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Towards a taxonomy for health living lab data collection devices

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Abstract: Living Labs in the Health and Wellbeing domain have the ability to integrate ICT tools and other technical devices into the research and innovation withing this domain. However, there is there is no systematic understanding what kind of ICT tools and other technical devices are used by living labs and how they can be categorized. This study presents the creation of a taxonomy for systematically grouping data and devices used in living lab concept, as well as the technical representation framework. The analysis concluded with 8 categories and 63 subcategories of data that are gathered from Living Labs using various technologies. The taxonomy and the included data model enables Living Lab researchers and customers quickly find what tools they need for their research while supporting open data movement among the living labs.

Keywords: living labs, data collection and representation, digital devices health and wellbeing

1 Introduction

Living Labs in the Health and Wellbeing domain are Research and Innovation ecosystems that foster user-center, iterative operation processes within a public-private-people partnership for creating innovation that supports people's Health and Wellbeing (Leminen et al., 2012). User-centered and knowledge-based economies reflect healthcare's demand on user's involvement in the field of co-creation and innovative digital activities and services. The concept of a Living Lab is the facilitation of end-user's engagement in open innovation activities as from the very beginning. Living Lab's perspective had the user as a co-creator rather that a service receiver with the vision to achieve successful user's involvement in the innovation process (Følstad, 2008). It has been referred recently, that Living Labs can be used as a methodological tool between public and private stakeholders and co-creation approaches. However, a common definition, robust methods and normative questions demand attention in order to make this approach valuable to public administration research (Dekker et al., 2020). Therefore, there has been proposed a common definition and a set of guidelines that can form the basis for using Living Labs in public administration research. Findings from systematic research reveal that Living Labs in Healthcare demonstrate design limitations as shortcomings in reporting and comprehensiveness; the aforementioned barriers can consequently limit the utility and trustworthiness of findings (Archibald et al., 2021). Mulder and colleagues (2007), almost a year after the incorporation of the European

Network of Living Labs (ENoLL), outlined the importance of finding harmonized methods and tools for LLs. The interoperability cube that had been proposed, was built on the assumption that the focus on synergies and those elements that Living Labs want to exchange with each other forms an appropriate basis for the harmonization of methods and tools. The cube identified these exchange possibilities and explicitly defined interoperability elements from organizational, technical and contextual perspectives in which different standards are relevant. However, there are not any other research data, to our knowledge, that reveals other attempts on the field of the harmonization of methods and tools in Living Labs.

Deeper understanding of the characteristics, processes, and tools in Living Labs is needed in order to better integrate them with the innovation activities of organizations (Schuurman et al., 2015). Living Labs have the ability to better integrate the opportunities offered by new ICT concepts and solutions to the specific needs and aspirations of local contexts, cultures, and creativity potentials. Although the use of ICT tools for data collection and digital Health interventions is widely spread among Health and Wellbeing Living Labs, the specific methods and tools used are under-researched (Kareborn & Stahlbrost, 2009). The European Network of Living Labs (ENoLL) who has been recognized as a key authority in living lab community, does not provide any information about ICT and other technical devices, even if it offers extensive information about living lab tools and methods.

As result, there is no systematic understanding what kind of ICT tools and other technical devices are used by Living Labs and how they can be categorized. The lack of a specific taxonomy creates challenges to external stakeholders that aim to use the services provided by Living Labs as they cannot easily find the tools that they envisage to use. The problem is also extended to data collection since there is no unified representation of the collected datasets, thus impeding the cross-organizational collaboration and the accessibility of Living Labs to external stakeholders. Despite the research on Living Labs methodology, the gap in the existing literature is remaining. Within our study, we aim to fill this gap in existing literature by presenting our results towards a taxonomy for health living lab data collection devices.

Objectives of this study

The current study states the following main research questions: RQ1: What kind of devices and equipment living labs are using for empirical data collection. RQ2: How these devices and equipment can be systematically grouped according to their usage purpose and characteristics. RQ3: Which is the specific data representation template that can be followed by each Living Lab and can also be extended based on each specific needs. This study is structured as follows. First, an overview of health and wellbeing living labs business models and the current understanding regarding technology assisted empirical data collection among living labs is presented. Second, research design including taxonomy development principles, data collection and analysis process are described. Third, the key results regarding RQ1-3 are revealed. Finally, conclusions and suggestions for further research are made.

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2 Current understanding of technology assisted data collection among health and wellbeing living labs

Health and wellbeing living labs

The first exploration of the Living Lab concept was done at the Massachusetts Institute of Technology with the creation of PlaceLab, that was an apartment equipped with hundreds of sensors aiming at sensing, prototyping, validating and refining several solution for supporting the occupants' health and wellbeing related to diet, exercise, medication adherence, and other interventions (Intille et al., 2005). This indicates that Living Labs have been strongly related with the exploration of health-related concepts and are inherently connected with innovative technological solutions. Although the term has evolved and can cover the exploration and validation of non-technological solutions as well, the use of ICT tools is still very broad. Furthermore, Living Labs in the Health and Wellbeing domain have now been diversified from test beds by offering opportunities for active participation of users in the exploration and creation of new ideas rather than just testing and validation. Nevertheless, many Health and Wellbeing Living Labs are still searching a sustainable business model and seeking different ways to popularize themselves over other rivaling collaborative innovation approaches (Santonen, 2021; Santonen & Health, n.d.).

The term "Health and Wellbeing research" addresses human health and aims to identify ways to promote health and wellbeing, prevent disability, intervene to improve care, and the overall quality of life. The complexity of the human condition almost always requires a multidisciplinary approach that relies on the collaboration with multiple and diverse stakeholder teams, including healthcare professionals, engineers, data scientists, sociologists, nutritionists, to name a few. Furthermore, the complexity and diverse organization of health care services and systems renders the investigation and interpretation of the use, cost, quality, accessibility, delivery, organization, financing, and outcomes of health care services a very complicated task (Ferreira et al., 2018; Steinwachs & Hughes, 2008). Finally, unlike in other areas, researchers in this domain heavily depend on time-consuming recruitment and engagement of participants (people with the specific sociodemographic and clinical profiles) for every step of their research in order to: design the intervention or service, refine, test the feasibility and evaluate the effectiveness. All these factors justify the fact that nowadays, according to ENoLL member statistics, Health and Wellbeing area is the most popular one across Living Labs. Even if the use of Living Labs in the Health and Wellbeing domain has not been systematically investigated yet, there is evidence that the Living Lab approach enables meeting the challenges quicker and facilitates the redesign of solutions and internationalization (Hyysalo & Hakkarainen, 2014; Santonen & Julin, 2019).

Technology assisted data collection in living labs

There are various examples in the literature indicating the use of technological tools for data collection but most commonly testing and validation of the technology in Health and Wellbeing Living Labs.

Korman et al. (2016) (Korman et al., 2016) investigated how Living Labs methodologies are applied in the rehabilitation domain and which are the key technologies for monitoring motor-cognitive activities. In their study, they classified the technologies used in three main categories, namely personal technologies, ambient technologies and external assistive systems. In the personal technologies category they assigned the technologies that are "worn by or on the person" (wearables and body sensor networks). They intended also in a categorization based on the outcome that each device generates, diving them in thermal, electrical, geometrical and mechanical types. The ambient technologies are defined as the ones placed in a person's living environment (home or social settings). The external assistive systems are the systems that "focus on the support of people with special needs" and are subdivided into emergency assistance services, autonomy enhancement services and comfort services. This research has done an attempt to classify technologies used in Living Labs in the rehabilitation domain.

Existing approaches for describing the technological tools used in the Health and Wellbeing domain

Even though Living Labs can meet the innovation challenges in healthcare quicker and in an effective way, the researcher in the field have identified the need for better conceptual and practical tools (Budweg et al., 2011) that can produce new research avenues for Living Labs. Currently there are some existing approaches for describing the technological tools used in the Health and Wellbeing domain both from contextual and purely technical scope. The World Health Organization have released a Classification of Digital Health Interventions (WHO, 2018) that categorizes digital and mobile technologies used to support healthcare systems that can be used to facilitate the dialogue between healthcare and technology oriented audiences. This taxonomy focusses on digital interventions and does not capture the categories of technologies used for data collection and can provide valuable insights towards new technological innovations. On the other hand, other frameworks also exist as the Control Objectives for Information and Related Technologies (COBIT) (Hawkins et al., 2008), Health Level Seven (HL7) (World Health Organization & International Telecommunication Union, 2012), International Standards Organization (ISO) (WHO, 2016) and the Open mHealth Library but they are intended to be used by computer scientists and software engineers serving the need for unifying technical terminology. The interrelation of the contextual level and data representation have not yet been established in Living Lab research and innovation ecosystems.

3 Research design

The selection of taxonomy development method

The importance and need for taxonomies is well recognized among scholars since ancient Greece (Godfray, 2002). Defining a taxonomy is one way to tackle problems relating the lack of common language between different stakeholders and helping addressing the inconsistency of terminology (Ward, 2012). Generally speaking taxonomy is referred a system for naming and organizing things, into groups that share similar qualities (*TAXONOMY | meaning in the Cambridge English Dictionary*, n.d.). There are many methodological ways to develop taxonomies. In this study, a development approach proposed by Nickerson et al. (2013) (Nickerson et al., 2013) is adopted as follows. A useful taxonomy should have following qualitative attributes (Ibid.): Concise,

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robust, comprehensive, extendible and explanatory. Living lab researcher and living lab research infrastructure user – a person who purchases or uses living lab research infrastructure services to conduct a specific contract-based research and development activity – where selected as meta-characteristic. The taxonomy aim is to help them to understand the possibilities of technology assisted data collection in a health and wellbeing living lab study. The empirical-to-conceptual approach was identified more appropriate approach, since the prior research on what kind of technologies living labs are using for data collection was limited.

Data collection and sample selection

First, a structured survey was sent to 10 health and wellbeing Living Labs taking part to European Commission funded H2020-project asking them to provide information about their data collection devices and equipment. The requested and collected information included: (1) data collection technology name, (2) short description of technology usage and purpose, (3) object of data collection (keyword), (4) equipment models used by LL (if available), (5) link to detailed specifications of the equipment (if available), (6) output data format and (7) to indicate if living lab has open data sets available. All 10 Living Labs responded to the survey.

Second, interviews with each 10 living labs core members (total N=30, duration per interview ca. 2 hours) were conducted in order to clarify the information provided in survey and gain more information on what and how devices were used for research purposes. During the interviews, the survey data was used as background material. The interviewees were asked to present study cases in which they used the specific devices presented, how they used them and for what purpose. Two interviewers were facilitating the discussion, one mainly doing the questions and the other was keeping notes. The sessions were also recorded but not transcript. The recording was used to retrieve specific details whenever needed.

Third, the collected data were analyzed by two independent researchers by following the same schema for analysis: (1) define the problem (e.g., monitoring heart failure), (2) find the technologies that could help address the problem (e.g. heart rate monitoring), (3) identify other uses of the same technology (e.g., it integrates blood pressure, weight, dyspnea, blood glucose, swellings, bpm, SpO2), (4) define categories for the technologies depending on the area of the problem (e.g., biosignals), (5) specify possible subcategories (e.g., heart rate, blood pressure). A meeting followed in order to compare the results among the two and reach consensus until the ending conditions were met (Nickerson et al., 2013).

The data representation processes were grounded to the results of the aforementioned analysis and the existing open frameworks for data modelling. The Open mHealth Library (https://www.openmhealth.org/) was used were standard schemas and sample data can be found, and was mapped to the contextual representation decided for the taxonomy.

4 Findings

Systematic grouping of data and devices used in Living Labs

The analysis concluded with 8 categories and 63 subcategories of data that are gathered from Living Labs using various technologies. Clear definition was formulated by the independent reviewers for each category, based also on existing literature. The main categories are:

1. Activity tracking/monitoring: monitoring and tracking fitness-related metrics such as distance walked or run, calorie consumption, and in some cases heartbeat,
2. Assistive technology: is used to increase, maintain, or improve the functional capabilities of persons with disabilities,
3. Biometrics: are biological measurements — or physical characteristics — that can be used to identify individuals,
4. Biosignals: any signal in living beings that can be continually measured and monitored,
5. Cognitive function: mental processes within a person's psyche that are present regardless of common circumstances,
6. Environment/context monitoring: characterize and monitor the quality of the environment, and establish environmental parameters,
7. Physiological monitoring: vital physiologic parameters so that clinicians can be informed of changes in a patient’s physiologic condition,
8. Virtual reality/interactive technology: allows for a two-way flow of information through an interface between the user and the technology through a simulated experience that can be similar to or completely different from the real world

In order to understand what kind of technologies and devices are used, specific examples are assigned to each category on the table below (Table 1).

Table 1 Resulted Categories and Subcategories, along with devices examples

Category	*Subcategory*	*Examples*
Activity Tracking/Monitoring	Body battery	Smartwatches (e.g. Empatica, wavelet wristband, fitbit, garmin)
	Body position	
	Calories burned	Orientation (e.g. Adafruit with 7 or 9 Degrees of freedom)
	Gait	
	Energy expenditure	Study of movement (e.g. Ainone Balance® Software, G-WALK)
	Human balance	
	Inverse kinematics data	
	Movement measurement	
	Orientation	
	Physical activity	
	Physical performance	
	Physiological and behavioural biomarkers	
	Temperature	

	Sleep	
	Steps	
	Stress level	
	Vo2	
	Well-being evaluation	
	Blood oxygen	
Assisting Technology	Alarm system	Humanoid Robots
	Engaged users	Smart toilet (e.g. INOTEC)
	Natural language understanding	Smart walker (e.g. ANDIN)
	Safe bathroom usage	
	Safe walk assistance	
	Technology Usage habits	
	Video stream	
	Voice commands	
	Walking speed	
Biometrics	Basic Biometrics (facial recognition)	
Biosignals	Electrophysiological timeseries	EMOTIV EPOC +
	Heart rate	Iliaktis
	EEG	
	ECG	
Cognitive function	Cognitive training	
Environment/context	Concentration levels	Air quality sensor
	Blind operation	Passive Infra Red sensor
	Door operation	Temperature monitor
	Technical alerts (Flood)	Smoke detector
	Technical alerts (Smoke)	Sensewear Armband
	Technical alerts (Temperature)	
	Alarm system	
	Luminosity	
	Indoor movements	
Physiological monitoring	Patient history & demographics	Pulse oximeter
	Weight BMI	iHealth Scale
	Virtual reality	
Virtual reality/interactive technology	Web Interaction	VR Healdset
	Gesture detection (smile)	Emocube
	Alternative and augmentative Interaction	
	Intuitive user interface	

Data representation template

An extensible data model is currently being implemented to visualize representations of the collected data elements and the connections between them. The main purpose is to provide an extensible data model to: 1) harmonize representation formats of the information exchanged that will be used from the Living Labs 2) empower other Living Labs to develop solutions that adhere to this common definition and 3) provide a shared, common schema. The designed model will precisely represent and handle patients' data information deriving from different devices or platforms (i.e heart_rate, BMI) and efficiently describe the collected dataset so as to produce meaningful metadata.

There are several state-of-the-art standards for data exchange that can be utilized for modelling pertinent domains, such as the Fast Healthcare Interoperability Resources-HL7 (FHIR-HL7, https://www.hl7.org/fhir/). For the Vitalise Data model we make use of the Open mHealth which is the leading app, mobile and platform health data interoperability standard to make sense of disparate patient-generated info. Open m Health is based on a common data schema which specify the format and content of data, such as heart rate readings and improves the ability of developers to build clinically usable products.

Vitalise data model consists of three sub-models which refer to the Vitalise Data, Dataset and Person Models (based on the project Requirements & Considering privacy – data protection rules). Different implementation tools were utilized for the models designing. Initially, the Open mHealth [https://www.openmhealth.org/] data Library was downloaded were standard common schemas and sample data for validation can be found, which were mapped to the contextual representation decided for the taxonomy. For the purpose of data model schemas editing and validating Json Buddy[https://www.json-buddy.com/] was used. In addition, a Python script was constructed based on jsonschema.RefResolver [https://python-jsonschema.readthedocs.io/en/stable/references] as a supplementary validation method. Specifically, the process workflow described below was followed for each of the three data model category: 1) Data collection to prioritise model development 2) Sensor type and categories definition awareness 3) Create upper levels regarding the data type categories 4) Use of OmH Standard Schemas & test data for suitability 5) Develop json schema-based model with $ref schemas ie acceleration 6) Create examples for added device types, define dataset statistics 7) Validation at each different level. Sample data validation against data point schema. Currently, the structure of the data model is defined and a first version of the Vitalise data and dataset point model is ready. Modifications based on data format and partner's input will be done by the end of the project. More standards like WoT Capability Schemas[https://webthings.io/schemas/] was also used to represent information that cannot be found in OmH library.

5 Conclusions

This study is a systematic attempt to create a taxonomy that will classify and define the data and devices that are used in Health and Wellbeing Living Labs in order to collected research data, test and validate solutions. Previously existing works do not approach the technology categorization in Living Labs and are restricted to the categorization of methodologies and tools (Leminen & Westerlund, 2017) or classification in a specific field of study (Korman et al., 2016).

The key theoretical contributions of this work are summarized in three main points (1) empirically constructed taxonomy for Living Lab data collection devices and equipment, consisted of 8 categories and 63 subcategories (2) a master list of individual devices and equipment used by Living Labs for data collection integrated within the taxonomy and (3) harmonized data model integrating existing open Libraries (the Open mHealth) describing the representation formats of the information exchanged that will be used by the Living Labs.

Living Labs are fostering open research and innovation approaches, thus make it mandatory to be accessible in an easy and effective way. A shared and harmonized vocabulary such as the proposed taxonomy makes living labs more accessible for newcomers as well as stimulates cross-organizational and research collaboration due unified language. The taxonomy and the included data model enables Living Lab researchers and customers to quickly find what tools they need for their research while supporting open data movement among the living labs.

Existing limitation of this work is the lack of validation of the resulted categories and subcategories, both with other living labs not included in the initial data collection but also from living lab researchers that will be the living lab costumers. To further study the existing taxonomy, the Delphi method will be used. The Delphi method is generally agreed that it can extract sound scientific evidence from experts opinions (Fusfeld, 1971) while it is a well-accepted systematic method used when seeking consensus among a panel of experts (Dalkey & Helmer, 1963; Hsu & Sandford, 2007). Moreover, the Delphi study method is commonly used for taxonomy creation (Hanson et al., 2020; Valentijn et al., 2015) as it is widely accepted that such qualitative methods can be appropriate for evaluating design aspect (Iivari & Venable, 2009) including taxonomies. We envisioned that the use of Delphi method will strengthen and improve the work done in this study.

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