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El cubo de armonización HSB Living Lab

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ABSTRACT

Living Labs are fast emerging instruments for advancing user-centred innovations in various areas of human activities. Due to their large diversity in terms of thematic approaches, constellations, practices, outcomes and longevity, various methodologies have been proposed to describe and link living labs in a consistent way. The theory has so far seen few applications. The strength of the present work is that it uses an existing and comprehensive methodology, entitled Living Labs Harmonization Cube (LLHC), on a concrete and relevant example – HSB Living Lab. The characterization of HSB Living Lab by LLHC is based on the authors' personal experience in the design, management and operation of this living lab for the last three years, which is supported by examples. The results show that HSB Living Lab has not yet reached full maturity in any of the six categories included in LLHC and identifies areas for future development.

Keywords: HSB Living Lab, living lab harmonization cube, innovations, co-creation, co-design

RESUMEN

Los Living Labs están emergiendo como instrumentos de innovación en actividades centradas en el usuario. Debido al variado rango de enfoques, constelaciones, prácticas, resultados y longevidad, igualmente variadas metodologías se han usado para describir los Living Labs. Pero estas metodologías pocas veces se han llevado a la práctica. La importancia del trabajo presentado en este artículo reside en que pone en práctica una metodología extensa y establecida, llamada "'Living Labs Harmonization Cube' (LLHC)", con un ejemplo concreto y relevante: el HSB Living Lab. La caracterización del HSB Living Lab según la metodología LLHC se basa en la experiencia personal de los autores durante el diseño, gestión y mantenimiento de este laboratorio en los tres últimos años, y se ilustra con ejemplos. Los resultados indican que HSB Living Lab aún no ha alcanzado la madurez en ninguna de las seis categorías de la metodología LLHC y permiten identificar áreas de mejora.

Palabras clave: *HSB Living Lab, living lab harmonization cube, innovaciones, co-creación, co-diseño*

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1. INTRODUCTION

Living Labs are relatively new but fast emerging instruments for advancing user-centred innovations in various areas of human activities. These primarily experimental environments, physical or virtual, are characterized by real-world conditions for ideation, prototyping and testing of innovations, e.g. inventions and associated business models through which they will be promoted at the market, as well as by methods for active involvement of users in the innovation process. Unlike conventional experimental environments, in living labs end-users are engaged as equal contributors to the innovation activities along with experts, rather than as being merely objects of experts' observations. This approach is then called co-creation. Due to this, living labs require adequate governance and management organizations that support collaborative efforts in terms of open-innovation projects and intellectual property rights.

Since the 2000s more than 300 living labs have been registered in Europe, (1). Reasons for this fast expansion of living labs can be found in a general understanding that user-driven innovations have greater success in meeting the needs of the market (2), which is also reflected in targeted support of living lab development by the European Commission, (3), as well as in other international initiatives like the Climate Knowledge and Innovation Community (Climate-KIC) initiated by the European Institute of Innovation and Technologies (4).

The practice of collective creativity, a forerunner to co-creation, started in the 1970s. Norway, Denmark and Sweden were leaders in implementing so-called participatory design as an approach for increasing the value of industrial production (5), (6). The user-centred design of working environments from the 1970s became a widespread approach for design and development of consumer products in the 1990s, (7), (8). Massachusetts Institute of Technology (MIT) in Boston was the first to introduce education facilities for students to perform real-world projects, which expanded later to living labs (9).

Market and business circumstances have greatly changed since the 1990s due to, among others, the rapid development of IT technologies as well as an increased awareness of environmental problems. Today, new business opportunities are found in global challenges such as climate and demographic changes, supply of fresh water and energy, but also in high quality and more personalized products and services. The construction sector is a particularly attractive area for innovations because of its large environmental impact. The building industry alone consumes about 24 % of the world's extracted raw materials (10) and about one third (11) of the world's energy consumption is utilized by buildings during the operation phase. The building industry also generates a relevant percentage of airborne particulate matter and landfill waste. Energy renovation of existing buildings in Europe is seen as a strategic measure to decrease the environmental impact of this sector (12). Despite a vast number of validated and economically valuable measures and technologies for improving the energy efficiency of buildings in the European context (13), the rate of energy renovation of buildings in Europe is low (14). This conclusion is not new (15), implying that programmes of technology transfers in general, even when they are promoting cost-effective solutions, are not powerful enough to transfer the knowledge from the building research into the building practice. It is thus suggested to consider socio-technical reasons behind the low rate of implementing energy efficiency measures in buildings, and to consider a technical change as a societal process (15).

User behaviour is an important factor in any social structuring of technical innovations (16), (17), (18), (19); at the same time it is difficult to model and generalize. Hence, living labs become important instruments for revealing the impact of priorities and lifestyles of end-users on the adoption or rejection of measures for sustainable homes. The recently opened HSB Living Lab was built with similar aims, while the focus is on student housing in urban areas. Its thematic area, infrastructure, practice and governance were developed in a co-creation process during which various interests of stakeholders were carefully gathered, evaluated and harmonized. As such it is a unique example of a collaborative research and development facility whose characteristics are evaluated in this work by the Living Labs Harmonization Cube (LLHC) suggested by (20).

Given the increasing attention and the accompanying monetary support to living labs, there is a need for a unified methodology of describing living labs with which it would be possible to predict their capacity to produce tangible outcomes, i.e. inventions adopted by markets, as well as to direct the research and investments in their development and operation. While the academic literature provides multiple methods for the description and characterization of living labs (9), (21), (22), (23), (24), the theory has so far seen few applications. The strength of the present work is that it applies an existing theory – LLHC, on a concrete and relevant example – HSB Living Lab. Besides, this living lab was developed without previous knowledge about LLHC, which provides conditions for unbiased application of LLHC. Furthermore, LLHC covers certain qualities of living labs, e.g. governance, which are missing in other methods. Finally, the assessment is based on the authors' personal experience in the design, management and operation of this living lab over the last three years.

1.1. The Building

HSB Living Lab is a five-storey building at the Chalmers University campus Johanneberg in Gothenburg, Sweden. With its 29 apartments for up to 40 tenants and net floor area of 1720 m², the building functions both as a student residence and a research infrastructure. For the latter, there are research facilities that allow investigations focused on social norms and living patterns as well as technical measures to change these towards more sustainable living. In addition, the building provides a sensor network to measure the quality of indoor environment, tag-based movement of objects, generation of waste, consumption of energy and water, as well as facilities for prototyping and demonstration of home facilities, IT solutions and building technologies.

In terms of energy use and the quality of indoor environment, the building has been designed to fulfil grade silver of the Swedish certification system Green Building (25), which is a middle grade between the basic requirements set by the Swedish building authorities (26) and the highest grade in the Swedish Green building certification system. It was a deliberate decision not to build a building that fulfils the highest standards for low energy buildings for two reasons: it would not bring innovations, merely only demonstrate the techniques that already exist, but also because the building will undergo various physical changes during its lifetime that would affect these performances. Other building qualities and the design process behind them are presented in sections 2 to 4.

HSB Living Lab is a part of the EU's initiative Climate-KIC and its flagship programme Building Technologies Accelerator (4).

1.2. The Living Lab Harmonization Cube – LLHC

Common methodologies for describing and assessing living labs are needed for two reasons: to share experiences and tools between the living labs (20), as well as to link the key characteristics of living labs with their tangible outcomes (9). The latter is particularly important for directing the research and investments into living labs, as well as for enhancing their relevance and longevity.

LLHC method was developed within ENoLL network (20) as a discussion facilitator between living labs on topics about sharing experiences and tools. The method addresses the following six aspects of a living lab: User involvement, Service creation, Infrastructure, Governance, Innovation outcomes, and Methods and Tools. Each aspect, corresponding to one side of the cube, is further split in a 3x3 matrix. The rows in a matrix, from top down, cover three development phases of the living lab: setup, sustainability and scalability, while the columns, left to right, indicate organizational, contextual and technological issues of the living lab, as shown in Table 1. Further details of the cube are presented in section 5. The more elements on the cube can be associated with a living lab, the more values a living lab has to exchange with other living labs in terms of knowledge, experiences, facilities, etc. The method involves a self-assessment and self-positioning of a living lab in comparison to other living labs.

The seventh criterion was suggested later to LLHC in order to identify the contribution of a living lab to the innovations generated within small and medium size enterprises (SME), (27). The SME-innovation criterion could be interpreted as a link between the key characteristics of the living lab and its tangible outcomes, which (9) is identified as missing in LLHC and other methods. This is further discussed in section 5.

1.3. The layout of the paper

Events and decisions that have led to the establishment of HSB Living Lab are summarized in section 2, in order to provide inputs for the LLHC assessment in the categories Service Creation and Governance. Section 3 provides examples of User involvements in a co-creation process as wells as Methods and tools and Innovation outcomes that have been tested in HSB Living Lab. The research Infrastructure is presented in section 4. Finally, the overall assessment of HSB Living Lab in all six categories of LLHC is presented in section 5, together with a short discussion on its impact on SME-innovations.

2. MAIN STAKEHOLDERS AND BUSINESS MODELS

Literature on the living labs methodology emphasizes the importance of active and harmonized involvement of the main stakeholders in the innovation process: companies, end-users, public organizations and researchers, see e.g. (24). A general idea with this so-called quadruple helix approach is to expand individual value-chain concepts into an interconnected system of values. Interests and motivations of each of the main partners should be built up around products or services that are useful (needed), usable (understandable) and desirable (wanted), as described by (7), and that are in accordance with the targets for sustainable development. However, due to these qualities living labs may become rather challenging organizations, both management and resource wise. Since there is not much information in literature about how the gathering of the main stakeholders happens in reality, the next section presents key events that have led to the HSB Living Lab.

2.1. Strategic partnership between the university and the building owner

The idea of creating a living lab infrastructure has been brought to Chalmers through two research projects: SusLab North-West Europe (28) and Homes for Tomorrow (29). The former introduced living labs as research instruments and the latter set up a framework for collaborative and transdisciplinary research on sustainable building, construction, and living. However, the major impetus in form of both the living lab methodology and financial support to collaborative research efforts between the academia and industry came through the initiation of a Climate-KIC supported flagship project, entitled Building Technologies Accelerator.

From the building owner perspective, the following circumstances played decisive roles: a long-term shortage of student housing in Gothenburg, difficulties in obtaining building permissions in central area of the city and a long-term commitment of the company to sustainable development. The business opportunity has been found in temporal student housing placed at the university campus and serving as both home and research infrastructure.

A strategic partnership between the Chalmers University of Technology and the building owner HSB was made in order to build a living lab to act as both student housing and a research infrastructure. In order to address the above-mentioned challenges with student housing in Gothenburg, it was decided to utilize the building during a 10-year period, after which it shall be moved to another place. Therefore, a modular building was proposed, whose modules would be fully manufactured in a factory and assembled at the building site.

2.2. Business model for the co-design and utilization of the building

The size of the building and the number of tenants were the only constraints set by the building owner with regard to economics and available building space. Other building qualities such as: shape and layout, content and function of private, common and public areas, construction materials and technologies, environmental performances, choice of tenants and research facilities were co-designed by a project team composed of building design professionals, researchers and potential tenants.

In the partnership between the building owner and the university, the role of academia is defined in a separate contract.

Table 1. Results of self-assessment of HSB Living Lab by LLHC.

	Organisational issues	Contextual issues	Technological issues			
	User involvement			**Service creation**		
setup	get users involved	type of users, effort, expectations required	provide tools to have users involved	organisation, training	idea generation, business support services	Communication services
sustainability	keep users motivated	need for unobtrusive methods	automatic data collection	governance	idea generation, services specific to stakeholders	collaboration services
scalability	different approaches for different users	knowledge on cultural and legal differences	need for low cost observation methods	management	market customization	Demonstration, validation prototyping

Governance			**Infrastructure**		
Commitment & responsibilities	to deploy collaboration practice	selected infrastructure providers	infrastructure used to deploy first defined scenarios	Ownership drivers / management structure	Management working practices
Financing service selection	collaborative infrastructure	best fitting infrastructures with environment	interoperable/ standardized infra-structures	Funding strategy dynamics	Sharing resources & infrastructure
Business models	collaborative infrastructures in e.g. ENoLL*	infrastructures to be adapted to other environments	most used infrastru-ctures	Extensions (services, partners, users)	Operational excellence

Innovation outcomes			**Methods & tools**		
Innovation, expertise, competencies	Target market, value for stakeholders	Innovation-supportive environments, idea, patent	Taxonomy of methods & tools	Appropriate methods for LL available	Technology support for methods & tools
IPR early phase innovation	Optimal degree of interaction, context sensitive	Supporting optimal interaction	Methods & tools are institutionalized	LL methods	Technologies are implemented
Involvement of experts, stakeholders	Extendable context, target market	Massively distributed, multi-user environment	Methods & tools are exchanged in e.g. ENoLL	Pan-European LL projects – sharing best practices	New technologies / possibilities through e.g. ENoLL

*or any other network of living labs

The research project manager, Shea Hagy, supported the building design team on issues related to research and co-creation, while the topics related to novel building technologies and integrative sensor network were supported by the other two authors of this work. Besides this, the accelerator hub named Johanneberg Science Park took the role of linking all involved partners but also future users within a business network and fundraising initiatives.

In order to secure a long-term commitment to the building design and its utilization as a living lab research infrastructure, the building owner set up a particular business model with the project partners. These were selected among renowned building design professionals, i.e. architects, construction and service engineers, with whom the building owner made successful partnerships in other building projects. By accepting the invitation to the project group, each company accepted to pay an annual fee and to allocate in-kind support to the project consortium during the life-time of the living lab - twelve years in total. The project fund, thereby created, works through seeding future innovation projects driven by the project partners. Conditions for the partnership had been to share the common interest with the building owner in respect to student housing and sustainability aspects as well as to contribute with a professional and inspiring role in the project consortium. The latter has prevented unnecessary competition between the project partners. The project group has gradually grown and today there are nine partners representing architecture, building contractor, building lot owner, HVAC designers, IT consultants, energy supplier, as well as producers of domestic appliances, kitchen and bathroom furniture, and storage.

2.3. Focus areas for future innovations

The joint work was organized in thematic working groups, both for designing research topics and the actual building, around the following focus areas:

- Building materials and technologies
- Minimization of resources
- Multifunctional common spaces
- Accessibility
- New production process
- Future housing association

Dozens of workshops and meetings have been organized around these subjects and more than 100 innovation projects have been identified. Some workshops were deliberately conducted as public-open co-creation events for various stakeholders, including students, local residents, academia, industry and officials of local administration.

Some past co-creation workshops include:

- Next generation clothing and laundry systems (2014)
- Project application and evaluation process (2014)

Next generation kitchen: Closing loop (2015) and Bio-Blender (2016)

- Upcycling workshop: Share Hub and Swap Cube (2016)
- Drive me (2016)

The co-creation workshop on the subject 'Next generation Laundry' produced some first innovation solutions for the living lab, i.e. refreshment cupboards and a multifunctional laundry, which were then co-designed by the project team and finally put in use in the house. Therefore, this particular co-creation process is described in more detail in the next section.

3. CO-CREATION AND CO-DESIGN OF THE LAUNDRY

The co-creation workshops that were organized for the purpose of defining HSB Living Lab were initiated and facilitated by the researchers from Chalmers who, besides contributing with expert knowledge on subjects covered in the workshops, developed an approach to introduce and guide other participants into the design process. The approach usually incorporated leading questions, informative and inspiring lectures by various experts, group design, presentation and documentation of new ideas. The main challenge was to formulate the leading questions that would focus participants on the purpose of a certain activity and then on products and technologies needed for this activity, as exemplified on the design of the laundry.

3.1. Co-creation of the laundry studio

On February 3rd and 4th, 2014, a co-creation workshop on the subject 'Next Generation Clothing and Laundry Systems' was organized at Chalmers with the aim of generating innovative ideas for water and energy saving solutions for clothes washing by considering how washing relates to other daily activities. About 35 participants attended the workshop including students, Chalmers researchers, officials from HSB and the living lab partners.

The co-creation workshop at Chalmers was running in parallel with another workshop in Houston, Texas where officials from NASA Johnson Space Center, Houston, and students from Rice University, Houston, were engaged in the same initiative. The researchers from Chalmers and officials from NASA brought to the workshop practices and theories of washing on Earth and in resource-scarce environments such as in space expeditions, respectively. These were then turned into guiding questions for the participants to bring them into the design process and to generate new ideas surrounding social and technological aspect of clothes washing such as:

- What is 'clean' / 'dirty'?
- Would you want to wear something seen as very dirty (by someone else)?
- Is there a guarantee for the cleanliness?

Clothing that doesn't look dirty and that smells fresh would allow the participants to wear it again, i.e. to postpone the washing. This result was the seed for refreshment cabinets, i.e. wardrobes with built-in channels for supply of fresh air where clothes could be aired while stored.

In a similar way, the following issues of conventional laundry were identified, e.g. boring, time consuming, resource inefficient – take space, energy for conditioning and people for cleaning. Discussions around how to solve these issues resulted into another concrete invention for HSB Living Lab: the washing studio, a hybrid between the laundry room and the meeting room placed in the entrance hall of HSB Living Lab, (see Figure 1).

3.2. Co-design of the laundry studio

The co-creation workshop on the next generation laundry proved that people are creative and capable to act as experts of their own experience (6). Nevertheless, the actual technical design of the multifunctional laundry and of the refreshment cabinets was conducted by professionals gathered in the project design team of the living lab. This implies that not all people can be designers because they may lack knowledge, conditions, tools or resources for design.

The technical solutions for the laundry were basically found by using well-known products and technologies, e.g. washing machines, sound barriers, built in ventilation ducts, sofas, and similar. However, the placement of the laundry in the entrance hall posed some new challenges in respect to the requirement on indoor environmental quality: to limit the noise and vibrations during washing, to quickly and safely remove water leakages, to prevent the smell of washing powder, to minimize the risk of fire in case of electrical short-circuits, and similar. Given that all these requirements have been fully solved, the conclusion could be drawn that there are no technological barriers for placing laundry functions in entrance halls but that the requirements for this particular part of the building should be revised.

3.3. Usage of the laundry studio

The multifunctional laundry at the entrance of HSB Living Lab provokes different reactions to first-time visitors, who generally agree that this solution saves substantial space in the building, without jeopardizing the indoor environmental

Figure 1. To the left: the multifunctional laundry placed as in the entrance hall of HSB Living Lab. To the right: the final design of the refreshment cabinet, installed in one of the apartments.

quality. Yet, many express doubts about feeling comfortable to wash 'in public'.

On the other hand, the tenants of the living lab seem not to have any issues in this regard. The washing machines have been used regularly since the building has been occupied. It is, however, still unclear if and to what extent the furniture in the laundry has influenced the social interactions between the tenants. During a number of visits that the authors of this work made to the living lab since it was put in use, not a single example of the social interaction between the tenants in this particular part of the building was recorded. This is an interesting outcome given that the social interaction has been one of the strongest arguments for placing the laundry in a public space. A preliminary conclusion is that the tenants are lacking motives or tools, e.g. a coffee machine, to interact in this particular space. This invention needs improvements, which will be considered in future projects. As pointed by (30), innovators must have enough creativity to envision, technical savvy to create, and courage to try entirely new complexes of behaviours, values and things.

4. CO-DESIGN OF THE RESEARCH INFRASTRUCTURE

Conducting research under real-world conditions is challenging because it requires methodologies that allow precise differentiation between the main and side impacts on a phenomenon that is in the focus of the scientific research. Further difficulties originate from various temporal, spatial and regulative constraints set by real-world operation, which are normally avoided in laboratory environments. In case of the living lab that operates at the same time as a home (one could therefore define it as a habitation living lab research infrastructure), the following challenges have been identified: tools and conditions for performing research and collecting data without disturbing tenants, safety of data storage and ethics, space for measuring equipment, replicability of experiments, and adaptability of the building to future research needs. The latter has led to two basic assumptions: the building design will need to permit evolution in space and function and adapt to changing needs of the research and users.

For the purpose of mapping the research needs, a series of interviews with Chalmers researchers was conducted (31). These were then categorized by their relationship and relevance to the user. Yet, the research projects that most influenced the building's physical design were 'Next Generation Building Envelopes', focused on new sustainable building materials and technologies, and 'Home Energy Management', collecting data on residents' energy consumption, etc. The authors of this work, since being directly responsible and deeply involved in these research projects, became also regular members of the building design team for the purpose of guiding the project team in the design of research facilities. Since similar examples of a co-design of research facilities are lacking in the recent literature, its main details and actors are presented hereafter.

4.1. Sensor network

Building services for heating, cooling and ventilation are the final means to create desirable indoor environmental quality (IEQ) in buildings. They are typically designed and sized based on static targets of IEQ and without insight into grid framework conditions, although they operate under highly dynamic conditions. Adaptation of power supply and air flow rates from these systems to the intermittent demands set by outdoor conditions, users preferences and grid conditions are then regulated by control systems. In residential buildings, the control systems are generally simple for economic reasons and can be easily overruled by tenants' activities.

Figure 2. To the left and in the middle: Data centre inside HSB Living Lab and Quuppa tag tracking system. Photo: Anna-Lena Lundqvist. To the right: tag position data visualization at the entrance floor.

The so-called Home Energy Management project aims at improving the utilization and operation of building services in residential houses by:

- Providing tools to the tenants with which they would be able to tailor the performance of these systems in accordance with personal preferences,
- Providing technological frameworks for better utilization of such technologies to fluctuating energy mixes on grid level, especially aiming to make better use of renewables.

The project focus is to optimize energy flows by the recognition, identification and assessment of patterns. This shall result in strategies for the energy demand management, e.g. for sensible heat, which correlates with the actual and predictable activities of residents. As a first step, the project members joined the co-design process described above with the creation and implementation of a sensor matrix, its necessary data handling system and a visualization platform. Using such a sensor and data network shall on the one hand allow evaluation of the general (but also individual) energy and material flows and on the other hand reach a high level of measurement quality and accuracy due to special requirements regarding the level of detail and replicability which must be addressed for scientific research.

Under the premise of accessibility during the building's construction period in spring 2016, sensors measuring the following physical statuses were selected and implemented: wall plug electricity consumption, room temperature, room relative humidity, room CO2 level, room air particle concentration, mass flow of main ventilation intake, mass flow of ventilation exhaust, temperature of ventilation exhaust, relative humidity of ventilation exhaust, tab hot water consumption, tab cold water consumption, waste water temperature, heating energy consumption per heat circuit, heat circuit mass flow, heat circuit temperature, location and acceleration of tags, outside temperature, outside relative humidity, outside CO2 level, wind speed, wind direction, global irradiation, PAR irradiation, precipitation, elevator position and move direction, elevator load, in-wall temperature, and in-wall relative humidity. Technical details about the sensors can be found on hll.livinglab.chalmers.se. To ease future sensor integration a cable based Power-over-Ethernet-network as well as wireless communication hubs are used.

The different sensor technologies and systems demanded development of an adequate data handling architecture that is able (a) to communicate with all sensors, (b) to reliably sort and store big data, and (c) to allow secured and fast access to collected data. Therefore, different servers and data exchange interfaces were installed to absorb the different data streams (XML files, SOAP messages, UDP push messages, ZigBee packages, etc.) and to merge the different intermediate database environments (MAMP, hbase, InterBase, etc.). Data availability is secured through automated daily backup routines. On top of the system architecture, a data access procedure was implemented that guides users by support of a graphical user interface (GUI) to specify the selection of data and to get access to it via a PGP key protected REST-API application. Fast handling and processing of data is done using functional programming languages, among others Prolog and Erlang. However, the described data platform is unique in itself with the benefit of being a portal-free solution and therefore not locked to one specific sensor communication technology.

Consequently, the aim of the project enlarged towards increasing the acceptance as well as speeding up the commercialization and the implementation of inventions regarding living lab measurement systems among property owners and managers (and other professional actors). In the first phase the project will provide empirical insights of the perception of the described systems including potential barriers for implementation and needs in terms of new inventions and innovation among the target group. In the second and third phase, innovations for energy management systems will be selected (or new inventions will be developed) together with target groups as collaborators and co-creators (e.g. using co-creation workshops). Both the implementation of the sensor matrix and the data handling system also enables a transfer of the created know-how and the process experiences to other living labs and applications in future.

4.2. Exchangeable walls

Market entry of novel wall elements, even when they are preferable from the sustainability point of view, is often difficult due to a general lack of knowledge for adopting new building technologies in the construction sector, as well as by complicated standardization procedures. Approved structural solutions, verified production process and optimized performance are seen as the corner-stones for bringing new generation building envelopes to the market.

The Next Generation Building Envelope Systems project has two tracks:

Development of novel building technologies that incorporate innovative building materials such as super insulation and phase change materials, or traditional materials produced by low-carbon technologies such as green concrete.

Demonstration and evaluation of full-scale prototypes of novel building technologies in real operating conditions.

For these purposes, twelve exchangeable wall sections of size 1.2 x 3.8 m were implemented in the building. As shown in Figure 3, six exchangeable walls are placed on the east side of the building and the other six on the west side because they receive different sun, wind and rain loads (the south-west direction is a dominant wind direction in Gothenburg, and the most exposed to driving rain). Furthermore, each exchangeable wall is placed in a different one-bed apartment. To the left and right of each exchangeable wall there is a window and a reference wall window and a reference wall respectively (see Figure 3). The reference wall is of the same size as the adjacent exchangeable wall, with a difference that its construction and placement cannot be changed. Moreover, each pair of exchangeable wall and reference wall belong to the same apartment. This configuration allows comparative studies on i.e. hygro-thermal or acoustical performance of novel (test) walls, since each exchangeable wall and its reference wall are exposed to the same outdoor and indoor conditions. Finally, test campaigns can be run in different ways. For example, it is possible to test 12 different novel walls at once and independently, or to test the same novel wall in 12 different apartments.

Weather conditions at the building are recorded by five weather stations: two are installed on the west side, on the second and the fourth floor, two on the east side, and one on the roof. The indoor conditions in each apartment are also recorded, as explained in the previous section.

The installation of novel walls for testing in the building is facilitated by specially designed wooden frames, which allow other wall thicknesses, i.e. between 120 – 350 mm, in comparison to the thickness of the reference wall (300 mm). Thus, test walls may have different thicknesses and appearances than the reference wall, on both the inside and the outside, although their interior surface will be placed in the same plane as the interior surface of the reference walls.

The frame for exchangeable walls allows the construction of a test wall outside the building, e.g. in a factory. Once the test wall is inserted in the frame, it will be installed in the building from outside, by a crane. This installation procedure is deliberately chosen for two reasons: to encourage innovations on modular and prefabricated wall constructions, as well as to decrease the installation time at the building site. The interchangeability of exterior wall elements is an important concept in order to permit the trial of various novel building materials in a real-time environment during the service life of a building.

During the spring of 2017, the exchange of walls will be tested in laboratory conditions, in full scale and by means of a provisional stand that accurately represents the actual walls in the building.

Besides the above described twelve exchangeable walls, there are two more on the third floor, one on each side of the building, in approximate size of 12x3 m (marked with light green in Figure 3).

4.3. Other facilities

The building is heated by hydronic heating, provided by a district heating network. At the second and the fourth floor of the building, the heat is delivered by an underfloor heating system, while radiators are used on the remaining floors. The combined heat delivery systems allow innovations related to either underfloor or radiator heating. The planned innovations related to the underfloor heating include self-regulated floor heating and utilization of return water temperature from the radiators. There is also a possibility to include ano ther heat source to the building besides the district heating system. A prototyping room, so called White Box, is available at the ground floor.

4.4. Research process and the project application portal

Another important characteristic of HSB Living Lab is its openness. Interested companies or universities may apply to conduct research or demonstration projects in the living lab, as shown in Figure 4. To facilitate the application and evaluation process, an in-house web portal and project application template have been designed. More on http://hll.livinglab.chalmers.se/en.

5. RESULTS AND DISCUSSION

The results of self-assessment of HSB Living Lab by using LLHC are summarized in Table 1. The coloured cells within each cube face show already fulfilled qualities and categories in HSB Living Lab, while the white fields refer to subjects that will be satisfied in the future. A short motivation to the assessment is provided hereafter.

User involvement: as presented in section 3, the co-creation workshops have been the main and successful means of engaging various users in the generation of innovation ideas. The user involvement is also secured by formal agreements between the tenants and HSB about the tenants' participation in research and innovation activities in the living lab. As Chalmers is responsible for the data collection and storage, ethical issues are covered through separate contracts.

Figure 3. To the left: the position of six exchangeable walls of size 1.2x3.8 m on the west side of the building, on the second and the fourth floor. The light-green area on the third floor indicates another fully exchangeable exterior wall of size 12x3 m. Animation by Eyebright. To the right: a photo showing the exchangeable and the reference wall during the construction in a factory.

Thereby, it is estimated that HSB Living Lab has fulfilled the basic setup requirements as shown in Table 1. Since it has been in operation for a less than a year, it is too early to judge about the other two development phases, i.e. sustainability and scalability.

Service creation: section 2 provides details on the business model for a long-term engagement and strong partnership within the HSB Living Lab consortium. While idea generation is primarily handled through co-creation workshops, the web portal is the main communication and business support service. Innovation ideas registered in the web portal (section 4.4) can obtain partner support and funding (see Figure 4). The co-creation team led by Shea Hagy has acquainted both respect and popularity, and has started to operate on commercial basis. There are plans to formalize this service in a start-up during spring 2017. As it can be seen Table 1, HSB Living Lab has reached substantial maturity in these regards.

Governance: while the business model from section 2 provides solid foundations for long-term commitments and responsibilities between the partners, much work is needed on items related to formalization of collaborative results, such as open source data and knowledge, intellectual prop-

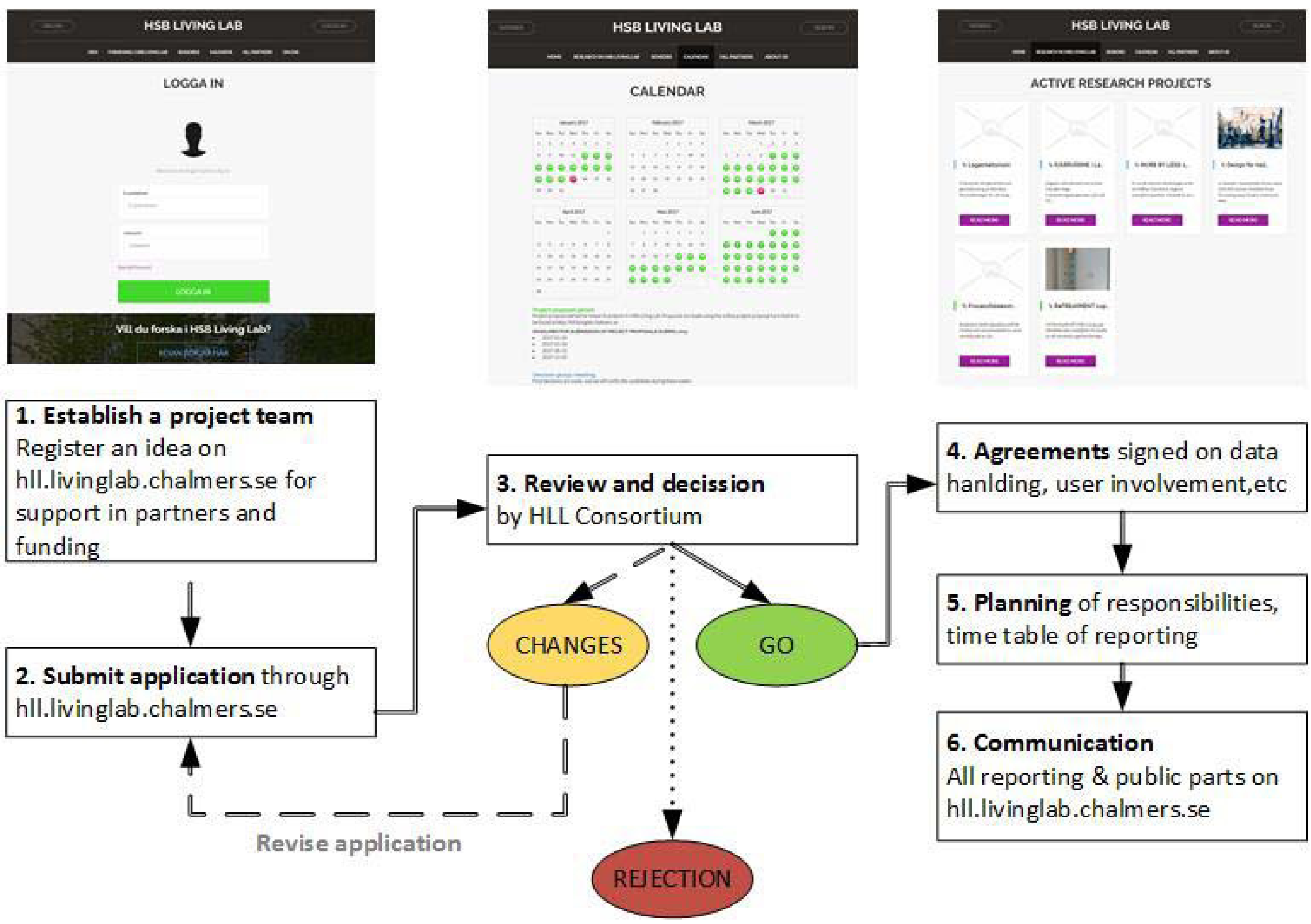

Figure 4. The flowchart of a project application process complemented with representative screenshots from the project application portal at http://hll.livinglab.chalmers.se/en.

erty rights (IPR), etc. These items are regularly discussed by the project team on project-to-project basis, in order to collect sufficient insight and knowledge. This is probably the aspect where experiences from other successful living labs could be of use.

Infrastructure: The use and management of the building is regulated by the contract between HSB and Chalmers and separate managers are appointed for renting and operation of the building as a residence (by HSB), as well as for maintenance of sensors and data collection (by Chalmers). The contract also regulates a basic funding strategy for the building during a ten-year period. The physical and IT infrastructures, which are described in section 4, are developed with a vision of excellence, adaptability, sharing and operability. Therefore, the living lab reaches maturity in these regards (sustainability), time will tell if it can be possible to scale up these concepts to other living labs.

Innovation outcomes: the thematic area of HSB Living Lab - sustainable living, defines clear objectives for further innovations. The concept of the building with small private areas, e.g. 50 m3 apartments, gathered around a common kitchen, bathrooms and living room, the laundry studio and the airing cabinets are the first potential innovation outcomes from this living lab. The ambition of the project team is to generate at least 2 innovations per year. As discussed in section 3.1, these innovations need to be further evaluated and improved before further estimates about their scalability can be made.

Therefore, it is concluded that HSB Living Lab fulfils the basic setup in this aspect.

Methods and tools: the co-creation workshops, the co-design of the building and research infrastructure, the data storage and maintenance, and the web portal presented in sections 3 and 4 are methods and tools that have been developed from scratch within HSB Living Lab. There are many valuable experiences that could be shared with other living labs with similar themes. The on-going work on the promotion of the innovation opportunities, open source management and IPR are the activities intended to secure both the sustainability and scalability of this living lab.

SME Innovation: although this aspect was not originally a part of LLHC (27), it is found to be important to comment here. Based on the inquiries made so far about HSB Living Lab and the project application portal, the authors conclude that there is a substantial interest among SME for demonstration of inventions in HSB Living Lab. However, SME generally have limited funds to run their projects in the living lab, as well as limited knowledge on how to obtain additional financial support from available funding programs. The role of academia is rather crucial in providing assistance and guidance to SME in this regard. At present, however, the capacity of the project team is limited to certain number of applications. This means that in future, the research part of the HSB Living Lab consortium should be increased to facilitate more support to SME.

6. CONCLUSION

This paper contributes to the current efforts in developing a common methodology for describing and assessing living labs by applying the LLHC method on HSB Living Lab. It introduces various management, organisational and technical details about this living lab as inputs to the six evaluation categories of LLHC. The paper also provides a discussion about the criterion addition to LLHC, so-called SME-innovation potential. The results show that HSB Living Lab has been developed in all categories but not yet reached full maturity in any of them, which clearly shows the areas for its future development.

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