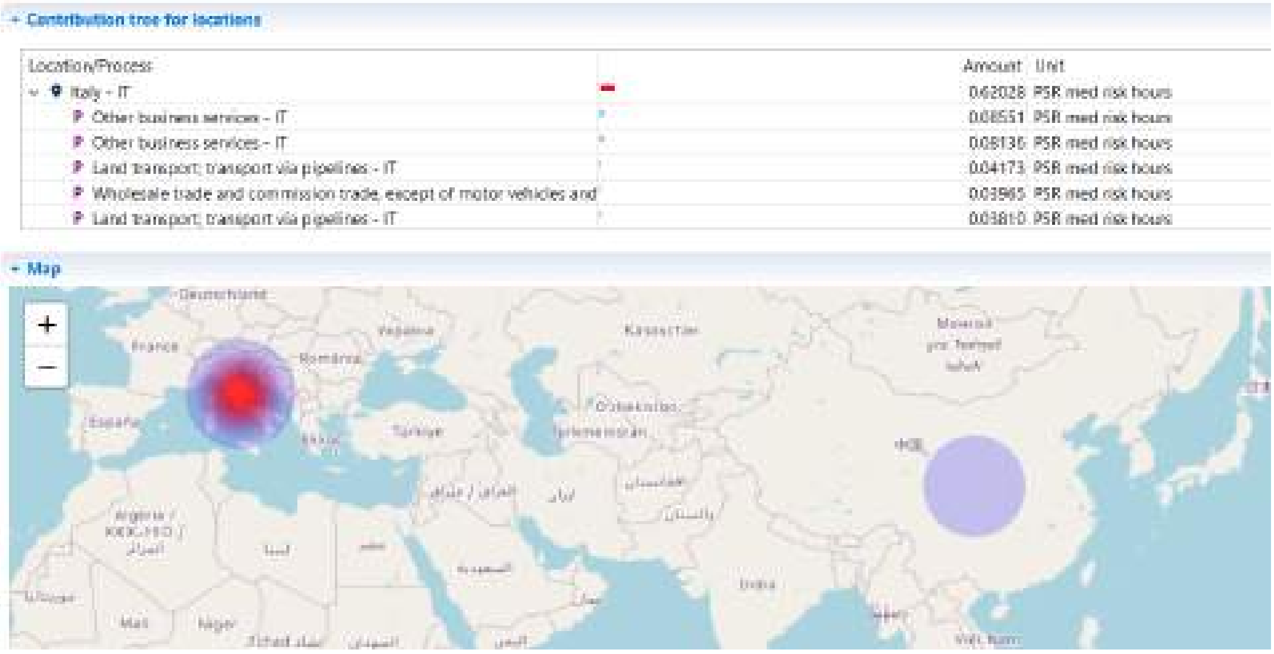


Figure 20: Geographic localization of the category "promoting social responsibility" in the construction sector in Italy

The **French construction sector** presents similar issues to the Italian one. Also in this case, safety and corruption issues appear to be linked to the sector itself, while the influence of upstream chains is significant for the other categories, see Table 2. It is also interesting to see that impacts for some categories occur in areas that are very far from France, for instance due to the **outsourcing of electrical machinery and equipment from China** which generates pollution in this country, rather than in France, see Figure 21. Although pollution is an environmental category, this also has implication on local communities, for instance in relation to respiratory diseases and damages to natural resources important for the likelihood of locals.

Table 2: Selected social impact category results for the construction sector in France (for 1 USD output of the sector)

Hotspots	Impact category	Upstream incl. direct (medium risk hours)	Direct (medium risk hours)	Share direct/total
construction goods, other business services, other non metallic mineral products, fabricated metal products	**Fair Salary**	7.53	2.12	28%
same as fair salary	**Industrial water depletion**	2.68	0.77	29%
same as fair salary	**Biomass consumption**	2.65	0.70	27%

same as fair salary	**Trade unionism**	2.50	0.70	28%
same as fair salary	**Value added (total)**	1.31	0.01	1%
construction goods	**Active involvement of enterprises in corruption and bribery**	1.10	0.70	64%
construction goods	**Safety measures**	1.06	0.70	66%
construction goods	**Non-fatal accidents**	1.05	0.70	67%
other non metallic mineral products, financial intermediation services, construction	**Promoting social responsibility**	0.41	0.00	0%
construction goods, other business services	**Migration flows**	0.32	0.08	24%
construction goods, other business services	**Health expenditure**	0.27	0.07	27%
construction goods, other business services, other non metallic mineral products, fabricated metal products	**International migrant stock**	0.26	0.07	27%
construction goods, other business services, computer and related services	**Certified environmental management system**	0.22	0.00	0%
coke and petroleum products and nuclear fuel, construction goods	**Public sector corruption**	0.19	0.01	4%
Construction goods	**Women in the sectoral labour force**	0.12	0.07	58%

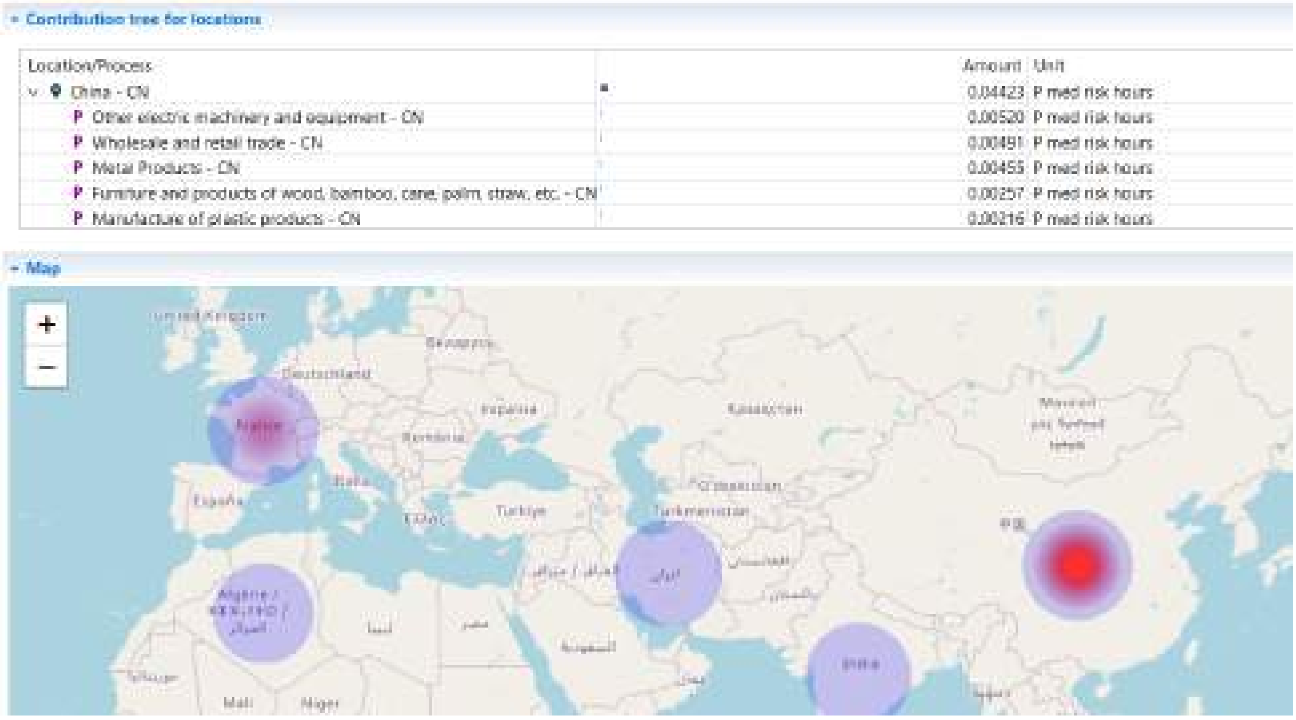


Figure 21: Geographic localization of the category "pollution" in the construction sector in France

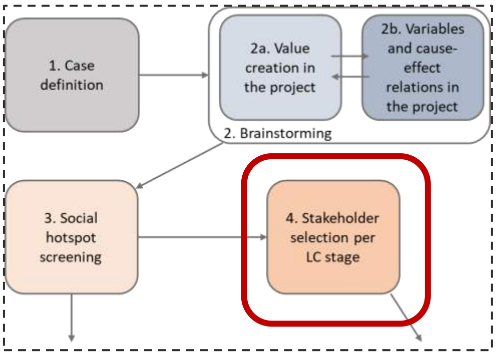
As for **Slovenia**, the construction sector presents similar issues to Italy and France, but with higher values in terms risk hours, see *Table 3*. This is due to the fact that to produce 1 USD of construction products in Slovenia, more than double of the time in Italy or France is needed. This implies that the **exposure to the risk is longer and potential impacts are, hence, higher than in France and Italy.** Also for Slovenia, the manufacturing of equipment and machineries used in construction in China results in **impacts shifted from Europe to Asia.**

Table 3: Selected social impact category results for the construction sector in Slovenia (for 1 USD output of the sector)

Hotspots	Impact category	Upstream incl. direct (medium risk hours)	Direct (medium risk hours)	Share direct/total
Construction goods, other non-metallic mineral products, retail trade, other business services	**Fair Salary**	16.12	5.33	33%
same as fair salary	**Biomass consumption**	7.51	2.41	32%
same as fair salary	**Industrial water depletion**	7.12	2.41	34%
construction goods, land transport	**Active involvement of enterprises in corruption and bribery**	3.95	2.41	61%

construction goods	**Safety measures**	3.79	2.41	64%
construction goods	**Women in the sectoral labour force**	3.69	2.41	65%
construction goods, other non-metallic mineral products	**Value added (total)**	3.13	0.02	1%
same as fair salary	**Public sector corruption**	1.05	0.24	23%
same as fair salary	**Trade unionism**	0.93	0.24	26%
same as fair salary	**Promoting social responsibility**	0.85	0.00	0%
same as fair salary	**International migrant stock**	0.73	0.24	33%
construction goods, other non-metallic mineral products	**GHG Footprints**	0.46	0.27	58%
construction goods, other non-metallic mineral products	**Non-fatal accidents**	0.39	0.24	62%
construction goods, other non-metallic mineral products, basic metals	**Migration flows**	0.29	0.05	16%
same as fair salary	**Health expenditure**	0.19	0.06	30%

4.4 Stakeholder selection



Based on the previous steps, it is possible to select which stakeholders to include in the social assessment, hence for which stakeholders the impacts will be assessed. This decision affects the definition of social indicators for the assessment. In most cases, it is important to include **residents** as stakeholders, as they will be experiencing the effects of the renovation process and the consequences of building operation and maintenance with renovated systems and envelope. If the focus is on the supply chains only, residents can be excluded.

Six stakeholder groups are proposed by the Social LCA Guidelines [5], namely workers, consumers, value chain actors, local community, society and children.

In addition, other categories can be addressed, such as building owners (when they differ from residents), building and facility managers, technology providers, and municipalities.

Finally, it should be considered that **stakeholders can be directly or indirectly affected by building renovations and may differ in the different life cycle stages**, for instance residents are not affected by the renovation technology manufacturing.

4.4.1 Application in INFINITE

In view of a stakeholder-centred approach in INFINITE, one of the main focuses is on **building residents**. Considering the importance of a life cycle perspective to avoid burden shifting among different stakeholders and life cycle stages, the focus of the social assessment is also on **local communities, workers, value chain actors and society as a whole**. Figure 22 provides an overview of the different stakeholders involved in the life cycle stages (those marked in blue represent the main focus of the analysis).

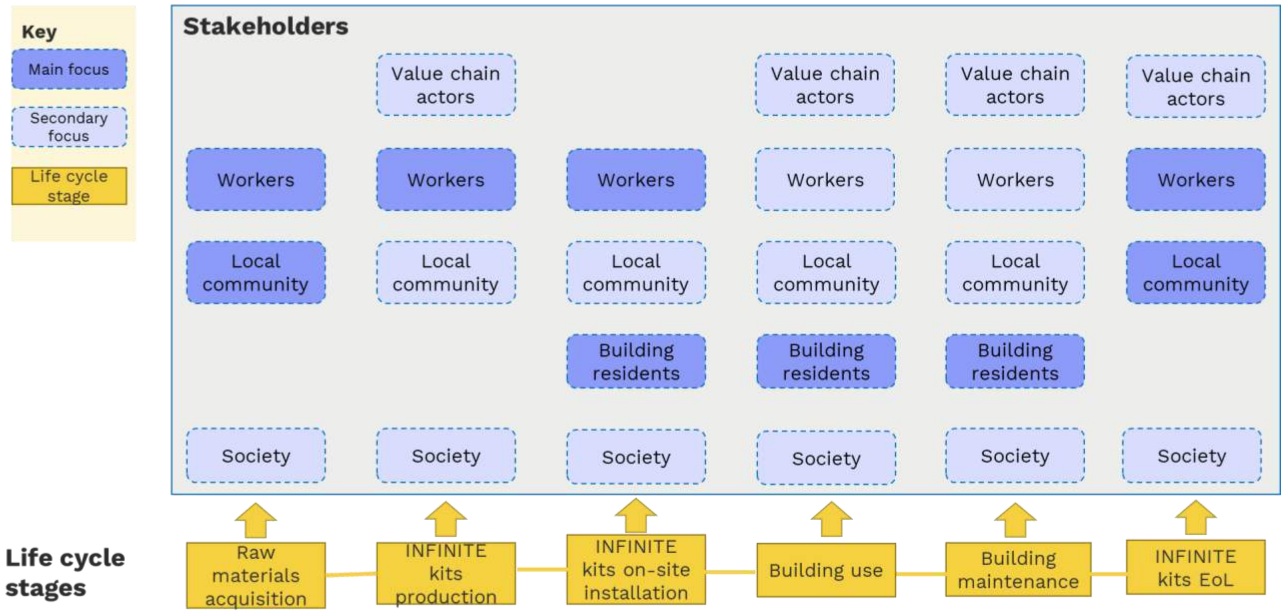
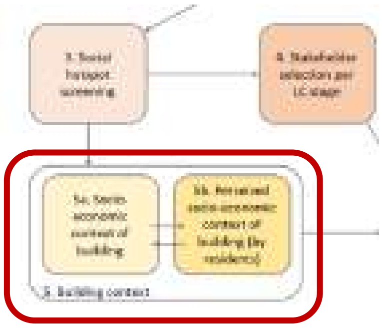


Figure 22: overview of different stakeholders per life cycle stage of building retrofitting

In addition, considerations about social impacts for **building owners, facility managers and technology providers** were made, although they represent a secondary interest and are already addressed by the work of IVE in WP2.

4.5 Understanding the building context



Investigating the social and socio-economic context of the building under renovation is crucial for the indicator selection, assessment and acceptance of the technologies and impact interpretation. Understanding the building context should also go beyond the building boundaries, as **cultural and anthropological factors at the building scale are often linked to local, regional and national specificities**. This step mainly focuses on **residents** in order to understand:

- **Social issues** in the dwelling and building;
- **Positive social aspects** in the dwelling and building;
- **Perception** of the above issues by residents, also considering that inhabitants may perceive different aspects that what can be seen by the researchers or facility mangers.
- Potential perception of the novel technologies.

Different approaches should be combined to have a building context picture that includes different points of view, and with specific attention to residents´ perspective:

- **Context analysis**: understand the social and socio-economic situation at macro- and micro-levels (building, district, city, region, country) through available statistics, literature and previous studies. **Field work** also plays a crucial role here, as it is highly recommended to practitioners to visit the city, area and building itself to have an impression of the situation.
- **Content analysis**: analysis of the social and socio-economic situation at macro-level (district, city, region, country) through newspapers, youtube channels, tv programmes.
- **Interviews with key stakeholders**: building residents should be indeed involved in individual and/or group interviews; beside them, it is useful to interview facility managers to have an idea of the issues and building context before meeting the residents; however, it should be remembered that facility mangers have their own perspective that can be different from the one of the residents.
- **Distribution of surveys to building residents**: this can be helpful to understand the main issues and perspectives before the conduction of interviews. However, questionnaires should not replace interviews, as the first would offer partial view on the situation. An example of survey that was used for the INFINITE project is provided in Annex 1.

The following aspects can be explored at the **macro-scale level** for the context analysis of the area/region where the building is located:

- Maximum and minimum temperature in summer and winter;
- Humidity;
- Unemployment rate;

- Environmental issues 8e.g. pollution);
- Environmental awareness and initiatives;
- Social initiatives;
- Retrofitting activities in the past;
- Education;
- Energy poverty;
- Income level;
- Security/crime rate;
- Age of the building stock;
- Rent fees;
- Public transport/accessibility.

The following aspects can be investigated through surveys and interviews with key stakeholders at the **building level**:

- Building property and management;
- Household composition;
- Education;
- Age;
- Income level, energy bills and rent fees;
- Current status of the building;
- Aesthetics of the building;
- Daylighting;
- Residents' satisfaction;
- Noise;
- Energy poverty;
- Energy sources 8e.g. gas boiler, PVs);
- health status of residents;
- Structural safety;
- Public transport/accessibility;
- Ventilation and cooling;
- Access to social housing schema.

4.5.1 Application in INFINITE

Depending on the demo case, different activities have been conducted:

- France: interview with facility manager Polylogis;
- Italy: interview with facility manager Casa Spa, field work in Greve in Chianti, group and individual interviews with residents;
- Slovenia: interview with facility manager; extensive field work conducted by IRI.

As a first step, **interviews with each of the three demo facility managers** were arranged to have an overview of the building, residents, current issues and positive aspects. Potential acceptance of technologies was also discussed with the managers.

For the Italian case, a simple **survey** was distributed to the residents, building on the discussions with facility managers, but also on hotspot and literature analysis. Finally, two days of **field work** were conducted in Greve in Chianti to talk with the residents about current issues, positive aspects, wishes for renovation and first impressions about the INFINITE technologies, see Figure 23.

Figure 23: photo from group interview at the Italian demo case

The following sections report a description of the building context for the three demo cases, with a focus on the Italian one, for which most of the investigations could be performed.

4.5.1.1 The Italian demo case

Context of town and district

The demo case is located in Greve in Chianti (Tuscany, Italy) and it is made of two twin buildings, built in 1978-79. Chianti area is green, quiet and well-known in the world. Many buildings were built at the end of 70´s in the countryside as "**houses for farmers**", hence social housing was intended for workers from agricultural enterprises, as there were many farms producing oil, wine and similar items. So many of those house types (red bricks) in the area were built in the 70´s in all Tuscany. At that time, the municipalities organized tenders for social housing only for farmers that worked in the agricultural sector. Most families living in the demo buildings, except those few that entered the dwelling more recently, have that background. During the covid-19 pandemic in 2020, Greve and all area of Chianti had huge **crisis and consequences from a touristic point of view**, because all Chianti area used to live from tourism, restaurants, resorts in the countryside, holiday farms.

Figure 24: Entrance of the Italian demo case property

Role of the building manager

Casa Spa is a publicly controlled company operating in 31 municipalities in Florence area (province of Florence, excluding Empoli area). The owner of public social housing is the Municipality only and **Casa Spa acts as building manager**. Relation with tenants takes place when signing the contract, during management, but also when there is the need to solve issues that may arise concerning the building (maintenance and prompt intervention). Casa Spa provides three different service types: **technical, administrative, management**. It works at different levels with tenants. The management sector is in contact with tenants more often, e.g. during inspections and maintenance. The technical department also deals with extraordinary maintenance and renovation of building. Administrative service is cross-cutting for resource management. Finally, a new department that deals with the social part and collects the human aspects and issues has been recently established. However, this department does not work as social service, as this is under the responsibility of the municipality.

Number and composition of households

Less than **15 people** live in the two twin buildings. Each building has 4 dwellings (the floor area is approximately 80 m^2 per dwelling). One dwelling is currently empty, therefore only **7 households currently live at the demo site**. **Most residents are old and retired**; they used to work as farmers in the vineyards nearby, in industrial plants or as housewife. All residents are Italian, except for a family with foreign origins that has been living in Italy for many years. Only one family is composed of younger members that still conduct a working life. It is also common for the residents to host their grandchildren at home during the day. **Most of the inhabitants have been living there for many years, some even since the building construction**.

The **average monthly rent** per dwelling is 158.12 Euros and is calculated based on the residents´ income.

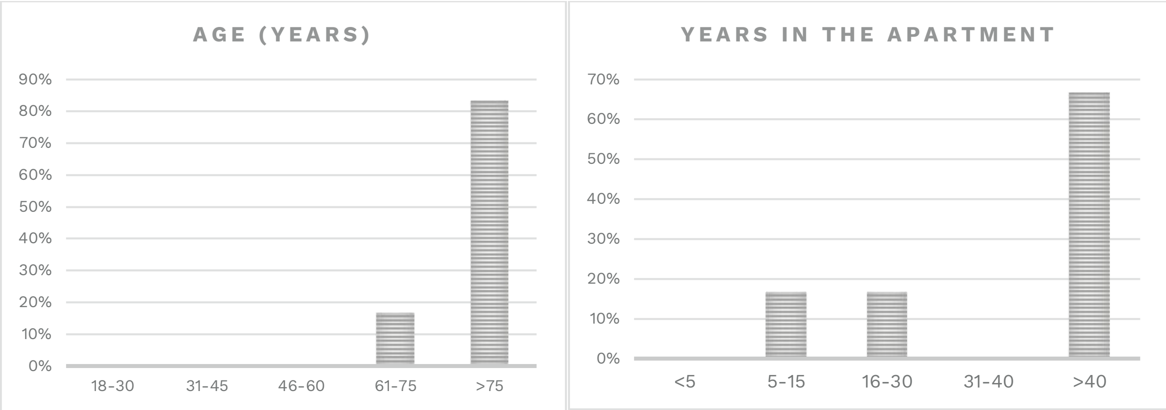


Figure 25: Survey results: age of the inhabitants (left) and number of years tenants have been living in the apartment (right)

Residents’ daily habits

Residents spend most of the time at home, as they are retired. As they are old people, they wake up early/very early and go to bed early/very early. In the morning, they mainly do household duties, and if they go out, they go out in the morning e.g. to buy food. **The core of all activities is the kitchen**, residents said they spend all the time in the kitchen, e.g. sitting on the table and watching TV. In Italian culture, **cooking and eating together is an important moment** of sharing and being together. They spend time in the kitchen also because in winter it is warmer due to cooking and many residents have a **wood stove** to overcome the limits of the inefficient and expensive heating system. Besides, the wood stove in their opinion is a cheaper way to heat the room; this opinion come also from their past. Residents hang clothes to dry out on the balconies.

Before the covid-19 pandemic, residents used to meet the neighbors more often in the garden and exchange a few words, but now it does not happen much. Anyway, inhabitants said that sometimes they have a little walk in the garden and sit on the bench. The liveliest part of the day is the morning, also because before they used to walk more and go to the village, but in recent times not anymore.

Residents do not have specific energy-saving practices, except for **using the heating as little as possible to avoid expensive energy bills**. Related to this, they also avoid switching the light on in the flat during the day.

Attachment to dwelling and building

Residents appear **happy to live in the building**, as they have been living there for most of their life. Some of them have lived there for 30 or 40 years. This is confirmed by the survey results, see Figure 26.

Figure 26: Survey results: happiness of the inhabitants to live in their dwelling and building

When residents were younger, they used to do a lot of **self-maintenance** and they still have **shifts to manage common spaces and the garden**, of which they are particularly proud.

Figure 27: Common garden of the Italian demo case

Current building status (current issues and positive aspects)

The **performance of the heating system is low**; that was originally a centralized system, which the tenants replaced with decentralized gas boilers. The **gas boilers are used both for the heating and domestic hot water**. Furthermore, there are a lot of **dispersions**, e.g. from single-glazing windows and façade. On the roof there are sandwich panels, but the thermal performance of the last floor is poor. Many tenants avoid switching on the heating because of the expensive bills they would receive; many of them rather use a wood stove. **In summer, temperature can be very high**, up to 40°C, thus creating discomfort to the residents. Some residents have ventilators, AC and awning to avoid direct light and heat in summer. Furthermore, **tenants are used to keep the windows open in summer** to allow fresh breeze to go through the dwelling. **Balconies** are currently in a bad status and deserve renovation.

Figure 28: facade of one of the Italian twin buildings (left) and picture of the balcony (right)

Some persons mentioned they have issues with **mold** formation.

The appearance of the building does not seem to be an issue for the residents, as they are more interested in solving the issues they see and experience (e.g. poor heating performance).

As the building is far from noise sources, noise from outside is limited. However, **noise between dwellings and from common spaces (staircase)** was reported by some tenants. This was also the reason of some discussion among tenants. No specific issues emerged concerning security. No specific problems were reported about unpleasant odors.

Overall, no specific maintenance issues arose during the interviews, except in one case where malfunctioning of the boiler and high maintenance costs to fix the boiler were reported.

Needs of the residents

Balconies, the presence of old windows (causing many dispersions) and inefficient thermal performance of the building in winter and summer are the main problems reported by the residents, see survey results in Figure 29.

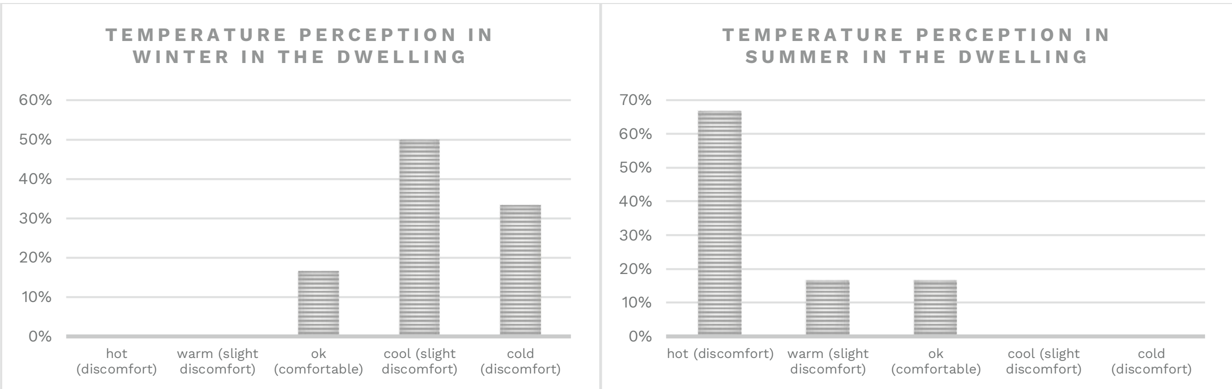


Figure 29: Survey results: temperature perception in winter and summer in the dwelling

Balconies are also a very important place for residents because they have plants and flowers, they dry the clothes and spend time outside when it is hot in summer evenings. Residents also like to cool the dwelling with **natural ventilation** (i.e. keeping windows of opposite rooms open).

Figure 30: View from an open window at the Italian demo case

In addition, **bad status of plumbing** due to rust has been reported by some inhabitants. Some residents reported lack of light in the garden, malfunctioning of the closing system of the front door and property gate, and lack of an elevator. **Lowering the energy bills** is also perceived as an important need by the users, especially considering that high costs do not correspond to a good thermal performance, see survey results in Figure 31.

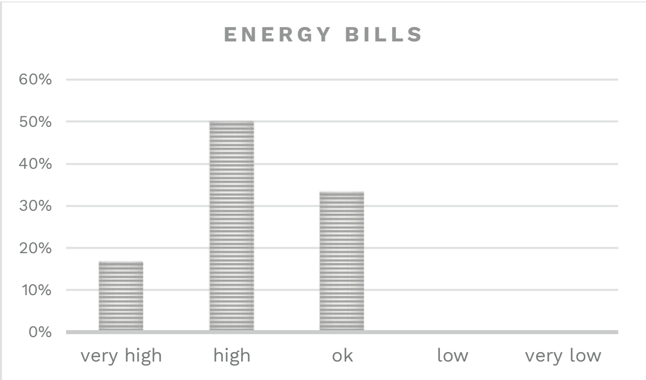


Figure 31: Survey results: residents´ perception of energy bills

Residents' awareness about retrofitting

Residents were informed about retrofitting and they seem overall happy, especially concerning the renovation of balconies. **Inhabitants do not appear worried about construction works and related aspects** (e.g. dust, work duration, scaffolding, noise, blocked roads), because they are aware that such disturb is needed in order to improve current building status and solve issues they perceive. However, they would of course prefer that the disturb is the least as possible, see survey results in Figure 32.

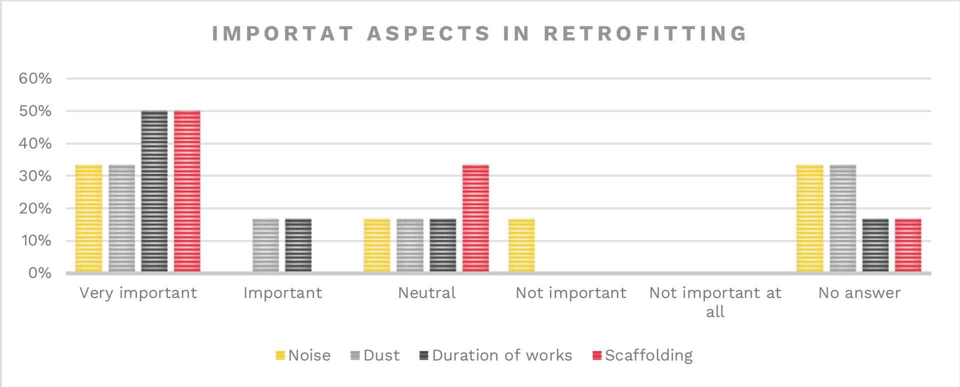


Figure 32: Residents´ survey: important aspects in retrofitting works

Although inhabitants overall seem to trust the work done in the project, the **residents were afraid of the cost of renovation and of the economic implication for them**. Overall, the feeling was that **residents invested their own money in the apartment** (e.g. they have AC or sun shading) and **would not be happy to see the improvements for which they paid vanish with INFINITE**.

Expectations of the residents about renovation

Beside the wish of addressing the needs and issues reported before, residents do not seem to have specific expectations: 1) because they are old and are afraid they would not see the accomplishment of the renovation in 4 years; 2) because **they feel that they do not have strong decisional power to influence the renovation**. It is also important to note that residents are not really interested in how the renovation will be done or issues like aesthetics, but rather that the actual and practical problems they have will be solved.

Summary of the analysis of the building context and residents' expectations

The neighborhood of the Italian demo case is very peaceful and quiet; it is not in the city centre, but close to it (walking distance). The area is green, the view is nice towards typical Tuscany hills and landscape. The other buildings in the surrounding are similar to those of the demo case, with some common green space and around two floors. The garden at the ground floor of the demo case appears to be very nice and well-managed. **Almost all balconies had plants and flowers** and some of them were also on the sills of windows.

The dwellers are quite open to talk, on the one hand they are interested in communicating their needs and problems; on the other hand they feel they are old and there are chances that they do not see the end of the project. They feel that they cannot influence the building renovation much, this is why **they are more interested in solving their main two or three problems in practice, without discussing about how things should be done or look like**.

4.5.1.2 The French demo case

Context of town and district

The building under study was built in 2002 and is located in Choisy-le-Roi, a municipality close to Paris. No specific problems or issues referred to the town and district were pointed out by the building managers.

Role of the building manager

Logirep is the building owner and manager of the French demo site. Once that the site to renovate is defined, Logirep starts working with local agencies and tenants to decide what is going to be renovated. Afterwards, they ask for a budget for the renovation works to an investment committee to which different renovation options are presented. Once that the scenario for renovation has been selected, Logirep engages professionals (architects and engineers) to detail the project and perform audits, such as the thermal one. When the renovation plan is ready, after that the budget is agreed with an engagement committee, a tender or public offer are made for the selection of the construction company and architect. After that the company is selected, Logirep prepares the site, i.e. it has **meetings with tenants and local agencies to present the renovation plan** and the company in charge of the renovation.

Number and composition of households

The building is made of two parts, one for social housing and one for University dorms. Only the first one will be considered for INFINITE retrofitting. In the building part under study there **are 31 dwellings. Mostly there are 2- or 3-room apartments.** There are 18 Type2 (2 rooms), 12 Type3 (3 rooms) and 1 Type4 (4 rooms). Inhabitants are mainly **families**, sometimes with children. There are also some retired people. **Tenants have been living in the building on average for 12 years**.

On average the rent price is EUR 7.65/m^2 and then the charges account for EUR 2.35/m^2. Charges are for caretaker, maintenance of common parts, electricity for elevator. The bills for energy are excluded from the rent and charges.

Current building status (current issues and positive aspects)

The main problem of the building is **high energy consumption for operation**. **The heating system is old and its performance is poor. The façade is poorly insulated** (the indoor insulation is only 80 mm thick). **Windows are also very old** (about 20 years old) and need to be replaced. Because of the poor heating performance and the related need to heat longer, **energy bills are high**. Sometimes there are humidity issues and status of common parts can be improved (e.g. wall paint). Malfunctioning of elevator was also reported by the building manager.

Electricity from grid is the source for heating and DHW.

Indoor air quality can be problematic in some dwellings because of **wrong user behavior** (for instance, it was reported that some tenants covered the ventilation with some tape).

No issues are related to the roof as some work has already been conducted for that part; the building has balconies that are enjoyed by the tenants, despite them not being too large.

Tenants are happy about the aesthetics of the building, but are in favor of the renovation of the façade, because it is old (it has not been retrofitted yet) and deserves some works.

Figure 33: photo from the French demo building

Needs of the residents

A survey was distributed to residents of the French site in 2019. The building manger believes that the results are still valid and are useful to investigate tenants' perception about problems or positive aspects in the building and dwelling, see Figure 34. The main issues that emerged are:

- Water infiltration through walls;
- **Ventilation** (but please consider that this can be also influenced by wrong user behaviour, therefore this point needs to be further investigated to understand the reasons behind);
- Status of windows and shutters;
- **Noise** from common spaces;
- Bad status of kitchen floor, common spaces (entrance and staircase) and lift malfunctioning.

Although heating was not reported as a problem in this first part of the survey, insulation and renovation of the heating were voted as the top priorities for renovation in the second part of the survey, see Figure 35.

Figure 34: Results for survey about residents' satisfaction concerning different topics (distributed in 2019 at the French demo site)

Residents' awareness about retrofitting

Residents were informed about retrofitting, as this was planned already 2 years ago and then postponed. A residents' survey was distributed in 2019 to prepare the renovation, as reported in the previous paragraph, see Figure 34. Overall, tenants are happy about renovation, although some complaints may always arise. **If disturbance can be minimized (e.g. noise) by shortening renovation duration, this will contribute to a positive perception of retrofitting for the tenants.**

It is possible that rent fees change after retrofitting, depending on the investment effort by Polylogis. There are usually two options adopted by the building mangers: either to apply an increase of rent (e.g. by 5%) or to introduce a special fee (e.g. 10 EUR per month over 15 years). The first option is more likely to be selected in the case of the French demo. However, it is expected that **the total fees (rent + energy bills) paid in the future after renovation will be lower than the current ones.**

Expectations of the residents about renovation

Based on the second part of the residents´ survey distributed in 2019 (see Figure 35), **top priorities include renovation of the facade with insulation and heating system**. These aspects are strictly linked to the poor thermal well-being and high energy bills. **Common spaces (hall and lifts)** are also expected to be renovated by the tenants. Finally, residents mentioned renovation of **dwelling ventilation** in the top 5 priorities for retrofitting.

Figure 35: priorities of residents for renovation of the French demo case

4.5.1.3 The Slovenian demo case

Context of town and district

The town of Ravne is a small town in White Valley bordered by forests and mountains; this is the most populated part of Carinthia in North Slovenia. It is a small town, around 7, 000 inhabitants, and the largest city in Carinthia. It is administrative, ports, economic, cultural, sport center of the valley and historical Carinthia in general. The economy of the town is based on **heavy industry, iron works, metal construction transport**. Most of the companies are located in the industrial zone and this is an area of former iron works. In 2017, there were 800 companies operating in the municipality and it has the largest share of employees in manufacturing; level of employment is around 60%. **The building is located on the border of the city center and was intended for workers that work in this manufacturing sector**.

The building was built in 1970; there is currently **one owner**: Stanovanjsko podjetje (STAN).

Role of the building manager

Stanovanjsko podjetje (STAN) works as facility manager for buildings and residents and is involved in different tasks: acquisition, establishment and management and updating of the records for apartment owners and residents; establishment, updating and keeping record of dwellings, business units and common spaces; reporting data on changes of ownerships of individual parts of the building to the organs of the Republic of Slovenia, providing information to apartment owners, organizing and preparing meetings for apartment owners, preparation of necessary information for concluding insurance contracts for common spaces, organizing insurance of common spaces and reporting claims to insurance companies, preparation of annual reports and on the management of the building, keeping archive, documentation; conducting technical tests that include inspecting the building and collecting data on necessary maintenance or renovation, making building maintenance plan, organizing discussion and adoption of maintenance plan, obtaining appropriate documents and permits for maintenance work, collection offers prices invoices, care of performance of regular maintenance work, repairs of defect during warranty period, preparation of claims for damages, care for implementation of maintenance work or minor value organization, urgent maintenance work, receiving notification, issuing orders and organizing rehabilitation of the dwellings that are in urgent situations; financial and accounting tasks, determination of financial obligations of maintenance costs and operating costs, distribution of maintenance and operating costs in accordance with rules and law, collection of liabilities of owners and tenants, recordings of receivers and payments, recovering liabilities of those accounting tasks. STAN has also individual contacts with tenants, for instance if they cannot pay the bills or have special needs.

Number and composition of households

There are many small apartments in the building and there is a big **fluctuation of people** there are not a lot of people that are in the building since the beginning. **All apartments are very small (30 m^2)**, because they were meant for workers. Workers often live in Ravne just for 2-3 years and have families in other parts of the country or even other countries. Many people that rent apartments from these private owners **are immigrants and seasonal workers**, this is why there is a high fluctuation. Around 90 people live in the building, they mainly belong to work-active population and elderly people. There are not a lot of families with children. Finally, **dwellings are also used as temporal housing**, e.g. for 2 weeks. On average 1 or 2 persons live in each dwelling. Many people in the building are **unemployed or receive low pension** (when retired) and/or receive **social financial support** by the State.

Current building status (current issues and positive aspects)

The building has 5 storeys and 69 dwellings and one business space which is located in the basement. **The roof and common spaces are old and need to be renovated.** There are not a lot of green areas and the building does not have outside common area for residents to connect and hang out there.

Figure 36: photo of the Slovenian demo case

The heating system performance is poor and tenants spend around 30 Euros per month for heating per apartment. However, **as the cost is not high in terms of absolute numbers, this is not always perceived as a problem by the tenants**; on the other hand, as apartments are very small, the heating cost is high in proportion to the size of the dwelling. Heating is provided by **district heating** based on waste heat originated from a steel factory. If hot water generation is included, bills in winter reach up to 50 Euros per month per dwelling. **Hot water is prepared centrally with electrical heaters**, which are considered to be quite inefficient. The mechanical ventilation installation is under the roof but is currently not working, the AC is only installed in offices and server rooms on the ground floor.

Apartments owned by the State are overall in a better status than those owned by private owner. For instance, windows were replaced by the State, but not the private owners, resulting in double-glazed windows in the first case, and still old ones in the second case. **Some apartments were also renovated by the State 1-2 years ago.**

Some dwellings have mold issues; this could be also related to **wrong user behavior** (not opening the window). Noise from outside was not reported as an issue. As for systems, except for malfunctioning of the heat pump for DHW, no other problems were reported.

Needs of the residents

For this section, it is recommended to refer to IRI work in Task 2.2 and 2.3, as extensive field work to understand the perception and needs of the residents was performed.

Residents' awareness about retrofitting

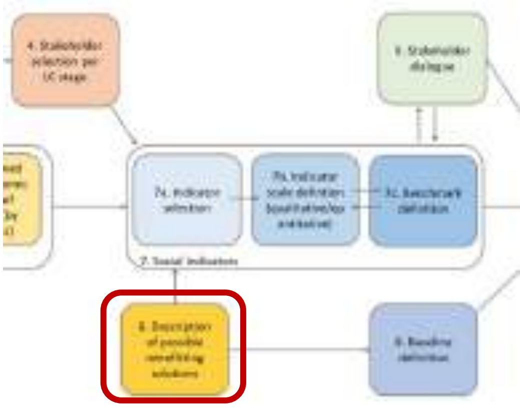
Residents are aware the retrofitting is planned. According to the building managers, **residents will be happy about renovation** as the building is quite old and needs improvements; disturbance during renovation works will not represent a significant problem. However, it will be important to **explain the purpose of the renovation and technologies, especially in those cases when renovation**

has already been recently performed (e.g. the case of replaced windows by the State). As for State-owned apartments, rent fees will not increase after renovation; this cannot be guaranteed for private apartments.

Expectations of the residents about renovation

A set of recommendations about the industrialised solutions social acceptance were elaborated starting from dedicated studies on the Slovenian context and are published here.

4.6 Description of retrofitting solutions



This step aims to define the retrofitting solutions developed in the project and with a focus on which specific technologies will be implemented in the different building case studies. Information about the technologies can be obtained directly from the **technology developers** and complemented with literature and web search. Beside describing the technologies from a technical point of view, it is recommended to **focus on the function, benefits and crucial points** that can be linked to them. Indeed, once that these aspects are investigated for each technology, it will be easier to understand which indicators should be selected to assess the social impacts of the renovation. A **qualitative description** is sufficient for this stage, as the main aim is to feed the social indicator step. Quantitative data can be also collected if already available for the different technologies, as they can help to decide about the assessment scale/approach for the indicator and feed the data collection in the next steps. **This step is expected to be conducted and expanded in an iterative way with the technology development in the project.**

4.6.1 Application in INFINITE

This section provides a brief description of the envelope industrialised kits developed by the INFINITE project.

Wood-based system for façade

The wood-based prefabricated module is the base element in which the different multifunctionalities will be integrated. The module is composed of a wooden frame (beams and columns) with insulation panel within it, one inner and one outer layer of panel (OSB or similar), vapour barrier, waterproof and windproof layer and the external cladding with its wooden substructure. In the inner part, also a compensation layer made of soft insulation panels to "adapt" the system to the existing façade will be included.

Functions/benefits:

- **improve the building thermal performances** -> reduction in the Heating and Cooling demand;
- integrations of other functional units to match with other performance requirements (**water-air tightness**).

Eco-compatible green envelope kit

The façade/roof greening solution integrates a set of possible modular and non-modular green systems which match at best with the industrialisation principles with the wood-based structure. The Green part of the KIT is considered as the external cladding anchored or leaning, with a metal substructure, to the prefab façade or roof. The Green KIT could include several possible grey water treatment possibilities and a Bio Electrochemical System able to purify water and generate very low voltage electricity.

Functions/benefits:

- improve the **building thermal performances** -> lowering the summer overheating;
- enhance the micro-clima, save and reuse water, preserve the wild-life (e.g. bees).

Energy and fresh-air distribution kit

The kit is based on the integration of the following main active components in the envelope module: (1) Mechanical Ventilation Unit (MVU) with heat recovery and water coil for air heating and cooling. (2) Air ducts with connection points for fresh and exhaust air. (3) Water pipes from the centralised energy generation. (4) Electric wires. (5) Sensing and control unit.

Function/benefits:

- Provide **fresh air for hygienic purposes**, as well as **space heating and cooling energy** to satisfy the thermal demand of the dwellings, without impacting too heavily with indoor works.

Smart window kit

The smart window kit is an easy-to-install smart and adaptive glazing solutions, integrated in an industrialised façade, to improve **indoor comfort and energy consumption**. The main feature is to provide an autonomous, sensing and dynamic glazing unit, to **improve the control of the solar radiation**.

Functions/benefits:

- Improve the control of the solar radiation via an innovative dual band smart glazing solution and a network of sensing and control equipment -> **lower the internal overheating risk, lowering the energy consumption, improve the visual comfort, provide privacy**.

Building integrated photovoltaic kit

The BIPV envelope kit is conceived as a glass-glass PV system integrated in the wooden-based prefab envelope systems (both roof and façade). This kit is looking specifically to 3 main aspects: (i) Technology interconnection (interfaces, overall construction optimisation and fire-safety); (ii) Aesthetic interconnection (color, finishing of the front glass); (iii) Energy interconnection (maximization of the energy match between the produced and consumed energy on-site and its relation with the building energy systems).

Functions/benefits:

- Produce renewable energy;
- Decrease the electricity grid demand;
- Integrate the PV panels "hidden" as external cladding (**aesthetic aspects**);
- Maximize the energy "matching" between production and consumption.

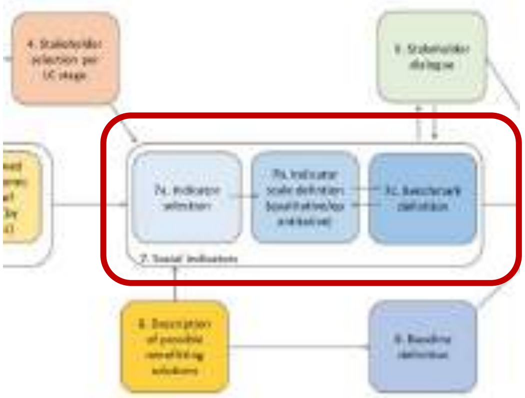
Building Integrated Solar Thermal

The BIST kit (Building Integrated Solar Thermal) is the integration of a solar thermal collector as energy generating cladding system under a Plug&Build logic to assure easy installation, maintenance and clean end-of-life. Thanks to a plug and play connector, the panels - as cassettes - can easily be pre-installed on the desired façades on a timber frame structure. The integration of the BIST panels into the timber frame modules is mechanical, aesthetical and hydraulic.

Functions/benefits:

- Produce Hot Water;
- Coupling with the existing system;
- Decrease the energy consumption;
- Integrate the BIST as a cladding in the facade (**aesthetic aspects**).

4.7 Social indicator definition



Social indicator selection is a crucial step for the methodology because this step will define which social aspects are assessed and how this assessment will be done, for instance if in a quantitative and qualitative way and if a benchmark will be established. Specifically, three sub-steps are part of the social indicator definition.

1. **Indicator selection**: which social issues or positive aspects are going to be assessed.
2. **Indicator scale definition**: how will the indicators be assessed and expressed, e.g. with single quantitative values, measured against a scale or with qualitative descriptions.
3. **Benchmark definition**: optionally, a reference performance can be identified against which the indicator collected for the specific case study can be compared.

Indicator selection

Based on the previous social hotspot screening and study of the building context, a selection of the topics to be addressed in the social assessment need to be defined. Such social aspects differ depending on the stakeholder and life cycle stage considered. In social LCA, these topics to be assessed fall under the **name "social sub-categories" or "social theme"**, which then are evaluated through "social indicators". The structure can be defined as following.

1. Stakeholder category: e.g. workers
   - 1.1 Social sub-category or social theme: e.g. health and safety
     - 1.1.1 Social indicators: e.g. fatal accident rate at the workplace; presence of safety measures.

One or more indicators can be chosen to describe one social theme. One or more social themes can be associated to one stakeholder category. The S-LCA Guidelines [5] provide a list of possible social aspects that can be assessed for workers, local communities, consumers, value chain actors, children and society. A list of possible indicators per social theme is also provided in the PSILCA database [31] for local communities, value chain actors, society and workers. For stakeholders that are specific to the case study, such as building inhabitants, it is suggested to elaborate indicators based on literature review, previous project reports and available standards, such as the EN16309:2014 Sustainability of construction works - Assessment of social performance of buildings.

Indicator scale definition

Once that a list of social indicators to consider for the analysis has been drafted, the practitioner needs to decide how these indicators will be assessed and related results expressed. Three approaches are possible:

- **Quantitative indicators**: single values quantifying the aspect under study, e.g. number of degrees °C to assess the indicator "indoor air temperature".
- **Semi-quantitative indicators**: a scale to classify the indicator can be drafted, for instance from good to bad, from very high risk to very low risk, from 1 to 5. The number of intervals of a scale can be defined for each indicator.
- **Qualitative indicators**: this is typically a description of the aspect, without quantifying it with single values or ordinal scales. "Yes" or "no" can also be a way to define the presence or absence of an aspect, e.g. presence of control systems for daylighting.

Not all indicators need to be assessed with the same approach, given the different nature of social topics. However, it should be noted that this affects the impact assessment phase and the user needs to be aware that results will follow the different nature of indicators, hence being qualitative, semi-quantitative and quantitative.

An indicator assessment scale is already provided for all indicators available in the PSILCA database, see Figure 37. If indicators for stakeholders other than those contained in PSILCA are considered, dedicated assessment scales need to be created.

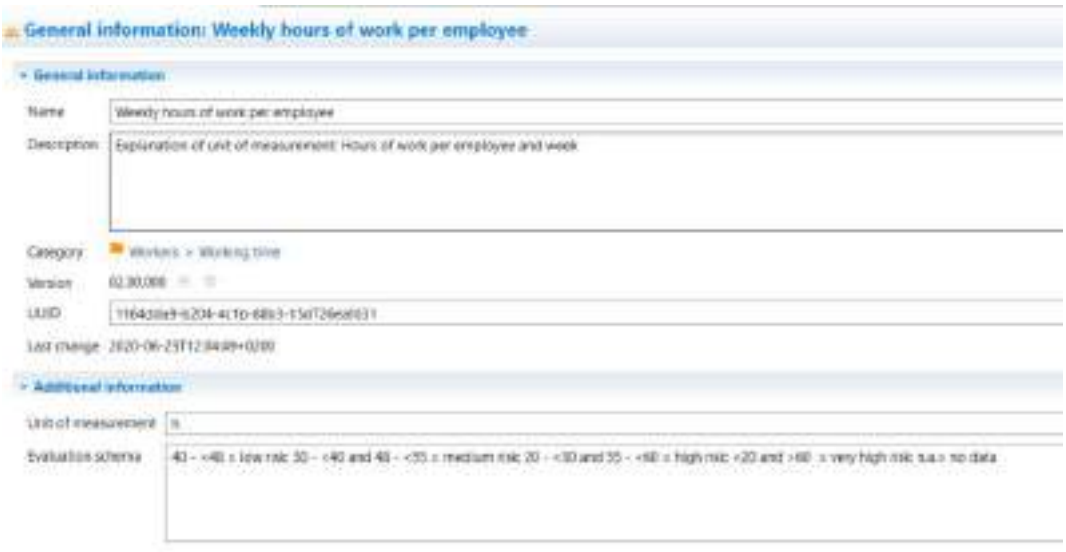


Figure 37: Example of social indicator scale in PSILCA

Benchmark definition

A reference can be defined against which to compare the data collected for the selected indicators. This sub-step is optional and is intended to be different from the baseline definition. Indeed, **it is possible that a system performs better than a baseline, but is still below a defined benchmark**. Therefore, a benchmark is useful to understand how an indicator scores at a general level, i.e. if it is generally “good” or “bad”, independently from how it performs compared to another baseline situation. In the case of social aspects, a benchmark can be defined in different ways, for instance:

- A benchmark can be a **“business as usual” performance**, below which an indicator is “worse than business as usual” and above which an indicator is “beyond business usual”;
- A benchmark can be the **compliance with local and national laws**, although this can raise doubts about the influence on cultural factors to consider something good only because this is accepted by a country law;
- A benchmark can be the **compliance with universally recognized human rights**, as defined by world-leading organizations, such as United Nations, International Labour Association (ILO), World Health Organization... ;
- A benchmark can be **a performance defined as “acceptable” by the user**; however this should be documented and all levels of a scale (if applied) should be described for transparency and reproducibility of results.

4.7.1 Application in INFINITE

A number of **indicators were selected for the assessment of building retrofitting impacts on building residents. Such indicators were identified for the use, maintenance, renovation works and design stages.** The indicator proposal is grouped under different social themes and provided in Table 4, Table 5, Table 6, Table 7. Such tables also report first suggestions for the assessment of the indicators according to qualitative, quantitative, semi-quantitative approaches. For some indicators, more than one assessment option is feasible. Finally, indicators are marked if they are influenced by the perception of residents and therefore there could be a difference between the real situation and what is perceived by the residents. As INFINITE will not focus and influence all of the proposed indicators for building renovation, those that are seen within the scope of INFINITE are marked in light orange in the tables.

As for the other stakeholders selected for building renovation, the indicator selection is made based on those available in the PSILCA database (for which an assessment scale is already provided). Specifically:

Workers (manufacturing and installation of the kits):

- Workers' wage,
- Accidents at the workplace,
- Indoor and outdoor air and water pollution,
- Presence of safety measures,
- Gender wage gap,
- Workers' gender balance,
- Child labour/forced labour,
- Freedom of association (trade union, right to strike).

Value chain actors:

- Sourcing of raw materials from local suppliers,
- Social responsibility in the supply chain,
- Corruption and bribery in the building sector.

Local community (manufacturing phase of the kit):

- Employment rate in the area,
- Greenhouse gas emissions (e.g. CO_2),
- Impact on forest areas,
- Level of water use,
- Biodiversity,
- Impact on agricultural areas,
- Extraction of ores,
- Extraction of biomass,
- Extraction of construction minerals (e.g. sand, gravel),
- Migrant workers in the construction sector,
- Respect of indigenous rights,

- Pollution in the area.

Local community (operation phase of the building):

- Employment rate in the area,
- Greenhouse gas emissions (e.g. CO_2),
- Level of water use,
- Biodiversity,
- Extraction of biomass,
- Extraction of construction minerals (e.g. sand, gravel),
- Pollution in the area.

Society:

- Contribution to economic development of the area/country,
- Public health expenditure.

No benchmark is set for the social indicators for residents in INFINITE. For all the other societal stakeholders the benchmark is based on the risk assessment scale provided in the PSILCA database. For all the indicators, a comparison is set with the baseline (see Chapter 0).

Table 4: Proposed social indicators for the building use phase (indicators significant for INFINITE goal and scope are highlighted in light orange)

Social theme	Indicator	Remarks	Source	Quantitative assessment	Semi-quantitative assessment	Qualitative assessment	(residents' perception)
Thermal well-being	Indoor air temperature (summer)		EN 16309:2014	°C	PMV and PPD categories; EN ISO 7730:2006		x
	Indoor air temperature (winter)		EN 16309:2014	°C			x
	Indoor humidity		EN 16309:2014	%			x
	Air velocity	In Slovenian DEMO case this is important - draught	EN 16309:2014	m/s			x
	Control of thermal comfort at dwelling level	can ambient temperature, humidity, air speed be controlled at dwelling level (if yes: manually or automatically)?	EN 16309:2014		Scale; 1-5: automatically + distinction individual rooms-1; yes (automatically)-2; manually + distinction individual rooms - 3; yes (manually)-4; no-5	yes/no	
	Monitor of parameters for thermal comfort at dwelling level	Can the temperature, humidity and air speed in the dwelling and/or the individual rooms be measured and displayed?	EN 16309:2014		Scale; 1-4: yes (measured and displayed at individual room level)-1; yes (measured and displayed at dwelling level)-2; yes (measured)-3; no-4	yes/no	
	Need to change temperature		EN 15251: 2007		Scale; 1-3: no (comfort) 1- sometimes (partial discomfort)-2; yes(discomfort)-3. Do you want the temperature in summer and winter: Higher (discomfort), no change (comfort), lower (discomfort)	yes	x

Quality of internal environment							
Indoor air quality	Ventilation rate	exchanges per person, type of the room	EN 16309:2014; EN 16798-1:2019	l/s per person; number of exchanges per hour (n-1)			x
	Risk of mold formation	based on the internal surface temperatures and the relative humidity	EN 16309:2014	WUFI mould Index by VTT and Fraunhofer or internal surface temperature (EN13788)	Scale; 1-5: from very high risk-5, high risk-4, medium risk-3, low risk-2, very low risk-1, based on expert judgement from building managers + data reported by dwellers		x
	Presence of harmful materials		Screening	VOC, formaldehyde, carcinogens μg/m3	Scale; 1-3: 1- absence of harmful substances of very high concern (SVHC) (REACH) or other substances exceeding toxicity thresholds-1: presence of SVHC or other substances exceeding toxicity thresholds, in <1% envelope weight-2; presence of SVHC or other substances exceeding toxicity thresholds, in >1% envelope weight-3	yes/no; list of harmful materials	
	Presence of unpleasant odor		Screening	Frequency of odor hours: Grid method (EN 16841-1:2016)		yes/no	x
	Control of ventilation by the user	through automatic control and / or manual takeover of control	EN 16309:2014		Scale; 1-5: automatically + distinction individual rooms-1; yes (automatically)-2; manually + distinction individual rooms - 3; yes (manually)-4; no-5	yes/no	
	Monitor of parameters for air quality at dwelling level	e.g. CO2 concentration, humidity, VOC	EN 16309:2014		Scale; 1-4: yes (measured and displayed at individual room level)-1; yes (measured and displayed at dwelling level)-2; yes (measured)-3; no-4	yes/no	

acoustic well-being	Soundproofing against noise from other dwellings		EN 16309:2014	Impact sound pressure level (EN 12354-1) and apparent sound reduction index (EN 12354-2); sound pressure level (EN 16283-1 and -2)		presence and thickness of internal insulation	x
	Soundproofing against noise from common spaces		EN 16309:2014	Impact sound pressure level (EN 12354-1) and apparent sound reduction index (EN 12354-2); sound pressure level (EN 16283-1 and -2)		presence and thickness of internal insulation	x
	Soundproofing against noise from outside the building		EN 16309:2014	Facade shape level difference, dB (EN 12354-3); sound pressure level (EN 16283-3)		presence and thickness of facade insulation	x
	Noise level due to system technologies		EN 16309:2014	Sound pressure level (EN 12354-5)		yes/no (noise issues); presence of system insulation	x
visual comfort	Visual connection inside-outside		EN 16309:2014	height of window ledge (m) or number of windows fulfilling ISO 16817 design criteria	Scale; proposal: from very good to very poor	yes/no	x

	Daylight		EN 16309:2014; EN 17037:2019	daylight factor (%); 3 interval scale (EN17307:2019): Min - 300lx Medium 500 lx High - 750 lx	Scale; 1-5: very good (window size is adequate to the size of the room, use of light control measures <20% daytime and light is adequate during use of the measures)-1; good (window size is adequate to the size of the room, use of light control measures <30% daytime and light is adequate during use of the measures)-2, medium (window size is adequate to the size of the room, use of light control measures <10% daytime and light is not adequate during use of the measures)-3, poor-4 (window size is adequate to the size of the room, use of light control measures >10% daytime and light is not adequate during use of the measures, or use of light control measures >30% daytime), very poor-5 (window size is not adequate to the size of the room)		x
	Use of artificial light		screening; EN 17037:2019	Hours of use of artificial light (h)		description of need to use artificial light during the day	
	User control of daylight at dwelling/room level		EN 16309:2014		Scale; 1-5: automatically + distinction individual rooms-1; yes (automatically)-2; manually + distinction individual rooms - 3; yes (manually)-4; no-5	yes/no	
User interaction with building systems	Service disruption of systems	malfunctioning of systems	screening	Duration of service disruption (h); frequency of service disruption (times per year)	Scale, 1-5: very good (never or once per year, disruption <half day)-1; good (once per year, disruption <1 day)-2; medium (twice per year, disruption < 1 day; or once per year, disruption >1 day)-3; poor (twice per year, disruption >1 day; or 2-5 times per year)-4; very poor-5 (>5 times per year)		x

	User-friendliness of equipment/systems	simple operation	screening		Scale: 1-5; very good (user needs considered in the design, easy to use, training provided, user interface)-1; good (user needs considered in the design, easy to use, no training provided or no user interface)-2; medium (user needs not considered in the design, easy to use, no training provided or no user interface)-3; (user needs considered in the design, not easy to use, training provided or user interface)-4; (user needs not considered in the design, not easy to use, no training provided or no user interface)-5	yes/no	x
	User training for equipment/system operation	provision of instructions to use systems/manual	screening		Scale; 1-4: yes (user training and manual)-1, yes (user training)-2; yes (user manual)-3; no-4	yes/no	
Safety and security							
Personal security and protection	Protection of building from intrusion	alarm and surveillance systems	adapted from EN 16309:2014		Scale: security level of locking systems	yes/no	x
	Illumination of common areas	garden, staircase, bike parking space; e.g. Lighting with motion detectors	adapted from EN 16309:2014		Scale: 1-5; very good (very bright: light in outdoor and indoor common areas)-1; good (bright: light in outdoor and indoor common areas)-1; medium (poor light in outdoor areas and good light in indoor areas or viceversa); poor (light missing in outdoor or indoor common areas)-4, very poor (light missing in indoor and outdoor common areas)	yes/no	x

Resistance to unplanned impacts	Structural safety	resistance to earthquakes	adapted from EN 16309:2014	increased resistance of the structure		Installation of devices or other measures that ensure mobility and shock resistance	
	Fire safety		adapted from EN 16309:2014	fire reaction class of materials and fire resistance of structures (REI)		Use of materials and products with a better reaction to fire class than required by existing regulations	
Resilience to effects of climate changes	Ability to drain water	(e.g. construction of the roof, sufficient dimensions for rain and drainage gutters; improved capacities for draining water in the ground and rainwater);	EN 16309:2014	Water tightness class (EN 12208)	Scale: proposal: ability to drain water from very good to very poor	systems to drain water	
	Automated rain protection	rain sensors that cause the windows to close; automatic backflow flaps; siphon systems	EN 16309:2014		Scale; proposal: no, yes (manually), yes (automatically)	yes/no	
	Prevention of facade elements from being detached		EN 16309:2014		Scale; 1-4; mechanical +adhesive-1; mechanical-2; adhesive-3; no fixing-4	prevention measures	
	Airtightness against wind		EN 16309:2014	Blower Door Test: Airflow (m3/s)		prevention measures (air barrier)	
	Prevention of snow falling from roof		EN 16309:2014			prevention measures	
	Control measures against solar radiation	shading (e.g. by panels, protrusions	EN 16309:2014		Scale; 1-5: automatically + distinction individual rooms-1; yes (automatically)-2; manually + distinction individual rooms - 3; yes (manually)-4; no-5	yes/no	

	Air conditioning/ventilation systems		EN 16309:2014			yes/no; description of system: natural ventilation, mechanical ventilation, AC	
Aesthetics	Building appearance		screening		Scale; proposal: based on number of years from latest building renovation; frequency of maintenance of envelope, windows and balconies	description (Do you like the building (yes/no) - why/ what do you (not) like?)	x
	Architectural quality of facade		screening			description; project for the design of facade involving an architectural studio	x
	Status of common spaces		screening		Scale; 1-5: very good-1; good-2; medium-3; poor-4; very poor-5. Based on observation	description (o you have any common spaces? Do you use/enjoy common spaces - why? What would you change?)	x
Psychosocial well-being	Feeling of ownership/attachment	to dwelling/building	screening		Scale: proposal: based on number of years living in the apartment	replies to interviews (Do you like to live in your apartment? Do you consider the apartment your "home"?)	x
	Presence of common areas		screening	area (m2)		yes/no; description	

	Presence of outdoor areas	garden, balconies	EN 16309:2014	area (m2)		yes/no; description (Do you use outdoor areas - why (not)?)	
Socio-economic aspects	Cost of energy bills		screening	Cost per month/year (€/m2)			x
	Rent fees		screening	Cost per month/year (€/m2)		In comparison with other buildings * Are the cost high/low?	x
	Fuel poverty	linked to average fuel price and income	Touceda, 2018	Residual income after bills (in relation to poverty line); fuel price (in relation to average national price)			
	Residents' awareness of energy and environmental issues		screening			yes/no	x
	Inclusion in building community		screening			description (Do you relate to other residents?)	x
Accessibility							
Accessibility to building services	Provision and simple operation of control systems	e.g. for heating, lighting, blinds	EN 16309:2014		Scale; 1-5: automatically + distinction individual rooms-1; yes (automatically)-2; manually + distinction individual rooms - 3; yes (manually)-4; no-5	yes, no	
	Accessibility of systems for people with special needs	for electronically or mechanically operated systems	EN 16309:2014			yes/no, description	
Accessibility to building facilities	Accessibility of entry/exit systems for people with special needs	electronically or mechanically operated (e.g. key / card-secured entry / exit systems, etc.);	EN 16309:2014	number of lifts, access ramps	Scale; proposal: no, yes (mechanically), yes (electronically)	yes/no, description	

	Provision of suitable orientation systems	tactile, visual and acoustic	EN 16309:2014			yes/no; description	x
Adaptability							
Ability of the building to adapt to individual and changing user requirements	simple dismantling / simple separation of components	internal components and systems	EN 16309:2014		Scale: 1-5; combination of type and accessibility of connections. Type of connection: Dry connection, reversible-1; dry connection, semi-reversible-2; irreversible connection (chemical compound) -3; irreversible connection (welding)-4. Accessibility: freely accessible-1; Accessibility with additional actions that do not cause damage-2; accessibility with additional actions with reparable damage-3; not accessible/irreparable damage-4 (source Drive0 project)	yes/no; description	
Ability of the building to adapt to changing technical requirements	Accessibility / easy dismantling of pipes and cables		EN 16309:2014		Scale; 1-4: freely accessible-1; accessibility with additional actions that do not cause damage-2; accessibility with additional actions with reparable damage-3; not accessible/irreparable damage-4 (source Drive0 project)	yes/no; description	
	Space for additional pipes and cables	that may be required in the event of a change in use	EN 16309:2014			yes/no	
Socio-environment al issues	Delivered energy demand	To be measured together with the cost of the bills	IVE	kWh/m2 /yr			
	Total water consumption		IVE	m3/m2 /yr			

Table 5: Proposed social indicators for the building maintenance phase

Social theme	**Indicator**	**Remarks**	**Source**	**Quantitative assessment**	**Semi-quantitative assessment**	**Qualitative assessment**	**(residents' perception)**
User disturbance	Frequency of regular maintenance		EN 16309:2014	Times per year (number)	Scale: proposal: based on the frequency level		
	Replacement frequency of windows		adapted from EN 16309:2014	lifespan (years)			
	Replacement frequency of external facade cladding		adapted from EN 16309:2014	lifespan (years)			
	Replacement frequency of roof cladding		adapted from EN 16309:2014	lifespan (years)			
	Replacement frequency of systems		adapted from EN 16309:2014	lifespan (years)			
	Accessibility to systems for maintenance		screening		Scale; 1-4: easily and freely accessible for technicians and tenants-1; freely accessible for technicians, but not tenants-2; not freely/easily accessible: accessibility with additional actions that do not cause damage-3; not freely/easily accessible: accessibility with additional actions that cause damage-4	yes/no, description	
	Service disruption due to regular maintenance	Usability of the building while the inspection / maintenance / cleaning and repair tasks are being carried out	adapted from EN 16309:2014	Duration of service disruption (h) and frequency of service disruption (times per year)	Scale, 1-5: very good (never or once per year, disruption <half day)-1; good (once per year, disruption <1 day)-2; medium (twice per year, disruption < 1 day; or once per year, disruption >1 day)-3; poor (twice per year, disruption >1 day; or 2-5 times per year)-4; very poor-5 (>5 times per year)		x
User engagement	Complexity of self-maintenance of systems		screening		Scale: 1-5; very good (user needs considered in the design, easy to maintain, training provided, user interface)-1; good (user needs considered in the design, easy to maintain, no training provided or no user interface)-2; medium (user needs not considered in the design, easy to maintain, no training provided or no user interface)-3;		x

					(user needs considered in the design, not easy to maintain, training provided or user interface)-4; (user needs not considered in the design, not easy to maintain, no training provided or no user interface)-5		
	User training for self-maintenance		screening		Scale; 1-4: yes (user training and manual)-1, yes (user training)-2; yes (user manual)-3; no-4		x
Socio-economic aspects	Maintenance cost		screening	Cost per year (€/m2)			x

Table 6: Proposed social indicators for the renovation works phase (indicators significant for INFINITE goal and scope are highlighted in light orange)

Social theme	**Indicator**	**Remarks**	**Source**	**Quantitative assessment**	**Semi-quantitative assessment**	**Qualitative assessment**	**(residents' perception)**
User disturbance	Noise level		screening	Noise pressure level (dB)	Scale; proposal: based on noise levels	description of installation process (considering consequence for noise generation)	x
	Retrofit duration		screening	Days (number)	Scale; proposal: based on number of days		x
	Need for relocation of residents		screening			yes/no	
	Blocked roads (road access) to building		screening		scale; 1-3: no blocked roads-1; blocked roads, but at least 1 access guaranteed to building-2; blocked roads, no access to building other than foot-3	yes/no (denied access to buildings)	x
	Dust level		screening	TSP, PM2.5 and PM10 (kg)	Tri colors (High, low, medium)	description of installation	x

						process (considering consequence for dust generation)	
	Equipment for retrofitting (scaffolding, cranes…)		screening		scale; proposal: based on volume/dimension of equipment (scaffolding, trucks, cranes)	yes/no; description	x
User demand	Finishing expectations	this could be in between installation and use	From IVE: Compare the promised finishes with reality, if they meet their expectations			yes/no; description	x

Table 7: Proposed social indicators for the retrofitting design phase (indicators significant for INFINITE goal and scope are highlighted in light orange)

Social theme	**Indicator**	**Remarks**	**Source**	**Quantitative assessment**	**Semi-quantitative assessment**	**Qualitative assessment**	**(residents´ perception)**
User involvement	Involvement of residents in decision making		screening	Number of contacts with residents	scale; 1-5: very good (involvement of residents at the beginning and during design process through interviews)-1, good (involvement of residents at the beginning of design process through interviews)-2; medium (involvement of residents at the beginning of and/or during design process through surveys)-3; poor (no involvement of residents, but investigation of residents' needs through building managers)-4; no resident involvement-5	yes/no	x
	Consideration of user requirements	in the design	screening		Scale; proposal: yes, no, partly	yes/no	x

	Evaluation of prototype		From IVE: As part of considering their requirements, perhaps present the systems/kits to the users so that they can give their opinion: if they know them and see them useful, at a basic level.		scale; proposal; from very satisfied to not satisfied	yes/no; description of procedure for prototype evaluation and users´ reactions	x

It is not always possible to collect the needed information to assess indicators according to the suggested quantitative and semi-quantitative approaches, as defined in the previous tables (Table 4 to Table 7). To overcome this limitation and still provide an assessment of industrialized retrofit in comparison to traditional retrofit, an **assessment matrix** was developed, as shown in Table 8. The matrix combines a **qualitative assessment of the current building context** (good, acceptable or bad, see Table 9) with a **qualitative estimate of the impact of industrialized or traditional retrofit on the context** (positive, indifferent or bad, see Table 10). Based on this combination, it is possible to identify 9 different situation and scores, as reported in Table 8. This matrix can be used to assess each indicator identified in Table 4 and Table 5 (**operation and maintenance** of the building).

Table 8: Assessment matrix applied in INFINITE to assess social impacts of industrialised retrofit in comparison to traditional retrofit

Retrofit impact		**Context assessment**		
		Good	Acceptable	Bad
Industrialized/ traditional retrofit	Positive	Improves something good (A)	Improves something acceptable (B)	Improves something bad (C)
	Indifferent	Does not affect something good (D)	Does not affect something acceptable (E)	Does not affect something bad (F)
	Negative	Worsens something good (G)	Worsens something acceptable (H)	Worsens something bad (I)

Table 9: Description of context assessment per indicator

Context assessment (per indicator)	Description
Good	The aspect described by the indicator is
Acceptable	The aspect described by the indicator is
Bad	The aspect described by the indicator is not

Table 10: Description of impact assessment per indicator

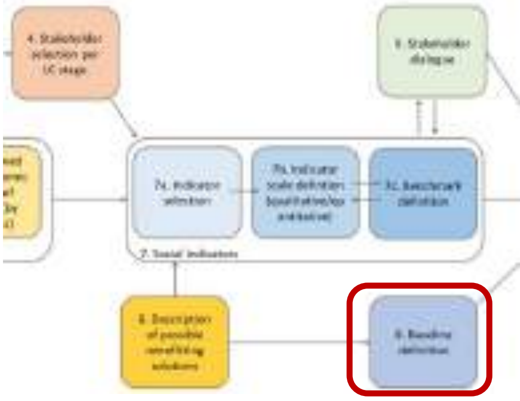
Impact of industrialized or traditional retrofit– based on current status	**Description**
Positive	introduces an improvement
Indifferent	does not change the situation
Negative	introduces a worsening

To assess indicators for the **renovation works** (installation of technologies) in Table 6, the key from Table 10 is adapted to assess the expected impact of industrialized retrofit in comparison to traditional one. Indeed, it does not make sense to consider the current status for the technology installation phase. The resulting assessment key for the installation of INFINITE industrialized technologies is provided in Table 11. To assess indicators for the design phase Table 7, criteria from Table 11 can be also used.

Table 11: Description of impact assessment per indicator (industrialized in relation to traditional retrofit)

Impact of industrialized in comparison to traditional retrofit	**Description**
Positive	A, introduces an improvement in comparison to traditional retrofit
Indifferent	B, does not change the situation in comparison to traditional retrofit
Negative	C, introduces a worsening in comparison to traditional retrofit

4.8 Baseline definition



This step consists in defining a **baseline**, i.e. a reference situation, against which social impacts of retrofitting can be compared. This is not a mandatory step, however, assessment results can be more meaningful when they are expressed in relation to another situation. It is indeed difficult to define if retrofitting can be overall good or bad in absolute values, while it is possible to communicate if a retrofitting scenario brings improvement or worsening in comparison to a baseline.

The definition of a baseline should be driven by the goal and scope of the study, life cycle stages considered and the selection of the stakeholders.

It is also possible to have **different reference scenarios depending on the stakeholder characteristics.** If impacts on residents are under study, it is suggested to consider the **current status of the building as a reference situation**, as inhabitants are typically interested in an improvement of their living conditions in comparison to the situation in the dwelling where they live. Only with such comparison it is possible to understand if the retrofitting has met the needs and expectations of the residents. In this case, **renovation works, use and maintenance of the building** are the main life cycle stages to be considered for the comparison of impacts on residents between before and after renovation.

It is also possible to **compare renovation impacts against other retrofitting scenarios** that could be implemented at the same building site, e.g. retrofitting with different technologies or level of prefabrication and industrialization. In this case, the **whole life cycle** (renovation solution manufacturing, installation, building use and maintenance, and end of life) can be meaningful for the comparison between different renovation scenarios. Furthermore, different stakeholders can be considered, e.g. workers, local communities, suppliers and the whole society. Residents can be also considered if there are differences in impacts for the installation of the solutions and building operation and maintenance among the different renovation scenarios.

Finally, it is important to define **what is going to be compared between the retrofitting project and the baselines/s and for which reference time**. This can be “a living environment for one year in the dwelling”, “the situation of one dwelling/building in the next 30 years”, “residents´ satisfaction of living in a dwelling/building”.

4.8.1 Application in INFINITE

As for INFINITE, the main focus is the **comparison of industrialized retrofitting proposed by INFINITE against traditional retrofitting**. Different scenarios can be defined as traditional retrofitting. However, given the importance of user-centred retrofitting considering the needs of the inhabitants, **as for the stakeholder "residents", the current status of the building without renovation is considered as additional reference situation**.

The comparative study expected to be performed in INFINITE is shown in Figure 38. This reports also stakeholders and life cycle stages involved in the different compared situations.

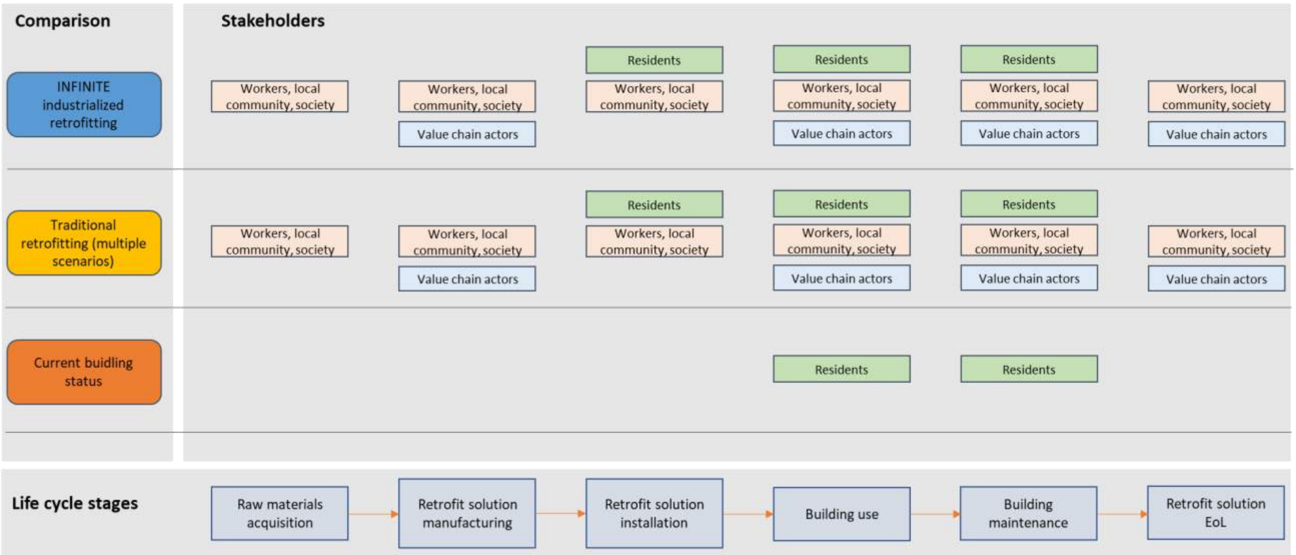
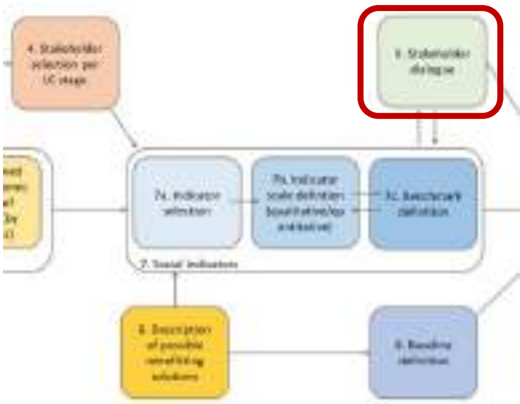


Figure 38: Overview of the comparative study in the INFINITE project, considering different life cycle stages and stakeholders

4.9 Stakeholder dialogue



This step refers to the **involvement of stakeholders** in the value chain of building retrofit to define which social indicators should be considered in the assessment. Stakeholders to be involved can include technology manufacturers, building managers, researchers, designers and local community representatives. Initiating a dialogue with stakeholders is beneficial to start the **data collection** and **discuss about expected benefits and challenges** of the retrofitting technologies. It is recommended to organize workshops where different stakeholders are brought together to have different points of view. Discussions in the workshop can start from the results of the hotspots screening (chapter 4.3) and building context (chapter 4.5), and can present a first selection of social indicators (chapter 4.7). The distribution of **surveys to building stakeholders** can be useful for the definition and prioritization of the workshop topics. Indeed, surveys can be helpful to have an overview of the opinion of different stakeholder groups on advantages and disadvantages of the developed technologies.

4.9.1 Application in INFINITE

4.9.1.1 Survey results

As a first step, a survey was distributed to technology providers in the project. At a second stage, the same survey was distributed to stakeholders involved in the value chain of building retrofitting value chains in Europe. In total, 34 replies were received. Most of the respondents were designers or sustainability specialists and were based in Spain, France and Italy, see Figure 39.

The survey had two goals:

- **To understand which and how stakeholders can be impacted by industrialized retrofitting solutions** (during manufacturing, installation, operation). The main focus was on workers, suppliers, local communities, society and building residents.
- To define **benefits and disadvantages** linked to the different industrialized technologies in comparison to traditional retrofit (workers, suppliers, local communities, society and building residents) and current status (for residents).

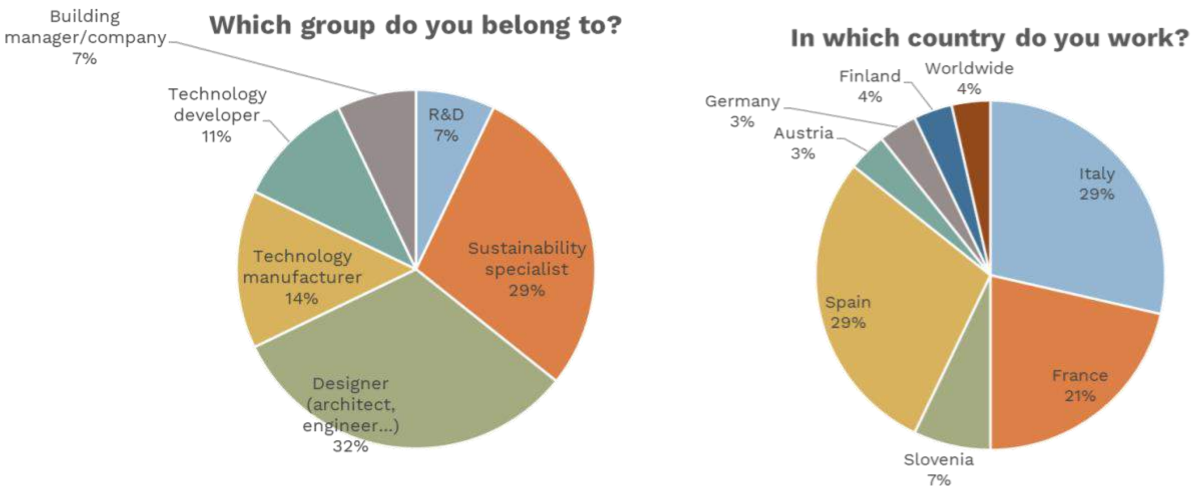


Figure 39: Overview of respondents to the survey distributed to stakeholders in building retrofitting value chains

The results of the survey can be summarized as follows.

Stakeholder workers

Aspects that can improve with industrialized retrofitting:

1. Health and safety (e.g. indoor plant pollution and accidents).
2. Workers' wage.
3. Gender equality (gender balance and wage gap).

Aspects that can get worse with industrialized retrofitting:

1. Lack of skilled workers and need to train them.
2. Accidents at the workplace (emerged specifically for smart windows).

Stakeholder suppliers

Aspects that can improve with industrialized retrofitting:

1. Social responsibility in the supply chain: companies are more aware of the social performance of their suppliers and choose accordingly.

Aspects that can get worse with industrialized retrofitting:

1. Amount of raw materials sourced from local suppliers.
2. Some suppliers between the technology manufacturers and the construction site may disappear.

Stakeholder local community

Aspects that can improve with industrialized retrofitting:

1. Employment.
2. Pollution and environmental impacts during technology manufacturing and building operation.

Aspects that can get worse with industrialized retrofitting:

1. Pollution and environmental impacts (use of resources) during technology manufacturing.
2. Employment/delocalization.

Stakeholder suppliers

Aspects that can improve with industrialized retrofitting:

1. Contribution to economic development in the area/country.
2. Expenditure on public health.

Aspects that can get worse with industrialized retrofitting: Not defined.

Stakeholder local community

Aspects that can improve with industrialized retrofitting:

1. Energy bills.
2. Residents´ wellbeing (thermal, air quality, psychosocial).
3. Value increase of the building.
4. Retrofit duration and residents´ disturbance.

5. Accessibility/easy dismantling of components (pipes, systems...).

Aspects that can get worse with industrialized retrofitting:

1. Maintenance costs.
2. Accessibility/easy dismantling of components (pipes, systems...).

Additional topics worth of discussion that emerged from the survey are listed below:

1. Off-site products quality can be certified as a guarantee for the owner and for the insurance company.
2. The quality management of the implementation will be improved with industrialized technologies leading to a better performance guarantee and reducing deviation cost.
3. Higher transparency across value chain could be a major advantage, but requires holistic project approach and cooperation.
4. There could be potential initial negative impacts on design: until technical issues have been resolved, design and appearance may be neglected.

4.9.1.2 Workshop results

After collecting and analysing the results of the survey, a workshop was held with representatives from all project partners (designers, technology providers, building managers and researchers). The workshop had the goal to discuss the findings of the survey and to identify required actions/conditions to make expected benefits really happen and mitigation measures to avoid/reduce negative aspects identified with the survey.

Topics discussed the most in the workshop were related to workers, local communities and residents, as they were the main stakeholders perceived in building renovation. The outcomes of the workshop can be summarized according to the following categories:

- **Health and safety for workers**: it can be difficult to change mindset of workers and introduce safety measures or change how the whole retrofitting process is managed off-site. Furthermore, workers may not feel to be part of the chain if industrialized technologies are implemented, as they would only be part of a small piece of the final product. Carpenters normally work outdoors (on site) and probably they will not be happy to work in a factory. However, the work environment in a factory is cleaner and within a controlled environment.
- **Lack of skilled workers**: specific training sessions should be organized for workers, both young and older ones. Training centres for installers can also be helpful to have dedicated sessions for the workforce. Language can be a barrier, if more complex technologies need to be explained to foreign workers. Visual guidelines (e.g., accessed with a QR code) could be used with workers that do not speak the local language.
- **Maintenance cost for residents**: there is the risk of increase of fixed maintenance costs (e.g., equipping technology with sensors); maintenance should be predictable (e.g. with sensors) and should always be communicated in advance to residents. It is also important to test technologies before they are produced and perform quality checks to reduce technology costs and maintenance. Accessibility/dismantling of components (pipes, system) depend on the systems used (some might be easier accessible, some more difficult).

- **Cause-effect relations among different social topics and burden shifting**: problems for one stakeholder category could not be a problem for another group of actors; therefore, it is important to consider the whole life cycle and multiple stakeholders at the same time.
- **Results of socio-economic assessment can be specific for one resident typology only** (e.g. elderly or families): it is needed to have a broader perspective on renovation, including different demo cases and dweller groups. Changes in tenants status should be considered when planning technologies, e.g. from a couple to family with children to elderly.
- **Employment**: if less time is needed to build industrialized technologies, there will be more construction sites active at the same time and more employees needed, especially if renovation is supported with subsidies. However, there is the risk that some prefabricated components are outsourced from abroad, for instance from Asia, with negative consequences for local employment. One option could be that **prefabrication is made within the local community** where technologies are going to be installed, i.e. **technologies from different manufacturers are assembled by local companies at a facility in the local area of the building**. To enable this, clear design, easy instructions and training courses for local workers are needed.
- **Improvement of neighbourhoods through energy communities** if renovation is made as an investment in a certain area. Other communities could be also motivated to do the same. Furthermore, thanks to prefabrication, less traffic and trucks are expected on site with benefits for pollution in the area.
- **Replicability of technologies** is important to reduce costs.
- **Benefits for building residents**: energy savings due to lower consumptions during building operation, increase of comfort once retrofitting is finished, short disturbance during renovation works. The building value can increase, although this could result in an increase in rent costs.
- **Customization of industrialized renovation solutions**: different colours and appearance of facades are needed for different types of solutions and customized aesthetics. Shape and size of the industrialized solutions shouldbe rather fixed, but with different cladding options.
- **Involving residents** since the beginning of the renovation process, it is crucial to develop technologies that will be actually used correctly and deliver benefits to the inhabitants.
- **Fear of technology and surveillance:** presence of sensors can lead to fear of loosing privacy. It is important that technologies have no complex interfaces and display simple indicators. It is important to explain the technologies to the residents, involve them in the design and test phase.

4.10 Data collection

Data collection is one of the most time-consuming steps in social life cycle assessment. It refers to the collection of information concerning (i) **the social topics and indicators** defined in the previous steps and (ii) **the physical quantities and costs of materials** and components to describe the solutions. The social hotspot screening, an understanding of the technologies, the baseline and future situations after renovation, and discussions with stakeholders are crucial for a successful data collection.

Data to assesses the social performance of building renovation typically include:

- Data per life cycle stage of the building.
- Data per stakeholder, social topic and indicator.
- Data about supply chains, e.g. location and social performance of suppliers.
- Data about direct local impacts during renovation, e.g. duration of renovation.

Collected data can be quantitative, qualitative or semi-quantitative, depending on the nature of the indicator or topic to be assessed and on data availability. Data sources and tools used for the assessment affect the type of data to be collected.

Possible data sources include:

- **Primary data** from technology providers, manufacturers and facility managers;
- **Data from sensors** installed at the building site before, during and after renovation;
- **Literature data** and previous social LCA studies;
- **Existing social LCA databases**, such as PSILCA or SHDB.

4.10.1 Application in INFINITE

Data collection in INFINITE required different approaches depending on the stakeholder and analysed life cycle stage, see Figure 40.

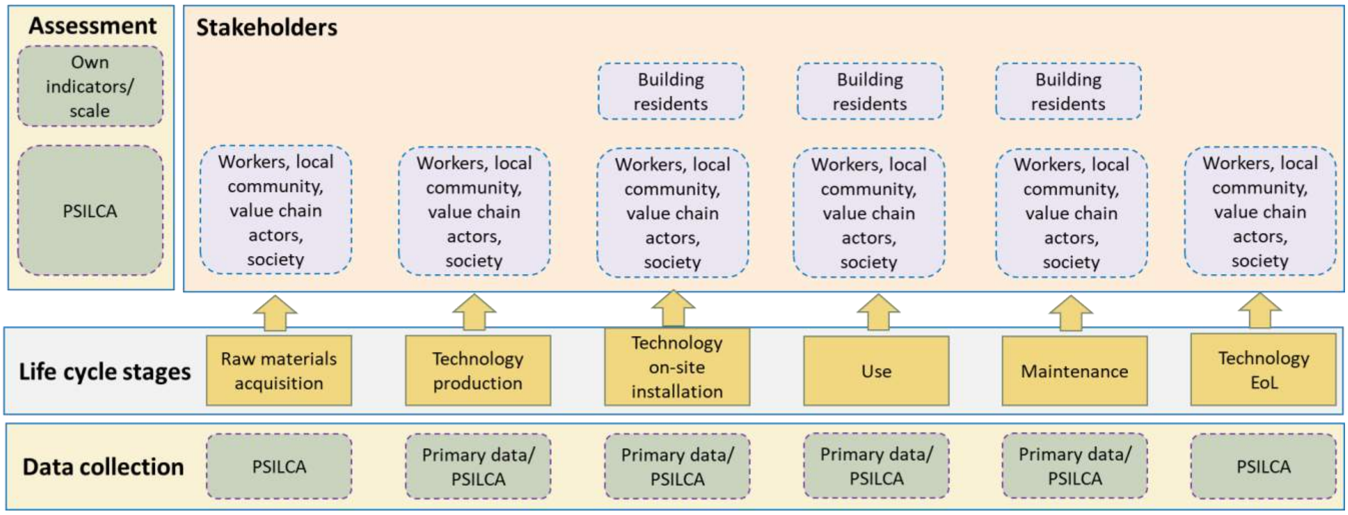


Figure 40: Overview of data collection approach per stakeholder and life cycle stage

As for building residents, quantitative data could be collected with sensors installed in the building demos to monitor the current building status concerning CO_2, temperature and humidity. However, given that only three indicators could be assessed with sensor data and as no further data were available at the time of the study, it was decided to evaluate all social indicators that describe impacts on residents during technology design operation, maintenance and installation (see from Table 4 to Table 7) using the qualitative assessment matrix developed in the project (see Table 8).

Technology providers could not provide any social data because of confidentiality. However, to demonstrate how data collection for social LCA in building retrofitting can be performed, **a case study is conducted with a focus on the life cycle of an industrialized façade with passive cladding in comparison to a traditional retrofit approach**. The test case is the façade of the Italian demo building.

4.10.1.1 Example case study: data collection of an industrialized timber façade in comparison to a traditional retrofit solution

The goal of the study is to quantify and identify **social hotspots** in the life cycle of an industrialized timber prefabricated façade and compare them with the life cycle of a faced for traditional renovation. The focus of the study us **15 m² of façade** (without windows) for the retrofit of the Italian building demo. It is assumed that the **service life of the façade is 50 years**.

Data collection for the industrialized façade

For the **industrialized façade**, the boundaries of the study include production (production of material layers and connectors, transport of materials to the façade assembly off-site, assembly of the façade, packaging), transport to the installation site, installation at building, use and maintenance, and end of life, see Figure 41. No impacts occur for use and maintenance.

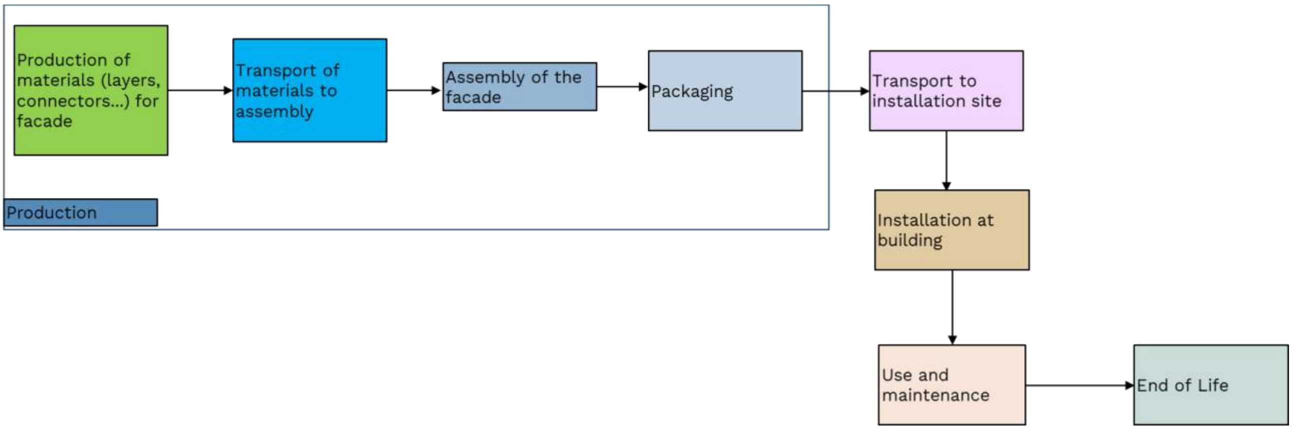


Figure 41: System boundaries of the social LCA study of the industrialized facade

The industrialized façade is composed of: mineral wool compensation layer, oriented strand board (OSB), vapour barrier tapes, timber frame with mineral wool, medium density fibreboard (MDF), waterproof membrane, wood vertical mullions and HPL (high pressure laminates) panels for cladding. The different façade components are produced in Germany, Austria, Italy, Croatia and Asia (connectors). The assembly phase includes electricity for hand machines and machinery. Packaging considers a nylon foil. Transport of materials to façade assembly and transport of the whole façade to the building site are considered. The installation phase includes: electricity for crane operation, diesel for lifting platform operation, renting of crane and lifting platform, waste packaging, lighting for security and operations, renting of fences and prefabricated box. The renovation phase is assumed to last for one month in the case of industrialized retrofit. The end of life considers the disposal of all materials not intended for recycling, i.e. incineration and landfilling of vapour barrier tape and waterproof membrane, and incineration of MDF. All the other layers are assumed to be recycled, in the best case of a design for disassembly approach at the early phase of retrofit design. **Recycling efforts are excluded** from the system boundaries, according to the cut-off method applied in the environmental LCA study.

Physical quantities and costs of industrialized retrofitting of the façade of the Italian building demo could be obtained from the environmental LCA and Life Cycle Costing studies (primary data from technology providers). **Worker hours** needed for the quantification of social indicators [31] could be calculated with primary data for labour costs and mean hourly wage per employee. These primary data were combined with **generic social information from the PSILCA database** for the stakeholders workers, local community, value chain actors and society. As no specific social indicators could be collected, social risks for the average “Construction” sector in Italy were assigned to the assembly and installation processes (see Figure 42), while social risks for the average “Sewage and refuse disposal, sanitation and similar activities” sector in Italy were used for the end of life. The drawback of the approach is **that average construction data were assigned to the industrialized renovation process.** Differences with traditional renovation are not reflected in the social risks in each life cycle stage, but rather in the process duration (worker hours) and inputs of each process (with related supply chains). Although not perfect, this approach is chosen to **overcome the lack of primary data and avoid arbitrary assumptions** on improvements with industrialized renovation in comparison to traditional retrofit.

▾ Outputs

Flow	Category
Active involvement of enterprises in corruption and bribery; very high risk	Value Chain Actors/Corruption
Certified environmental management systems; low risk	Local Community/Access to material ...
Children in employment, female; low risk	Workers/Child labour
Children in employment, male; medium risk	Workers/Child labour
Children in employment, total; low risk	Workers/Child labour
Contribution of the sector to economic development; low opportunity	Society/Contribution to economic de...
DALYs due to indoor and outdoor air and water pollution; very low risk	Workers/Health and Safety
Domestic and external health expenditure (% of current health expenditure); low risk	Society/Health and Safety
Domestic general government health expenditure (% of current health expenditure); low risk	Society/Health and Safety
Drinking water coverage; low risk	Local Community/Safe and healthy li...
Embodied agricultural area footprint; no risk	Local Community/Environmental Foo...
Embodied CO2 footprint; high risk	Local Community/GHG Footprints
Embodied CO2-eq footprint; medium risk	Local Community/GHG Footprints
Embodied forest area footprint; no risk	Local Community/Environmental Foo...
Embodied value added total; medium risk	Society/Contribution to economic de...
Embodied water footprint; very low risk	Local Community/Environmental Foo...
Emigration rate; very low risk	Local Community/Migration
Evidence of violations of laws and employment regulations; medium risk	Workers/Social benefits, legal issues
Extraction of biomass (related to area); very high risk	Local Community/Access to material ...
Extraction of biomass (related to population); very low risk	Local Community/Access to material ...
Extraction of fossil fuels; very low risk	Local Community/Access to material ...

Figure 42: Example of social risks assigned to the installation phase of the industrialized INFINITE facade from the "Construction" sector in Italy (from the PSILCA database)

Data collection for the traditional façade

For the **traditional façade**, the boundaries of the study include production of material layers and connectors, transport to the installation site, installation at building, use and maintenance, and end of life, see Figure 43. No impacts occur for use and maintenance.

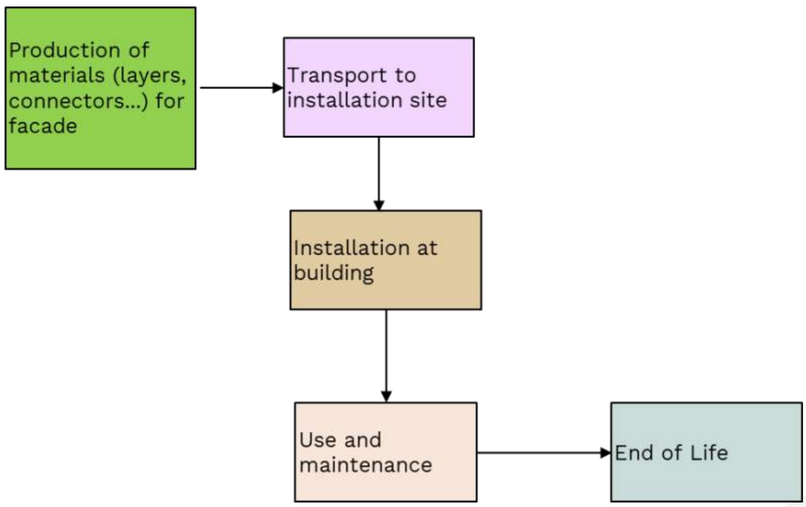


Figure 43: System boundaries of the social LCA study of the traditional facade

The industrialized façade is composed of: base layer and masonry support (mortar), EPS insulation, thermal coat support layers, bituminous membrane, aluminium vertical mullions and HPL (high pressure laminates) panels for cladding. The different façade components are assumed to be all produced in Italy, except for the cladding which is produced in Austria. Transport of materials to the building site is considered. The installation phase includes: electricity for machine operation, diesel for machine operation, renting of scaffolding, curtain, hoist tower and driller and equipment, transport of material and waste management at the construction site, lighting for security and operations, renting of fences and prefabricated box. The renovation phase is assumed to last for five months in the case of traditional retrofit. The end of life considers the disposal of all HPL panels and substructure (incineration); all the remaining materials are disposed as inert waste.

Physical quantities and costs of traditional retrofitting of the façade of the Italian building demo could be obtained from the environmental LCA and Life Cycle Costing studies (which are based on the regional Price List for Tuscany[6]). **Worker hours** needed for the quantification of social indicators [31] could be calculated with secondary data for labour costs and mean hourly wage per employee (regional Price List for Tuscany[6]). These data were combined with generic social information from the PSILCA database for the stakeholders workers, local community, value chain actors and society. As no specific social indicators could be collected, **social risks for the average "Construction" sector in Italy were assigned to the installation process** (see Figure 42), while social risks for the average "Sewage and refuse disposal, sanitation and similar activities" sector in Italy were used for the end of life.

Figure 44 reports an example for modelling thermal coat support layers for the Italian demo case through cost data for the inputs from different construction sectors.

Figure 44: Example of modelling a traditional renovation solution with the PSILCA database in openLCA

Figure 45 shows an overview of generic social information linked to the Italian sector "manufacture of other non-metallic mineral products", which is used as input for the model of traditional renovation (see Figure 44).

[6] Regional price list for Tuscany, province of Florence https://prezzariollpp.regione.toscana.it/2021/firenze

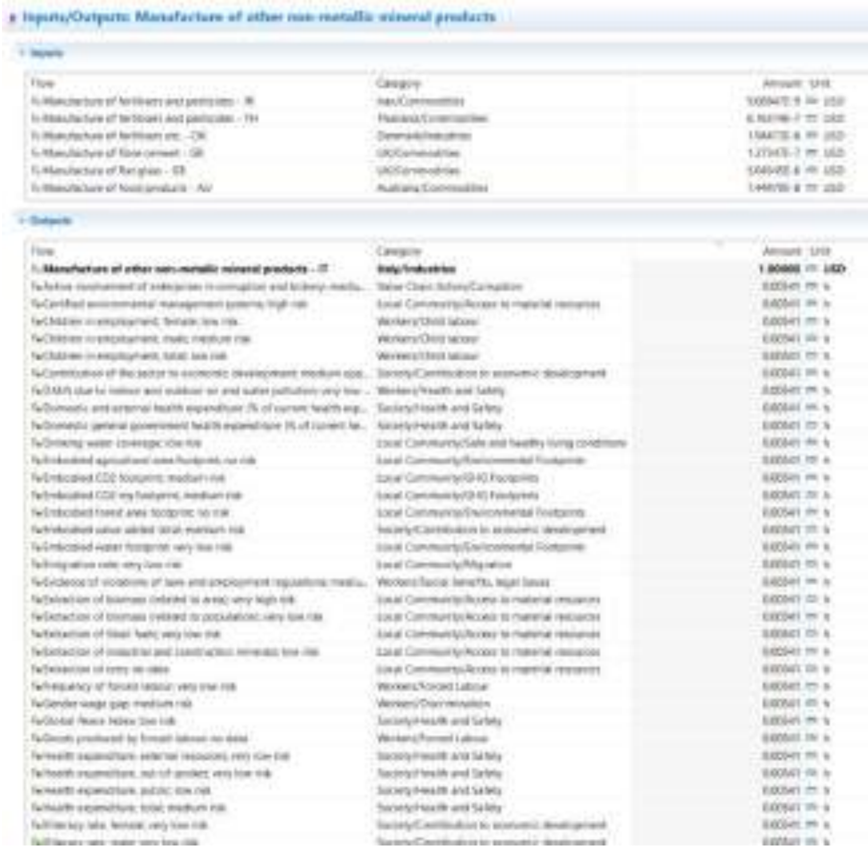
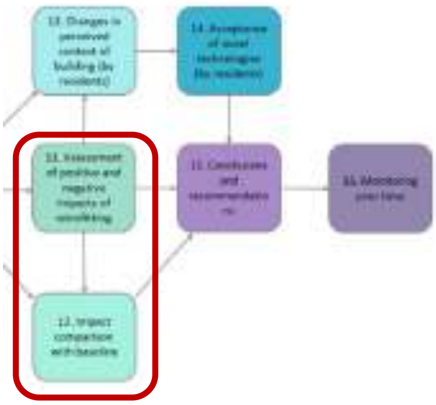


Figure 45: Example of generic social information available for construction sectors in the PSILCA database

4.11 Social and socio-economic impact assessment



Social and socio-economic impact assessment is referred to the evaluation of positive and negative impacts of retrofitting in comparison to the identified baseline. The impact assessment is based on the data collection for the different indicators and stakeholders. Based on the approach used for data collection, impacts can be assessed in a quantitative, qualitative or semi-quantitative way. Dedicated life cycle assessment software (e.g. openLCA and SimaPro) can be used to calculate social impacts by combining collected primary data and background social databases (e.g. PSILCA and SHDB). To put impacts into context, it is common to compare social and socio-economic impacts with a reference situation, which can be a different renovation scenario or the current building status.

4.11.1 Application in INFINITE

This section evaluates **potential social impacts** of INFINITE, considering that the retrofit had not started at the time of the social assessment.

4.11.1.1 Potential social and socio-economic impacts on building residents

Potential impacts on building residents are evaluated by applying the matrix from Table 8 and Table 11, following the indicators identified for this stakeholder group in the operation, maintenance and installation phase of the building. Indicators to be assessed were selected from the lists contained in Table 4, Table 5 and Table 6 based on the **importance of the indicator for the context and for the scope of the project**. Therefore, for the selection, the social hotspot screening, the building context and stakeholder dialogue (see chapters 4.3, 4.5 and 4.9) were crucial steps. The Italian demo building was chosen as a validation case due to the extensive field work and data collection.

Table 12 and Table 13 report results for the operation and maintenance phase respectively, following the color codes and key defined in the matrix from Table 8. For each indicator, it is possible to first check how the current situation (without retrofit) is evaluated (good, indifferent or bad) and the expected impact on the current situation that can be achieved with industrialized and traditional retrofit. The expected impacts with industrialized and traditional scenarios are described in the table to justify the choice of the performance code from the assessment matrix. Indicators that would require further attention in the monitoring phase (see chapter 4.14) (to double check whether the preliminary assessment was correct) are framed in light blue.

Table 14 shows results for the renovation works and installation phase of retrofit technologies. In this case, industrialized impacts are shown in relation to traditional retrofit impacts, by applying the color codes and key from Table 11.

The main findings of the assessment are:

1. Major improvements in physical (e.g. thermal comfort) and psychosocial well-being of residents are expected with both traditional and industrialized retrofit.
2. **Energy bills** are expected to be reduced with traditional and industrialized retrofit due to an improved thermal performance of the envelope.
3. **Control and monitoring of thermal, visual and air quality parameters** can notably improve with industrialized retrofitting, if sensors and adaptable building management systems are implemented (aBMS).
4. **Complexity of systems may increase** with industrialized retrofit, thus leading to disturbance (e.g. noise) during system operation, **challenges for easy dismantling** and higher **maintenance costs** than with traditional renovation technologies. These issues can be

prevented by implementing design for assembly and disassembly (DfA/D) principles at the early stage of design.

5. Retrofit duration, residents' disturbance (noise, dust), relocation risks during renovation are expected to decrease to a large extent with industrialized retrofit.

It is recommended to perform a new evaluation for the defined indicators, once that the retrofit has been completed.

Table 12: Assessment of the building operation impacts on residents with industrialized and traditional retrofit in comparison to the current building status

		Context assessment (current status building – Italian demo)							
Operation phase of the building		**Good**		**Acceptable**		**Bad**		Reason for choice	
Social theme	**Indicator**	IND	TRAD	IND	TRAD	IND	TRAD	IND	TRAD
Thermal well-being	Indoor air temperature (summer)					C	C	building envelope will be completely replaced and guarantee a good thermal performance in winter	
	Indoor air temperature (winter)					C	C	building envelope will be completely replaced and guarantee a good thermal performance in summer, together with ventilation	
	Indoor humidity			B	B			building envelope will be completely replaced and together with ventilation will guarantee humidity conditions (30% winter, 50% summer)	
	Control of thermal comfort at dwelling level			B	E			aBMS will ensure that temperature and other thermal parameters can be controlled by users at dwelling level	Sensors will be installed only for indoor temperature and the heat pump, does not imply a big change of thermal parameters
	Monitor of parameters for thermal comfort at dwelling level			B	E			aBMS will ensure that temperature and other thermal parameters can be displayed by users at dwelling level	Sensors will be installed only for indoor temperature and the heat pump, does not imply a big change of thermal parameters

	Need to change temperature	C	C	building envelope will be completely replaced and designed to guarantee indoor temperature according to standard (19-21°C winter, 25-27°C summer)	building envelope will be completely replaced and designed to guarantee indoor temperature according to standard (19-21°C winter, 25-27°C summer)
Indoor air quality	Ventilation rate	B	B	Ventilation is designed to keep CO_2 concentration below 1000 ppm	
	Risk of mould formation	C	C	Mechanical ventilation together with a renovated building envelope	
	Presence of harmful materials	B	B	All materials for renovation fulfil EU safety standards	
	Control of ventilation by the user	C	F	aBMS will ensure that ventilation parameters can be controlled by users at dwelling level	Ventilation is centralized, users will not have full control per dwelling
	Monitor of parameters for air quality at dwelling level	C	F	aBMS will ensure that IAQ parameters can be displayed to users at dwelling level	Sensors will be installed only for indoor temperature and the heat pump
Acoustic well-being	Soundproofing against noise from outside the building	A	A	building envelope will be completely replaced and guarantee a good sound insulation	
	Noise level due to system technologies	G	D	integration of systems (pipes ventilation, BIPV and BIST) in facade and balconies may result in noise for residents	Systems are not integrated in the envelope, there should be no difference in system noise

Visual comfort	Daylight	A	D			The sun shadings with sensors and Electrochromic windows will better manage daylighting and solar radiation considering external conditions	windows are changed but this will not result in change from current situation
	User control of daylight at dwelling/room level			B	E	Sensors and aBMS will allow controlling of sunscreens and related devices	windows are changed but this will not result in change from current situation
User interaction with building systems	Service disruption of systems			B	E	With sensors planned maintenance becomes easier and this reduces disruptions	No changes expected
	User-friendliness of equipment/systems			H	E	If systems become more complex and integrated and managed partially via BMS, user-friendliness may decrease unless this is taken into account during BMS design	No changes expected, no major user interaction foreseen with systems
	User training for equipment/system operation			H	E	If systems become more complex and integrated and managed partially via BMS, more training is needed, especially for elderly people that are not used to technologies	No changes expected, no major user interaction foreseen with systems
Resistance to unplanned impacts	Structural safety			B	B	This will be guaranteed by the retrofitting technologies	
	Fire safety			B	B	This will be guaranteed by the retrofitting technologies	

Resilience to effects of climate changes	Ability to drain water			B	B			This will be guaranteed by the retrofitting technologies	
	Prevention of facade elements from being detached			B	B			This will be guaranteed by the retrofitting technologies	
	Airtightness against wind					C	C	building envelope will be completely replaced	
	Prevention of snow falling from roof			B	B			This will be guaranteed by the retrofitting technologies	
	Control measures against solar radiation			B	E			The sun shadings with sensors and Electrochromic windows will better manage solar radiation considering external conditions	windows are changed but this will not result in change from current situation
	Air conditioning/ventilation systems			B	B			Mechanical ventilation will be installed	
Aesthetics	Architectural quality of facade			B	B			Architectural quality guaranteed by retrofitting	
	Status of common spaces			E	E			no major changes foreseen	
Psychosocial well-being	Feeling of ownership/attachment	A	A					It can be improved if residents see solved main issues they perceived, e.g. balconies, energy bills, window status	
	Presence of outdoor areas	G	G					Space in the garden can be reduced by technical room for heat pump and storage	

Socio-economic aspects	Cost of energy bills					C	C	Energy bills will decrease because the envelope and the systems will become more efficient	
	Rent fees			E	E			No change, changes will be for the bills and maintenance costs	
	Fuel poverty					C	C	Energy bills will decrease and residents will have a larger amount of income remaining after paying rent+bills	
	Residents´ awareness of energy and environmental issues					C	F	The aBMS will help to visualize consumptions and feel the energy	There will be no changes, only indirect changes due to cheaper bills (the economic dimension will be perceived over the environmental one)
Accessibility and adaptability	Provision and simple operation of control systems					C	F	Control systems are provided through a BMS, for a simple operation, users´ needs should be considered in the design	no changes expected
	simple dismantling / simple separation of components					C	F	DfA/D is applied during the design process, but complexity of systems increases	assembly/disassembly not systematically applied
	Accessibility / easy dismantling of pipes and cables					C	F	DfA/D is applied during the design process, but complexity of systems increases	assembly/disassembly not systematically applied

Socio-environmental issues	Delivered energy demand					C	C	Energy demand and consumption will decrease because of more efficient building envelope and systems
	Total water consumption			E	E			no major changes foreseen

Table 13: Assessment of the building maintenance impacts on residents with industrialized and traditional retrofit in comparison to the current building status

IND = Industrialized; TRAD = Traditional; BMS = Building Management System; IAQ = Indoor Air Quality; DfA/D = Design for Assembly / Disassembly

Maintenance phase of the building		**Context assessment (current status – Italian demo)**							
		Good		**Acceptable**		**Bad**		Reason for choice	
Social theme	**Indicator**	IND	TRAD	IND	TRAD	IND	TRAD	IND	TRAD
User disturbance	Frequency of regular maintenance			H	E			Systems become more complex and may require more maintenance	No changes expected
	Accessibility to systems for maintenance			B	E			DfA/D is applied during the design process, but complexity of systems increases	assembly/disassembly not systematically applied, although accessibility of systems should not be affected

	Service disruption due to regular maintenance	B	E			With sensors, planned maintenance becomes easier and this reduces disruptions, but complexity of systems may increase	No changes expected
User engagement	Complexity of self-maintenance of systems	H	E			If systems become more complex and integrated, maintenance can become complex unless this is taken into account during design	No changes expected, no major user interaction foreseen with systems
	User training for self-maintenance			H	F	If systems become more complex and integrated, more training is needed for maintenance, especially for elderly people that are not used to technologies	No changes expected, no major user interaction foreseen with systems
Socio-economic aspects	Maintenance cost	H	E			Given complexity of systems, maintenance costs may increase	maintenance costs may increase but not affecting overall expenses at a large extent

Table 14: Assessment of industrialized retrofit impacts on residents in comparison to traditional retrofit

Retrofitting (technology installation) phase of the building – Italian demo			Reason for choice	
Social theme	**Indicator**	IND/TRAD	IND	TRAD
User disturbance	Retrofit duration	A	Time for retrofit is reduced	Months
	Need for relocation of residents	A	Not needed	May be needed, e.g. for balconies
	Blocked roads (road access) to building	A	Road access reduced for less time	Access to building blocked for longer time
	Dust level	A	Less operations on site	Assembly of the envelope occurs on site
	Equipment for retrofitting (scaffolding, cranes…)	A	Only cranes and lifting platforms, scaffolding not needed	Scaffolding needed

4.11.1.2 Potential social and socio-economic impacts on local communities, suppliers, workers and society

Due to lack of social data from technology providers, it was not possible to perform a full social LCA for the building demos in INFINITE. As for the stakeholders of local communities, suppliers, workers and society, positive and negative impacts identified during the "stakeholder dialogue" step apply (see 4.9.1.2).

However, to demonstrate how a social life cycle impact assessment can be performed in building retrofitting, a case study is conducted with a focus on the life cycle impacts of an industrialized façade with passive cladding in comparison to a traditional retrofit approach. The test case is the façade of the Italian demo building.

4.11.1.3 Example case study: social impacts of an industrialized timber façade in comparison to a traditional retrofit solution

Social impacts for 15 m² of façade retrofitted for the Italian demo building are compared between traditional and industrialized approaches. Results are calculated with the Social Impacts Weighting Method [31] with the PSILCA 3 database and openLCA.

Selected impact categories based on the previous hotspots screening and Italian building context are presented in Figure 46. 100% is associated to the scenario with the highest impacts; the other scenario is expressed as relative impacts in comparison to the most contributing scenario. A full definition of the impact categories is available in the PSILCA manual [31].

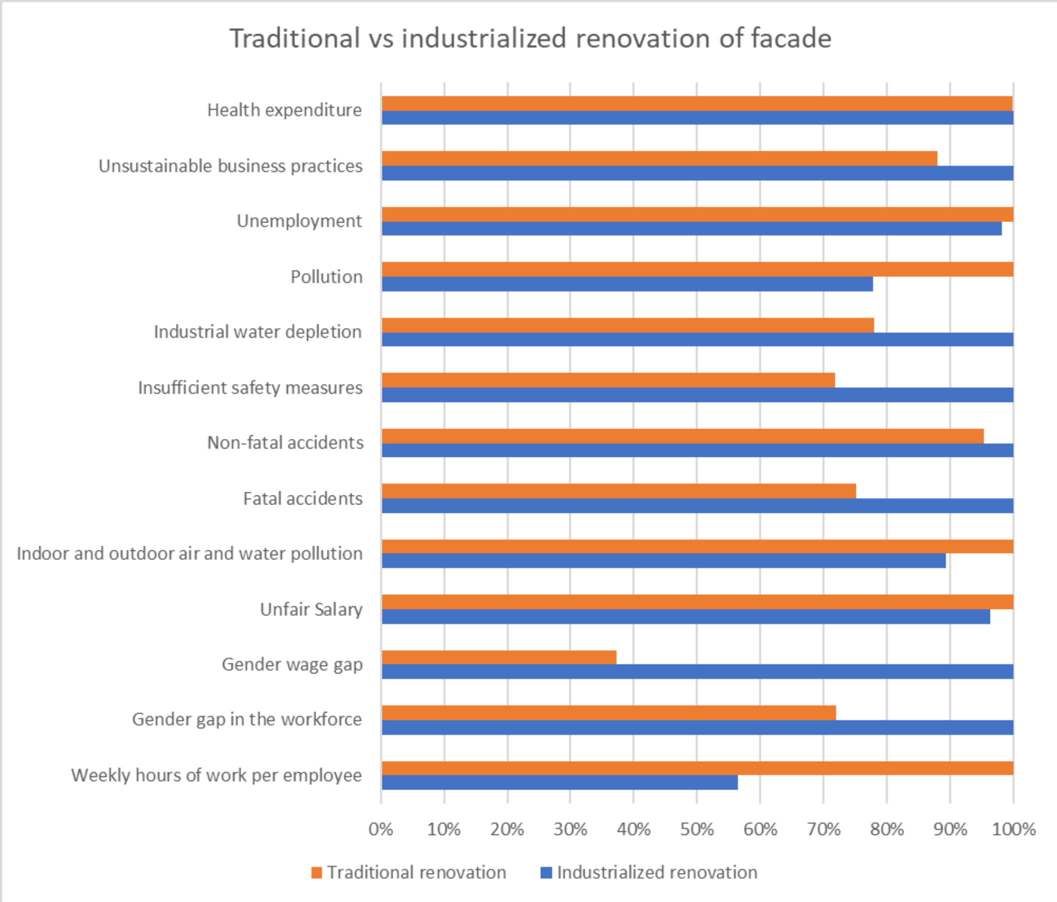


Figure 46: Social impacts comparison between traditional and industrialized renovation for 15 m² of façade

The outcomes show that **it is not possible to highlight one scenario performing better than the other in all categories.** Social impacts of industrialized renovation are lower than the traditional case for **unemployment, pollution, indoor air and water quality at the workplace, unfair salary and weekly hours of work**. On the other hand, traditional renovation shows lower impacts for **gender wage gap and gender gap in the workforce, unsustainable business practices and health and safety** (accidents and safety measures). Some of these outcomes contrast with the expected benefits identified in the workshop and surveys with building stakeholders (see chapter 4.9.1); this shows the **importance of considering whole life cycle impacts**, including supply chains, and not only direct benefits in the technology off-site assembly and installation.

Industrialized renovation impacts are affected by the **additional step of assembly and more complex technologies** (i.e. more materials with higher supply chain impacts). This often results in higher life cycle impacts than traditional retrofit. However, **duration of construction works, renting of equipment and material and waste management on site** are key drivers for the installation phase. Indeed, if only the installation stage of the façade is considered, industrialized retrofit performs better than traditional renovation in all impact categories, see Figure 47.

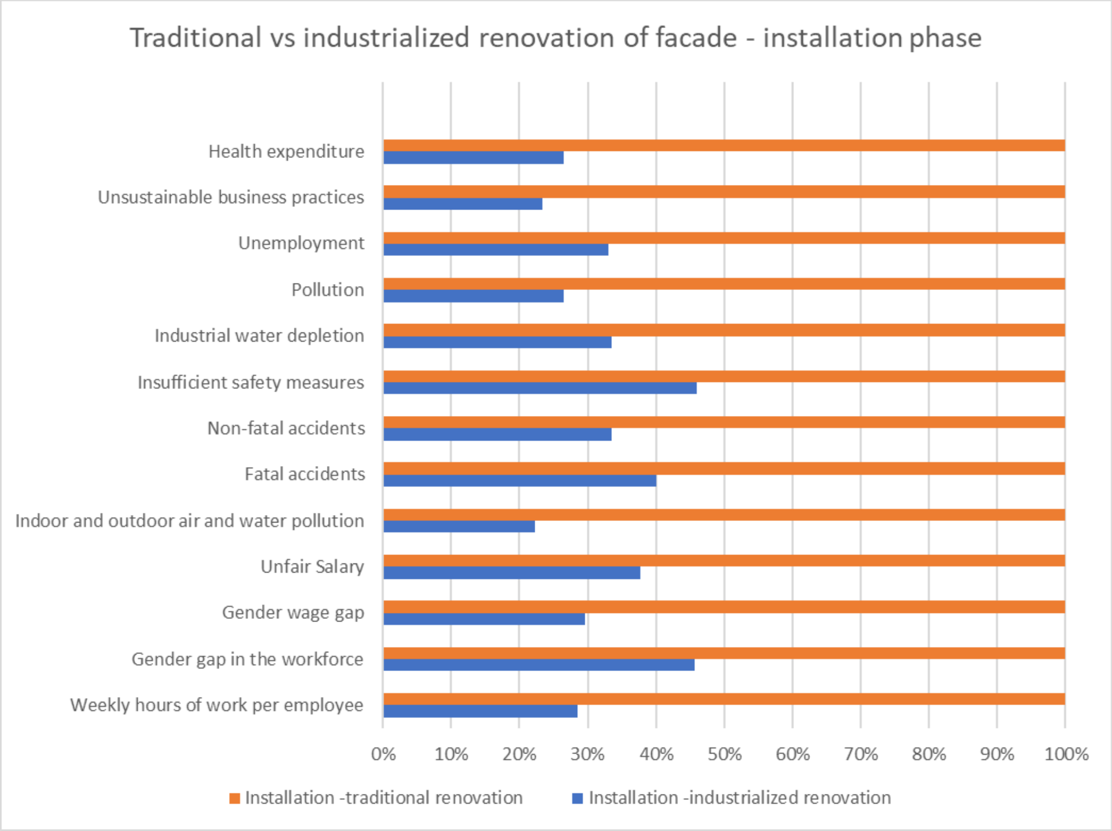


Figure 47: Social impacts comparison between traditional and industrialized renovation for 15 m² of façade – installation phase

Please note that more detailed information was available concerning the location of suppliers of materials for industrialized façade, while components for traditional renovation were assumed to be mostly coming from Italy, due to lack of data. This results in **more widespread impacts for industrialized renovation**, e.g. in Croatia or Asia, see Figure 48.

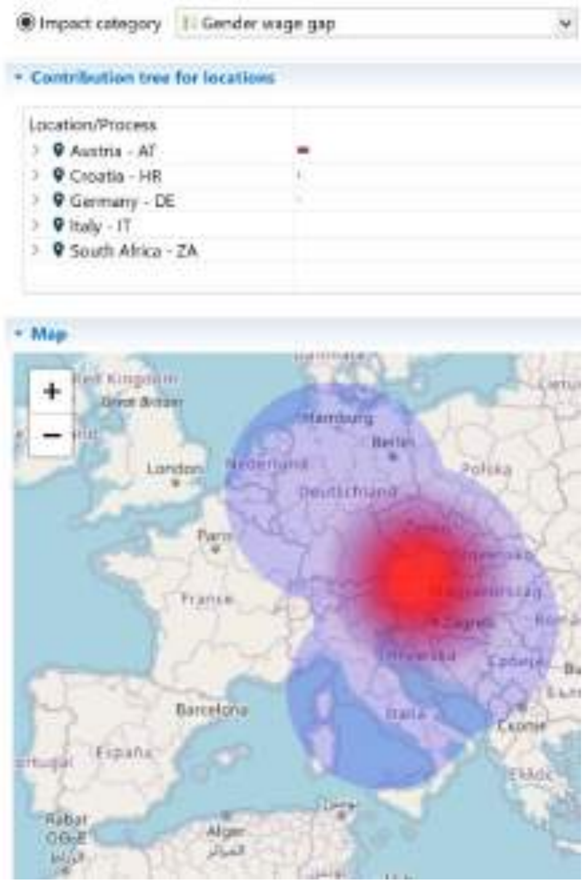


Figure 48: Example of geographic localization for "Gender wage gap" impacts in industrialized retrofit life cycle

It can be concluded that **industrialized retrofit typically shows higher production impacts because of more complex life cycles and the additional assembly step**. On the other hand, **installation impacts are much lower for industrialized retrofit due to less time, materials and waste on site**, i.e. less exposure to the risks. End of life impacts are not significant in any of the two scenarios. As an example, the life cycle contribution is analysed for the categories of fatal accidents and gender wage gap, see Figure 49 and Figure 50 respectively.

Figure 49: Life cycle contribution to risk of fatal accidents – traditional vs industrialized facade renovation

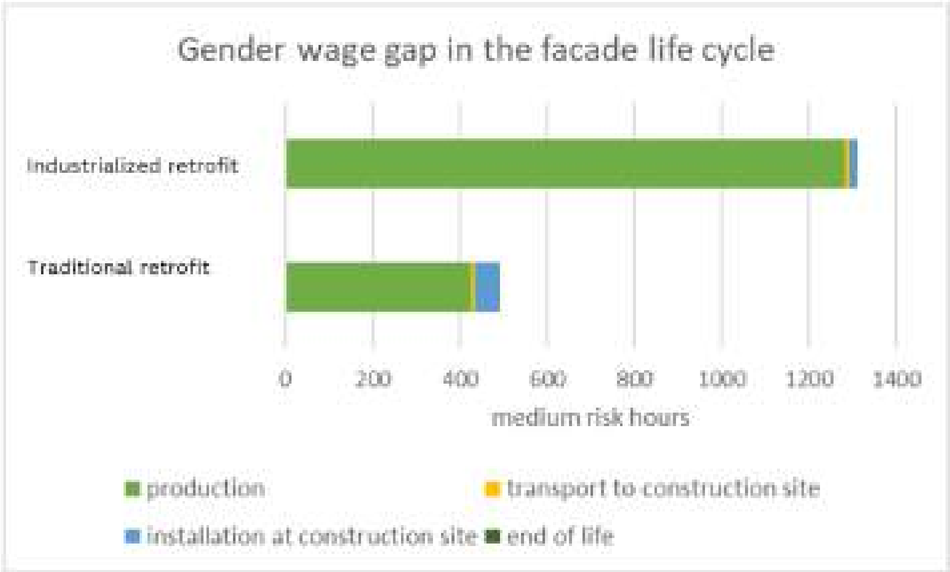
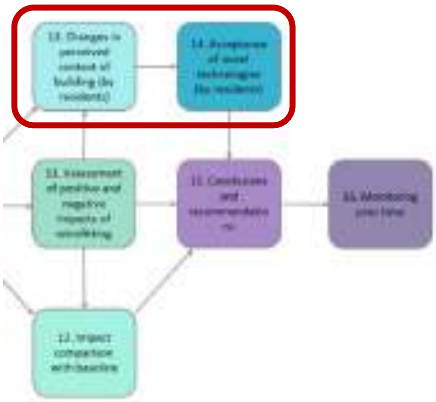


Figure 50: Life cycle contribution to gender wage gap – traditional vs industrialized facade renovation

These results largely depend on the data available in the PSILCA 3 database. Specialized datasets on the production of the specific façade elements in this study could show different results e.g., for the risks of fatal accidents, gender wage gap and gender gap in the workforce.

4.12 Perception and acceptance of novel technologies



Social LCA usually focuses on potential or actual social and socio-economic impacts with the aim of representing the perspective of different stakeholders, but avoiding subjective evaluations. However, when it comes to industrialized retrofit technologies, it appears crucial to **understand how residents perceive and interact with the new technologies** and if renovation can solve current problems experienced in dwellings or at the whole building level. Technology perception and acceptance by residents should be regarded as important as technical performance and “objective” measurable social impacts. Residents will be the first users of the technologies and responsible to use and maintain them correctly. Therefore, **if residents do not understand or appreciate the renovation solutions, it is likely that technologies will not operate in the best possible way**.

Data about perception and changes in perception of problems for the current building status should be collected by involving residents in workshops where technologies are explained in a simple way. Surveys could be also distributed before and after renovation. Data about technology perception and acceptance can be already collected during the field work to investigate the building context, see chapter 4.5.

4.12.1 Application in INFINITE

Perception and acceptance of novel technologies were investigated during the field work in Slovenia and Italy. Interviews with residents could not be conducted for the French case. The next section presents the outcomes of the perception analysis for the Italian demo. Drivers to retrofit acceptance for Slovenia and France are briefly discussed. For more information about field work and conclusions for the Slovenian case, please refer to the public Deliverables D2.2 and D2.3[7].

4.12.1.1 The Italian demo case

Preliminary perception about new technologies (based on field work with residents)

[7] INFINITE building renovation website: https://infinitebuildingrenovation.eu/

It is important to note that, as most of the residents are quite old, **familiarity with technologies is poor**. Residents have a mobile phone where they can use basic functions to receive and make calls and TVs. Furthermore, residents do not appear to be overall interested in technologies as they were born and grew up in times where technology did not exist yet. **Many residents are not familiar with checking thermostat nor the energy consumption from energy bills**. Younger residents, instead, have many technology appliances and are open to novelties that can be introduced with INFINITE, such as the possibility to monitor and control temperature and other indoor parameters.

It is also important to note that many residents have a wood stove and enjoy using gas for cooking. Furthermore, wood stove was reported to be used to heat water for meal preparation and to hang up clothes to dry in winter. Also, although inhabitants are not happy with the heating performance, **it could be problematic to change from radiators to air-based heating, as these people have been using radiators for 30 years or longer**.

As for INFINITE technologies, most of the residents did not know about them, e.g. photovoltaic, green envelope. But when explained, they were quite **interested in the novelty** and gave their opinion as far as they understood the technology. Younger people were more familiar with the technologies, especially photovoltaic. For all technologies, **the motivation of reducing energy costs was well-understood by the residents.**

Photovoltaic panels and smart windows encountered the most positive reactions among the interviewees. In the first case, this was because of the clear link with clean energy generation and cost saving; in the second case, there was quite some curiosity around the technology, although residents stressed that they liked having the **possibility to keep windows open and to look outside** (through transparent glass). Furthermore, some residents have sun shades (awning) and they would not be happy to see them removed. The ventilation concept should also take into account that residents are used and enjoy controlling natural ventilation. Noise from ventilation system was also reported as a concern.

As for **green envelope**, residents were afraid of maintenance costs, humidity and animals that could make their nest in the green roof or façade. In general, residents were not particularly interested in the appearance of the façade.

Finally, it is interesting to report that old residents of a dwelling have monitoring displays in at least two rooms. These were given as a present by their children and they liked that they can see temperature, humidity and especially weather forecast. In general, **involving younger relatives of old inhabitants to explain and use the novel technologies is recommended**, considering that this is already a common practice for anything related to technologies and technology appliances.

Drivers for retrofitting acceptance

New balconies and the improvement of the temperature in summer and winter are suggested as the main aspects to be communicated to the building inhabitants. Sustainability and environmental issues do not appear to be perceived by the residents. However, energy saving is understood to be linked to **saving energy bill costs** and can be an important driver to technology acceptance. **Younger inhabitants seem to be more sensitive to the topics of waste, energy saving and environmental issues,** although this is often understood through the related economic implications.

Too complex topics may be unclear to the residents and, in general, they are not interested in getting too many insights about the technologies, they mainly want to see the results and see their problems solved.

Residents showed a good relationship with building managers and among them (except for the case of an argument among two tenants because of the respective noise). It seems that if there is **trust** and **if residents understand the value/reason of INFINITE work in the project**, then they are more open and happy to give a contribution. Talking about complex topics and issues may result in being unclear and in ruining a relation of trust with the residents, therefore it would make sense to be clear and simple, but still professional (which contributes to creating trust between the residents, building managers and the INFINITE researchers).

Overall, all residents seem happy with the building and dwelling, because they have always lived there and created their families. Dwellings appear cozy and nice places, where, although people do not get a high pension, they still make their best to have a nice and comfortable home. It looks as if people are attached and care about their homes, this is also why they have complaints about smaller issues that they see (e.g. windows' frame, balconies' plaster, plaster in the living room...). **Windows, temperature in winter and summer and balconies are the main problems reported by the residents, while the garden and the kitchen appear to be the main positive aspects**. Residents do not seem to take care about the appearance of building and they are already happy with that. These are old people that have been living there for many years and are used to certain things and the way their life takes place. Changing this could not make them happy, unless they understand that some technologies are introduced or some changes are made to achieve further benefits for them. For instance, removing the radiators the gas stove for cooking may not be well. **Improving something that they see as a problem (e.g. balconies) could have quite some impact.**

People will be happy if problems are solved or improved, if costs are reduced, if the new technologies are not complex. This type of users will not be able to use complex systems. The argument of sustainability or energy saving does not appear an important point for technology acceptance, unless this is linked to or explained as a way to save energy costs.

Finally, it is important to think that **in 5-10 years the tenants of flat may be completely different from the current ones and with very different needs and understanding of technologies**.

4.12.1.2 The French demo case

Drivers for retrofitting acceptance (based on interview with building managers)

Cost savings for energy bills can be an important driver for acceptance. However, the building manager also plans to address the environmental benefits of INFINITE renovation when introducing the INFINITE solutions. Furthermore, **too complex technologies (for instance smart windows) may be a barrier to renovation acceptance, if not adequately explained**. Improved thermal performance (through insulation and better heating system) and refurbishment of windows are the main topics to be communicated to residents. Renovation of common spaces, such as staircases and elevators, will also contribute to a better acceptance of retrofitting works.

4.12.1.3 The Slovenian demo case

Drivers for retrofitting acceptance (based on interview with building managers)

Lower energy cost can be one of the main drivers to renovation acceptance. In addition to that, **improved windows, ventilation and larger balconies** will indeed be well perceived by the residents. Finally, presenting and explaining the novel technologies to tenants can call for a sense of satisfaction to live in a special place full of innovation. It is also important to discuss with residents about the opportunity given by this European project to **bring the state of the art of EU research and industrial innovation** to a town which is usually not included in such large European projects.

4.13 Conclusions and recommendations

This step is expected to summarize the outcomes of the social impacts on different stakeholders part of the investigated system, as stand-alone and in comparison to baseline situations. **Recommendations** should also complement this section to propose **solutions to mitigate negative impacts and maximize positive aspects**. Furthermore, **suggestions to improve technology acceptance** by residents should also be summarized in this step. To define recommendations and suggestions, it can be valuable to involve partners, designers and technology manufacturers at the early stage of design to propose improvement actions that are technically and economically feasible.

4.13.1 Application in INFINITE

Based on the social assessment in the project, the following conclusions and recommendations can be made to improve the social performance of industrialized retrofit solutions:

- **Health and safety** is expected to improve at building construction sites with industrialization, as this would reduce exposure to risks related to material and waste movement and management. Furthermore, time spent by workers for on-site activities will be reduced and scaffolding may not be required anymore, thus reducing the risk of fatal and non-fatal accidents at workplaces. On the other hand, if technology assembly is moved from building sites to industrial plants, there may be a **lack of skilled workers** for off-site assembly of new and more complex solutions. **Training and visual guidelines** for workers are recommended to make sure that safety issues are not shifted to the off-site assembly site.

- To show benefits of industrialized renovation it is important to have **market data** to show a comparison with a **benchmark** and added value with industrialized renovation, especially for private housing.
- Industrialized renovation is expected to **reduce disturbance** for residents due to less works that need to be performed on site.
- Conditions/actions to make industrialized renovation streamlines include **policies and commitment of local and national authorities with subsidies**. Industrialized renovation must be **upscaled** at neighbourhood level to increase demonstration and perception of benefits.
- **Employment** can be a challenging topic to assess for industrialized renovation, because there is the risk that benefits are concentrated in the locations where the factories are (e.g. due to delocalization),; it could be considered to perform the last steps of prefabrication within the local community.
- **Maintenance costs** are a hotspot industrialized renovation, as technologies become more complex and may require more maintenance. However, maintenance could be desiged as more predictable thanks to the use of sensors and building management systems.
- **A life cycle approach is recommended.** If direct benefits can be achieved with industrialized retrofit in the technology assembly and installation stages, complexity of technologies can **increase supply chain impacts** in the production stage, as more materials need to be produced and outsourced (also from global supply chains).

To increase industrialized technology acceptance by residents, the following recommendations can be made:

- Pay attention to complexity of technologies: involve residents in their design and testing and organize **trainings when technologies are installed** (also involving relatives of older residents).
- Include the **display** of parameters interesting for residents, e.g. weather forecasts, to increase the interest in new systems.
- **Promote benefits of technologies.** Visualization of **energy savings** can help people in the acceptance of technologies, e.g. display relation between energy and energy bills.
- **Calm technology principle**: residents should not fear to be controlled by technologies or that they do not have any influence over them. Allow for customization of how and when technologies should operate.

4.14 Monitoring over time

The last monitoring step is important to **verify whether expected social and socio-economic impacts occurred in the retrofit value chain**. It is recommended to perform monitoring at different points of time, for instance after one and five years after renovation. Monitoring foresees an **update of the data collection** performed for the preliminary social assessment (see Chapter 4.10) and should again involve different stakeholders, such as residents, technology manufacturers and building managers.

4.14.1.1 Application in INFINITE

Monitoring was not possible at the time of writing the report, as renovation had not started. However, monitoring after retrofit is foreseen for the three demo cases through the same sensors used before renovation for the pre-monitoring phase for CO_2 concentration, occupancy rate, temperature and humidity. It is recommended to **perform interviews or distribute surveys** to the **building residents** to investigate their **perception about the renovation works and the installed technologies and if problems identified before renovation still persist**. Monitoring over time should also be used to refine the assessment results calculated before renovation.

5. Conclusions and further outlook

A **step-by-step methodology** for the assessment of social sustainability of industrialized retrofitting has been defined; the methodology has been validated with the INFINITE project, with a focus on the Italian demo case.

The methodology enables the consideration of **different stakeholders** involved in retrofitting, for instance residents, workers, local communities.

It is recommended to **combine different approaches** for the investigation of social impacts of retrofitting, such as social life cycle assessment, use of existing databases for social analysis, literature review, field work.

Field work (interviews with local facility mangers, inhabitants and observation) and close work with social scientists is crucial for the context analysis of the buildings under renovation.

The three INFINITE real demo buildings have been extensively studied through different kind of activities and **a good picture of inhabitants and buildings current status** is now available.

The **social topics** significant for the different stakeholders under study in the renovation process have been identified; for the different topics, **specific indicators** have been developed for the "residents" category, indicators for the other stakeholders (workers, value chain actors…) were instead taken from the PSILCA database for social LCA.

For each indicator, a quantitative, semi-quantitative or qualitative assessment is proposed. An **assessment matrix** with color codes was developed to overcome limitations related to lack of quantitative data.

Based on the methodology application, **INFINITE has shown the potential to**:

- improve **health and safety** conditions for **workers** in the construction industry;
- improve **living conditions of local communities,** if less polluting manufacturing processes for construction solutions are implemented;
- improve **well-being of residents**, e.g. considering thermal well-being, happiness to live in the building, air quality;
- be more easily accepted by residents if their needs and expectations are taken into account, if technologies are simple and user-friendly, if overall costs are reduced (rent + energy bills).

Maintenance costs, complexity of technologies and employment are challenging topics that deserve further investigation.

It is crucial to include a life cycle perspective in the analysis, as it could be that direct benefits (e.g. safety at the work place or gender balance in the workforce) are achieved for industrialized technology assembly and installation, while other burdens are still associated or shifted to supply chains for the production of industrialized components. Indeed, industrialized technologies are expected to be more complex, i.e. requiring more materials and from more widespread supply chains.

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Annex 1: Resident survey template

QUESTIONNAIRE FOR BUILDING RESIDENTS

This questionnaire has been developed in the INFINITE project funded by the European Commission. The project aims at shaping how we should renovate buildings in the future: in short time, with sustainable solutions and involving building residents.
The questionnaire is anonymous and will serve to understand and consider residents 'needs and expectations. ***Thank you for your precious time!***

GENERAL INFORMATION

1. What is your age?

☐18-30 ☐ 31-45 ☐ 46-60 ☐61-75 ☐older than >75 years old

2. How many persons live in the dwelling (including you)?

Adults: Children:

3. How many years have you been living in the current dwelling?

☐less than 5 ☐ 5-15 ☐ 16-30 ☐31-40 ☐>40 years

4. How happy are you to live in your dwelling?

☐very happy ☐ happy ☐ neutral ☐not happy ☐not happy at all

5. What do you like the most in your dwelling and building?

____
____

6. What do you like the least in your dwelling and building?

____
____

7. How do you rate the energy bills you pay?

☐very high ☐ high ☐ ok ☐low ☐very low

8. How interested are you in environmental issues and energy savings?

☐very interested ☐ interested ☐ neither nor ☐not interested
☐not interested at all

YOUR BUILDING AND DWELLING

9. In winter, how do you perceive the temperature in your dwelling…?

☐hot (discomfort) ☐ warm (slight discomfort) ☐ ok (comfortable)
☐cool (slight discomfort) ☐cold (discomfort)

10. In summer, how do you perceive the temperature in your dwelling…?

☐hot (discomfort) ☐ warm (slight discomfort) ☐ ok (comfortable)
☐cool (slight discomfort) ☐cold (discomfort)

11. How do you perceive the indoor air quality in your dwelling…?

☐clearly acceptable ☐ acceptable ☐ neutral ☐unacceptable
☐clearly unacceptable

12. How do you perceive the noise level in your dwelling…?

☐clearly acceptable ☐ acceptable ☐ neutral ☐unacceptable
☐clearly unacceptable

13. Do you have any of the following issues in your dwelling? Multiple answers possible.

☐stuffy air ☐ unpleasant smell ☐ mold ☐noise from outside
☐noise from other dwellings ☐noise from common parts (e.g. staircase) ☐glare
☐noise from technical systems ☐too much daylight ☐too little daylight
☐other: ______________________________

14. In the event of building retrofitting, what would be a priority for you…? Multiple answers possible.

Renovation/Improvement of….

☐heating system ☐ balcony ☐ ventilation ☐indoor air quality
☐windows ☐building appearance ☐common parts (e.g. staircase)
☐other:______________________________

15. In the event of building renovation, how important would be the following issues?

Minimization of…	Very important	Important	Neutral	Not important	Not important at all
Noise	☐	☐	☐	☐	☐
Dust	☐	☐	☐	☐	☐
Duration of works	☐	☐	☐	☐	☐
Other: __________	☐	☐	☐	☐	☐