The Five Strands of Living Lab

A Literature Study of the Evolution of Living Lab Concepts in HCI

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Since the introduction of the iconic Aware Home project [39] in 1999, the notion of "living laboratory" has been taken up and developed in HCI research. Many of the underpinning assumptions have evolved over the past two decades in various directions, while the same nomenclature is employed—inevitably in ambiguous ways. This contribution seeks to elicit an organized understanding of what we talk about when we talk about living lab studies in HCI. This is accomplished through the methods of discourse analysis [66, 69], a combination of coding, hypothesis generation, and inferential statistics on the coded data. Analysing the discursive context within which the term living laboratory (or lab) appears in 152 SIGCHI and TOCHI papers, we extracted five divergent strands with overlapping but distinct conceptual frameworks, labeled as "Visited Places", "Instrumented Places", "Instrumented People", "Lived-in Places", and "Innovation Spaces". In the first part of this paper, we describe in detail the method and outcome of our analysis that draws out the five strands. Building on the results of the first part, in the second part of this paper, each of the five types of living lab is discussed using some of the prototypical examples of that kind presented in the literature. Finally, we discuss the raison d'être and future position of the living lab as a method within HCI research and design and in relation to advances in sensing technologies and the emerging world of intelligent built environments (e.g. smart city, smart home).

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**; *Ubiquitous and mobile computing design and evaluation methods*; User studies; Laboratory experiments; Field studies.

Additional Key Words and Phrases: Living Lab; Living Laboratory; Human-Building Interaction

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1 INTRODUCTION

Conducting research in an authentic yet experimental setting is no longer what motivates the extensive investments in "living lab" infrastructure and studies. Their scope has moved far beyond creating a laboratory that resembles living spaces. Ambitious large scale living labs projects have materialized, such as the London PEARL Living Labs [54] that aspire to build 4000 permanently-monitored apartments, the Swiss Smart Living Lab that brings together 12 research groups from three universities to further multidisciplinary work on sustainable living [68], and the Malmö Living Labs

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that seek to democratize the innovation process through establishing long-term relationships with the co-designer participants [12]. Clearly, what we have witnessed is a rapid departure from the initial premises of living lab. What is not clear, however, is the new direction(s) and whether the notion has been essentially hijacked to communicate tangential ideas. Or, is this the logical expansion and exploration of the idea, coinciding with new possibilities for pervasive data collection and directed to meet the pressing societal challenges of the time? It is not clear because of the marketing hype muddying the water what Living Labs are and can offer, as to what they offer HCI researchers. Here we examine how they have been described, framed and used in relation to particular spaces and settings where research is conducted versus more generally, as a methodological approach to innovating spaces.

It is our observation that despite the marketing rhetoric surrounding living lab projects, particularly in recent years in Europe [49], there is not much rigor in clarifying what outcomes are expected from this approach—that would not have been achieved through less demanding methods. With the lack of such clarification, one may even consider the hypothesis that living lab methods, in some cases, are favored merely because of their visibility—to impress fellow scholars or potential investors with an abundance of research facilities and resources.

The ambivalence about the new meanings of the term and lack of consensus about associated concepts are also notable in the HCI literature [17]. This stems from numerous reasons and has led to the current situation where the evolution of living lab concepts are only traceable in a significant amount of scattered literature. This is the first aim of our paper. The goal is to capture the common patterns and points of divergence in how the HCI community collectively perceives the notion of living lab. In the interest of clarity and focus, we confine our work to the specific lens of HCI, without overlooking the many cases where HCI researchers contributed to interdisciplinary living lab projects. To this end, we analyzed 152 papers published in the SIGCCHI conferences and the journal of TOCHI that mention the term "living lab". The initial analysis of the papers, through coding techniques, inspired a hypothesis suggesting that several evolving comprehensions of living lab trends exist in the current HCI literature. Quantitative analysis of the various parameters extracted from those papers supported our hypothesis and revealed five distinct trends of living lab studies in the HCI literature. We label the five trends as "Visited Places", "Lived-in Places", "Instrumented Places", "Instrumented People", and "Innovation Spaces". We also describe the characteristics of each trend referring to their prototypical examples. It is, however, worth noting that, while conceptually distinct, these varied trends are not practically incompatible, such that many living lab projects contain more than one trend.

What we present in this paper is an attempt to clarify our collective understanding(s) of the term and the interdependencies of the concepts that have been associated with it. We believe that such clarification is necessary and timely considering the reemergence of the notion and the increasing propensity of HCI for employing it in different contexts and scopes, as well as the plausible possibility that living labs will play an important part in the future of HCI research and design [17]. This is the main motivation for the contribution we offer and its specific focus on the HCI literature. This work, however, is not a systematic review of living lab literature (classification of methods used, research questions addressed, etc.). It seeks a more modest but an essential objective, that is, to investigate the different set of ideas and concepts that the term "living lab" represents. It is not clear because of the marketing hype muddying the water what Living Labs are and can offer HCI researchers. Here we examine how they have been described, framed and used in relation to particular spaces and settings where research is conducted versus more generally, as a methodological approach to innovating spaces.

The remainder of this paper is structured as follows. First, in Section 2, we present a background to the originating and more recent discourses surrounding living lab ideas. Section 3 is dedicated to the analysis of the literature, including the way we selected the papers, method of analysis, as well as the results and the interpretation of the results. The main outcomes of the presented study are the five extracted trends which we exemplify and compare in Section 4. Section 5 builds on the results of the literature study and offers reflections on the future of living lab as a method in HCI research. Finally, we draw conclusions with a summary of our contributions in Section 6.

2 BACKGROUND

It has been long established that the physical and social context in which an activity takes place is likely to be relevant to how that activity unfolds [14]. In that direction, living laboratories committed themselves to the study of complex phenomena in their naturalistic settings and to address problems where they are. In one of the early examples, chronocyclegraphy—an invention in 1910s that allows for capturing human motions—was used to study the patterns of movements in mockup kitchen spaces, the work that informed the optimization of layout in the famous Frankfurt Kitchen project [29] (see Figure 1). In another inspirational project, during the 1970s, the urbanist and journalist William H. Whyte, in his "Street Life" project, utilized time-lapse motion filming to study what made certain urban spaces, such as Seagram Plaza in New York, more appealing than others [70].

In HCI, living lab ideas reemerged more recently in the 1990s, to respond to the need for researching contextual requirements for designing and evaluating embodied interactions of ubiquitous and social technologies [23]. Projects such as Georgia Tech's Aware Home [39] and Classroom 2000 [2], and MIT's House_n [35] pioneered the creation of living environments equipped with a rich network of sensors to assess ambient intelligence and context-aware services (for a review of example such projects see [12, 31]). Since then, capitalizing on advancement in sensing techniques and with the rise of topics such as Internet of Things and Domotics, living lab projects have been progressing both in depth and breath [3, 36, 52]. Moreover, framing and conceptual contributions have been offered within HCI. William Mitchel and his colleagues from the MIT Media Lab are credited for one of the most prominently cited attempts to define living labs [27], which was followed by many others proposals, including Eriksson et al. [24], Ståhlbröst and

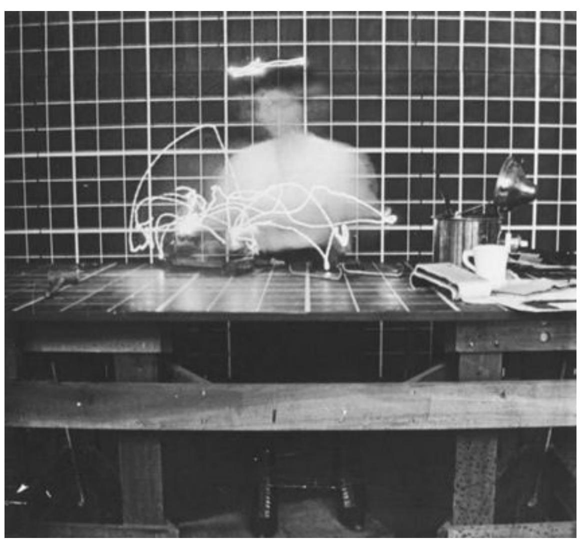

Fig. 1. In the mid-1910s, Frank and William Gilbreth invented chronocyclegraph, a tool that allowed them to study human motion. In one of the early examples of living lab, chronocyclegraphy was used to study movements in a prototyped kitchen. The result informed the famous Frankfurt Kitchen project, a mass-produced kitchen with a layout that was intended to minimize the traveling distances.

Bergvall-Kåreborn [64], and Ballon et al. [9] (a list of living lab definitions is provided in [21]). In an analytical discussion, Chi [19] compared evaluation through living lab methods against the other alternatives in HCI. Also, as a design method, seminal framing attempts position living labs within the Sanders' map [55] in relation to user-centered design, participatory design, and so forth [21, 53].

The evolution of living lab concepts in HCI, however, has been influenced by a multitude of forces, some of which are from other disciplines, which in parallel started to build their own living labs to address their own specific concerns. In Business Management, to bridge the gap between research and innovation [59, 60, 67], what is pronounced in the so called "European Paradox" [22], the idea of living labs have been examined as a solution. The main objective has been to involve users early on in the innovation process [44, 45, 58]. Almirall and Wareham [7] performed a case analysis of four living lab projects of such kind; in the same paper they also gave a review of living lab ideas in the Management scientific domain. In the same domain, Bergvall-Kåreborn and Ståhlbröst [11] distinguish two points of view on living labs as an innovation milieu and as an innovation approach. They present the traces of these two approaches in the management and innovation literature and show how they can enrich each other.

Another major force from the domain of Architecture and Building Performance Engineering has given a new form to the idea pursuing human-centric solutions for concerns such as as Sustainability [47] and Comfort [28].

The mutual learning and influence of living lab projects from various domains, the internal dynamism of HCI, and the investment in individual and consortium of living labs like ENoLL [26, 49], have created a confluence of interconnected factors that together reform the understanding of living labs. It is well-recognized that there is not a univocal concept of living lab in HCI, nor a firm agreement on its practical dynamics, problems, and possibilities [7, 17, 25, 46]. This is also our position. We acknowledge the diversity of living lab conceptions in HCI, but as a potentially positive reality that can be built upon effectively *if* it is elucidated and better understood.

3 ANALYSIS OF LITERATURE

In this section, we describe the method and the results of the qualitative and quantitative analyses that we performed on a selected collection of HCI Living Lab literature. The objective is to explore and examine the collective understanding(s) of the notion of living lab in HCI as well as the interdependencies of the concepts that have been associated with it. The method that we employ is directly derived by this objective and draws on the methods of content and discourse analysis in three steps of exploratory reading and hypothesis generation, coding, and quantitative analysis of coded data to validate the hypothesis.

3.1 Selection of papers

Our analysis focuses on published material. Particularly, we look at living lab studies published in the SIGCHI (Special Interest Group on Computer-Human Interaction) conferences and the journal of TOCHI, from 1999 to 2018. This provides a sample collection that is significant enough to be a reliable representative of the relevant literature while small enough to allow for an analysis of each paper with a reasonable effort. 152 papers were extracted through a query to the ACM Digital Library. The query fetches all the SIGCHI and TOCHI papers since 1999 that mentioned in their main body of full-text, any of the following terms in singular or plural forms: "Living Laboratory", "Living Lab", "Live Laboratory", "Live Lab"[1]. There is no trace of these terms published before 1999 as part of SIGCHI or TOCHI.

[1]For replication purpose, the list of papers can be retrieved with the same query to the ACM Digital Library (https://dl.acm.org/) by limiting the publication date upper-bound to 2018 (including 2018).

3.2 Method of Analysis

Starting with an exploratory approach, we read the articles and extracted parts that explicitly or implicitly linked to living lab ideas. This enabled us to build up a broad understanding of how living labs are essentially written about. In this initial step we looked for common patterns in the text that could reveal the authors' perception of the term. We found three components that typically constitute the discussion related to living labs in a paper:

- *"Living Lab Assumptions"*: A set of assumed methodological advantages that support the choice of running the study in a living lab setting (e.g. high ecological validity, engaging stakeholders in the design process, data collection over a longer period of time, etc.).
- *"Living Lab Setup"*: The physical infrastructure to facilitate data collection and experimental intervention (e.g. full-scale mock-up environments controlled and monitored by the experimenters, actual buildings or urban spaces observed with retrofitted sensors, etc.).
- *"Living Lab References"*: Citations referencing the description of a particular living lab facility or abstract discussions of the method.

These three components were extracted through an iteration of reading and discussion by two researchers, following the Summative Content Analysis [33] method.

The variations of the first two components are at the core of the analysis that we develop in this section. The References, while being insightful in certain cases, include many pointers to own or colleagues' work, which makes them a less informative source and thus they were not investigated in our quantitative analysis. Therefore, we focused the development of our analysis on the Assumptions and Setups, concerning which three initial observations were made:

a) the Assumptions vary considerably across papers (being aware of the fact that sometimes different wordings are used to express similar concepts in different papers), b) there exist several types of Setup which vary not only in terms of scale and function but, more importantly, in terms of affordances for research, and

c) there seem to be dependencies between the Setup and the set of Assumptions in a paper.

These observations led us to speculate that since the constituting components of how living labs are conceptualized, i.e. Assumptions and Setups, vary meaningfully, we might be able to trace several self-standing trends of living labs in the HCI literature. Moreover, it appeared to us that there is a meaningful match between the type of infrastructure that is described as the living lab in a paper and the way in which its methodological advantages are argued. More precisely, we formulated the following hypothesis:

Hypothesis H: *The current HCI literature contains several evolving trends of living lab studies that can be uniquely identified by their Setup and each carry a distinct yet overlapping set of Assumptions.*

In order to grasp what exactly the Assumptions and Setups include, find out their relations and interdependencies, and to find evidence supporting the above hypothesis, we carried out the following steps, in the mentioned order:

(1) Exploratory reading: for each paper, in a reading iteration of papers, a set of ideas that could be considered as Assumptions (with the previously-mentioned definition) were noted. In order to avoid redundancy, as progressing in the list of papers, we used the same labels for similar ideas. In the same round of reading, we also noted information about the data collection infrastructures and categorized them into classes that would represent different Setups. The outcome was an initial list of Assumptions and a possible classification of Setups. We then

combined conceptually similar/adjacent Assumptions and created a shorter re-labeled list of Assumptions. A similar procedure was applied to the list of Setups. The first reading iteration and the extraction of the lists of Assumptions and Setups was done by one researcher (one of the authors of this paper). The two lists of Assumptions and Setups, the labeling of each item in the lists, as well as writing a short description for each item were finalized in discussion with the other co-authors of this paper as well as a junior researcher who contributed to the coding process in the next step.

(2) Coding: in the next iteration of reading, we filled out a table in which each row corresponds to a paper and each column corresponds to an Assumption listed in step 1. The content of the cell is either 1 or 0, depending on whether the Assumption is mentioned in the paper or not. The table has one additional column that specifies the type of Setup that can be best assigned to the paper. Coding was done by two researchers separately. The two coders then discussed the points of disagreement and discarded what remained unclear from the quantitative analysis in the next step.

(3) In the last step, the aim was to investigate the hypothesis stated above. We ran Principal Component Analysis on the coded data (generated table). This method enabled us to a) make visible clusters of Assumptions that co-occur in papers, and b) search for potential relations between the clusters of co-occurring Assumptions and the Setups.

3.3 Results

In this section, we give a detailed account of the outcome of the analysis as we described in three steps in the last section. As we will see at the end of this section, these results will lead to an understating of the use of the term living lab in the literature that validates the hypothesis *H*.

3.3.1 Living Lab Assumptions and Setups (step 1). Table 1 and 2 provide the results of the exploratory reading task we described above as step 1, through which a list of Assumptions and Setups were extracted. More precisely, the objective of this step was to classify the methodological assumptions that are associated with the term living lab and to specify the distinct data collection infrastructures that support the living lab studies reported in the 152 papers in our database. Table 1 shows the nine extracted Assumptions along with a brief description of each and the number of papers in which they appeared. For each Assumption, we use a label that is typically utilized in several of the papers either as the exact terms or their derivatives. Two types of Assumptions were discarded from this list: 1) the ones that appear in almost every paper (e.g. user-centered) because of the nature of our selection (HCI literature), and 2) the ones that appear only in a few papers (the threshold was 5%)[2].

Table 2 describes the five extracted Setups along with the number of papers in our pool in which the term living lab is used to refer to such infrastructure. For each Setup, we used a label that, contrary to the Assumption labels, are not taken from the terminology utilized in the studied papers. The labels are constructed by us (the authors of this paper) in an attempt to reflect the nature of each Setup and to highlight their differences.

We had to discard two papers from the analysis as the data collection infrastructure was not clearly described.

3.3.2 Coding (step 2). The coding task consisted of determining, for each paper, which of the nine Assumptions can be found in the text or illustrations related to living lab ideas, and also which of the Setups is the closest to the data collection infrastructure described in that papers. As mentioned before, the coding was done by two HCI researchers,

[2]Please note that we are not claiming that this a complete list of methodological advantages of living labs; the Assumptions that we listed in Table 1 are the ones that appeared repeatedly in the pool of papers that we analyzed.

Table 1. The living lab Assumptions extracted from the selected papers. What we refer to as Assumption is an assumed methodological advantage that support the choice of running the study in a living lab setting.

Living Lab Assumption	Description	Occurrences
Real-Life	In living labs, studying human behavior can be done in naturalistic living environments.	111
Intervention Evaluation	Living labs can provide environments that are appropriate for deploying and evaluating designed (technological) interventions.	92
Research Infrastructure	Living labs support research processes by providing an enduring assembly of resources that can be shared by several groups of researchers, can be developed by them, and evolve to support future research agendas.	81
N	Higher numbers are expected from living lab studies, in terms of the population of subjects, as well as the number of studied contexts and activities.	74
Longitudinal Study	Living labs can offer practical possibilities to continue the data collection over longer periods of time. By creating an atmosphere where sensing and intervention are accepted, to a certain degree, by the occupants (participants), studies can continue without creating a sense of being in an ephemeral situation.	67
Stakeholder Engagement	Living lab environments can serve as the site for communication between the stakeholder and the researchers. They can host sessions of participation in design and contribution to translating research results to applicable changes in the stockholders' daily routines and practices.	58
Policy Change	Because of their evolving nature in continuous contact with the stakeholders, research findings that come out of living lab experimentations hold a potential to impact policies faster and more effectively.	44
Interdisciplinary Study	Living labs can support interdisciplinary research in two ways: 1) by encouraging research groups from different disciplines to bring their sensing equipment and mutually benefit from each other's databases, and 2) by creating a physical space for collaboration where groups of researchers participate in the experiments conducted by colleagues and benefit from reciprocal participation.	43
Innovation	By receiving feedback and engaging future users in the process of innovation, living labs are considered to be one of the promising solutions for more successful products and services.	36

Table 2. Various types of Setups extracted from the selected papers. What we refer to as Setup is the infrastructure to facilitate data collection and experimental intervention in a living lab setting.

Living Lab Setup	Description	Occurrences
Visited Places	Resembling a living environment and embodying several sensors, they host participants for a limited duration from hours to possibly weeks.	37
Instrumented Places	Existing living environments that are instrumented temporarily by researchers to be monitored for a specific study.	44
Instrumented People	Participants carry a set of mobile and wearable devices that collect data about their physical and digital activities.	21
Lived-in Places	Real living environments that are built to serve as living labs. They embody sensors and host occupants permanently or for long durations.	19
Innovation Spaces	Workshop environments that are either created or appropriated to host co-design, co-creation, or merely interactive feedback sessions.	29

in the first phase separately (Percent Agreement for Assumptions and Setups, 89.2% and 92.8%, respectively), and in the second phase the points of disagreement were discussed. Out of 1520 coded values, the two researchers could not agree on 24 values, attributed to seven papers. In two papers the Setup was not clear and in five papers there were disagreements on the Assumptions. These seven papers were removed from the data, and an array of coded data as following was produced:

$$V = \begin{pmatrix} A_{1,1} & A_{1,2} & \cdots & A_{1,9} & S_1 \\ A_{2,1} & A_{2,2} & \cdots & A_{2,9} & S_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ A_{145,1} & A_{145,2} & \cdots & A_{145,9} & S_{145} \end{pmatrix}$$

The outcome is a matrix V, with ten columns and 145 rows. $A_{i,j}$ is a binary value indicating whether or not Assumption j appeared in paper i. S_i contains a value between one to five and indicates the type of Setup in paper i.

In the next step we sought to find patterns in matrix V, specifically looking for interdependencies between A and S values in a row. As the details are described in the following, matrix V is the input to the Principal Component Analysis that we performed in step 3.

3.3.3 Analysis of Interdependencies (step 3). By investigating the interdependencies between the Assumptions and the Setups and among the Assumptions themselves, in this part of the analysis, we sought to find evidence in the data that suggests each of the Setups correlate with a specific pattern of Assumptions. For example, we expected that if the study presented in a paper is conducted in a Visited Place, the authors, with a high probability, mention concepts related to Intervention Evaluation, and Real Life, but with lower probability ideas similar to Innovation and Interdisciplinary Study (for the description of these terms, please see Tables 1 and 2). Without aspiring to find clear-cut clusters, our aim was to search for tendencies in the data that may clarify the different conceptual directions that living lab trends may be taking.

Principal Component Analysis (PCA) was performed on the Assumptions as the original variables ($A_{1,1}$ to $A_{145,9}$ in matrix V). PCA is one of the well-established methods to uncover and visualize interdependencies in multivariate datasets, and a good fit for our objective to investigate interdependencie between Assumptions and Setups in the coded data [1]. Figure 2 shows the resulting Correlation Circle diagram, in which each vector represents an Assumption. The angle between two vectors is an approximation of the correlation between the two Assumptions they represent. The smaller the angle between two Assumptions the higher the likelihood that they co-occurred in the papers. For example, the small angle between *Longitudinal Study* and *N* indicates that in most of the papers that one of these Assumptions was appeared as a concept associated with the idea of Living Lab the other one appeared as well. On the other hand, the wide angle between *Intervention Evaluation* and *Stockholder Engagement* suggest that these two almost never co-appeared in a paper. The magnitude of the vectors in Figure 2 specifies their "contribution to the variance in the data", that is, the higher the magnitude of vectors the more statistically reliable the above inferences based on the angles between vectors (redundantly, this is also represented with color-coding). PCA also provides values that determine whether the contribution of each variable is statistically sufficient to be able to infer conclusions in terms of their correlation with the other variables [10]. Table 3 shows the summary of statistically significant correlation values between the process variables and the first three principal components. The correlation results highlight the six most influential variables, which we will also use for developing the analysis in the next part. Figure 2 suggests patterns in the occurrence of Assumptions—some expected and some unexpected. An example of an expected correlation is a positive one between *Longitudinal Study* and *N*, while a less expected one (and thus more interesting to analyze) is the

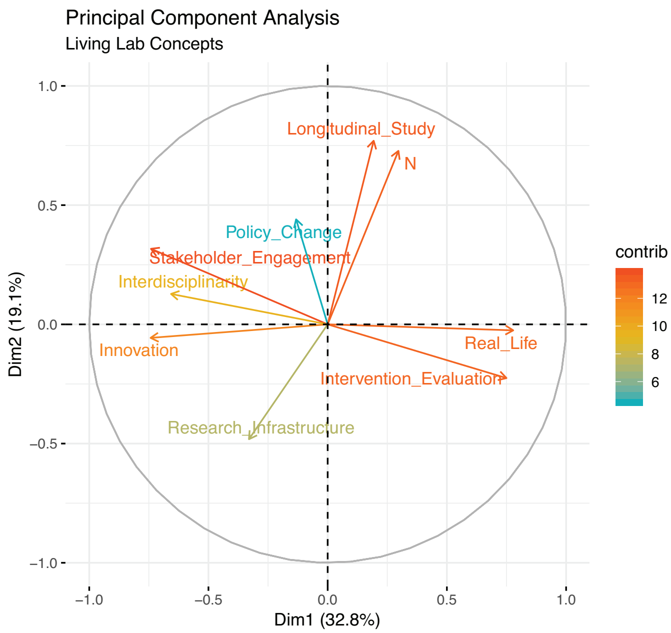

Fig. 2. The nine living lab Assumptions correlated with the first two principal components. The angle between the vectors is an approximation of the correlation between the Assumptions. The contribution of variables to the variance in the data is color-coded and also represented by the magnitude of the vectors.

negative correlation between *Longitudinal Study* and *Research Infrastructure*. We will discuss these patterns further in the next section where we will characterize living lab trends based on their co-occurring Assumptions.

The correlation values and diagram only demonstrate the influence of Assumptions and their relations. To have a more complete picture that also includes the Setup variable, in the next visualizing attempt, we render the data points (i.e. papers) color-coded based on their Setup. Figure 3 shows the Normal Confidence Ellipses superimposed on the data points positioned along the dimensions of the first two principal components. In other words, for each Setup, the diagram draws an area that contains the most of data points corresponding to that Setup (with confidence level equal

Table 3. The statistically significant correlation values between the process variables and the first three principal components. The values which were not significant were removed from this table. The first three factors explain 32.8%, 19.1%, and 13.2% of the variance in the data, respectively.

	Principal Components		
Variable	*First*	*Second*	*third*
Real Life	0.452	-	-
Innovation	-0.432	-	-
Intervention Evaluation	0.436	-	-
Stakeholder Engagement	-0.431	-	-
Longitudinal Study	-	0.587	-
N	-	0.554	-

Fig. 3. The result of PCA illustrating the correlation between the living lab Assumptions and the areas that cover the data points (i.e. papers) with the same living lab Setup. The separation of areas covered by the five types of Setup suggest distinct yet overlapping conceptual frameworks associated with each living lab trend.

to the mean plus one standard deviation on each side). The data points and confidence ellipses are color-coded based on the corresponding Setup; the center of each ellipse is specified with a bigger dot. As mentioned before, only the variables (i.e. Assumptions) that showed statistically significant correlation with the first or second principal component appear in the diagram (specified in Table 3).

With a look at the distribution of areas across the 2D plane in Figure 3 one can see the overlaps but also a fairly distinct positioning of the ellipses. Please note that in a perfectly random setting where there is no correlations between set of co-occurring Assumptions and the Setups, all of these ellipses would have expanded over the whole surface of the plane. However, in the following we try to offer a more precise reading of the visualization in Figure 3. First, we take one exceptional Setup out of our discussion, explain the rest and then bring the exception back to the picture. The exceptional case is the Instrumented People (the orange ellipse), which overlaps considerably with two other Setups (Instrumented Place and Lived-in Place). The four other Setups cover rather distinct areas in the rendered space and the center of each falls inside a different quadrant of the Cartesian system. Given that the organization of data points along the axes of the first and second components is the best possible way to illustrate the nature of variance in the data, the separation of ellipse areas can infer that Setup is a fairly accurate distinguishing factor, and thus, a good identifier for the living lab trends. In other words, each of these four Setups (Visited Place, Instrumented Place, Lived-in Place, and Innovation Space) corresponds to a portion of the data that can be characterized well by the values of the

Assumptions—the PCA original variables. Now, considering the exception, we argue that the last statement is true also for the Instrumented People. This Setup corresponds to the portion of the data that almost always mentions two adjacent Assumptions (Longitudinal Study and N), with no particular tendencies towards or against other Assumptions. The combination of Longitudinal Study and N, what we would like to refer to as the "Scalability" factor, is the key characteristic of the Instrumented People trend and distinguishes it from the others. In fact, for the other four Setups, we could and will discuss their specific key Assumptions. However, their visible separation provides enough evidence for the purpose of examining our hypothesis.

In conclusion, the result of the PCA on the occurrence of Assumptions and Setups, as illustrated in Figures 2 and 3, makes visible evidence for supporting the hypothesis *H* that we formulated earlier. The statistically significant correlation between the first two components and six of the Assumptions suggests that the variations in the data are related to the meaningful differences in how living labs are conceptualized in different papers. In addition, the visually distinguishable areas in Figure 3 suggest that Setup is a good identifier for the living lab trends. These are the two indications we have found in the data that support our hypothesis. Even though parts of our reasoning are based on visual observation and do not suffice to formally validate a hypothesis, we argue that it was a beneficial step not only to confirm the hypothesis, but also to make visible the directions along which the trends of living labs diverge. We sketch these directions in a schematic diagram shown in Figure 4. In the next section, we explain the elements of this diagram and use it to compare the five trends of living labs, with examples.

3.4 Summary of Analysis and Results

In this part we sumerize the main outcomes of the analysis as described above. The choice of the method of analysis (exploratory reading, coding, and PCA) was directly driven by the specific goal of this study, that has been to render insight into the collective understanding(s) of the notion of living lab in HCI as well as the interdependencies of the concepts that have been associated with it. We hypothesized that different understandings of the term living lab are distinguishable in the literature and that these strands of understanding correspond to the alternative forms of living lab infrastructure. The first two qualitative steps of analysis revealed the list of methodological advantages that has been associated with the idea of living lab (i.e. Assumptions) and distinguished the alternative data collection infrastructure that living lab projects have been expected to make available to the HCI researchers (i.e. Setups.). Through a coding task we created a matrix of values that shows for each of the papers in our study set which Assumptions are associated with the understanding of living lab in that paper and which type of Setup is considered as the data collection facility. The PCA was then performed on the coded data to validate the original hypothesis. It did provide quantitative evidence supporting the hypothesis and also could visually reveal some of the different characteristics of living lab trends that we will try to elaborate in the next section.

4 THE CHARACTERISTICS OF THE LIVING LAB STRANDS

The distinctions and common characteristics of living lab trends contain more intricacies than what the PCA could reveal. Each of the five trends provides different opportunities, entails different experimental considerations, may be most suitable for specific types of research questions, and so forth. These are what we will try to cover in this section. First, we sumerize a grasp of PCA results in a schematic diagram. Next, for each trend, we present a discourse that takes the diagram as the starting point but expands it to elaborate on the attributes of that trend with reference to some of the prototypical examples from the pool of studied papers.

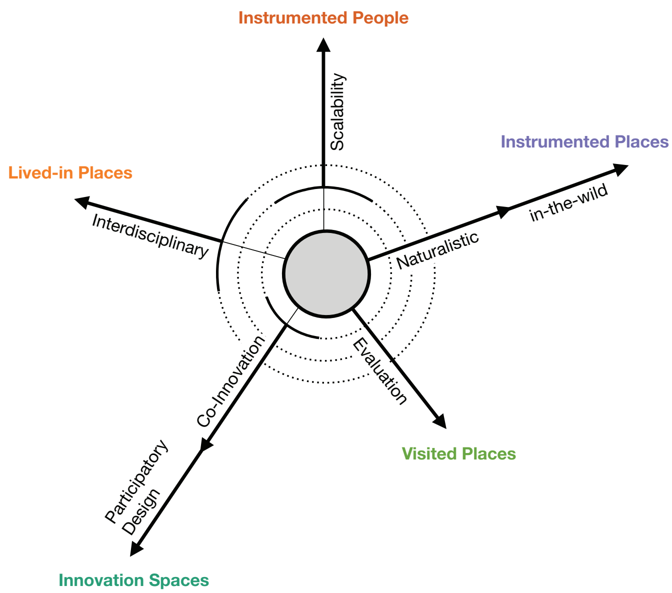

Fig. 4. Living Lab Trends: the evolution of the core and new ideas leading to five trends of living lab. The diagram is a schematic abstraction of Figure 3; the arrows correspond to the variable arrows; the Scalability arrow represents both the Longitudinal Study and N.

4.1 Overview

The schematic illustration of living lab trends, shown in Figure 4, is essentially inspired by what is visualized in Figure 3, abstracted from some of the details, and with slight rearrangements of elements. The fist aim of this section is to explain how this illustration is created and what it signifies. The Assumption vectors in Figure 3 are transformed into arrows (or forces) that each push forward one of the five strands.

When examining this figure, starting from 1) Visited Places, the suggestion presented in the schema is that they are motivated primarily by the specific needs for the evaluation of (embodied) interventions. This is an interpretation that can be inferred from the configurational relations of Assumption vectors and Setup areas in Figure 3, particularity from the spatial alignment of the Intervention Evaluation vector with the Visited Place ellipse and the position of its center point. Figure 4 re-illustrates this with an arrow named "Evaluation" pointing to the Visited Place strand. Continuing a similar task for the other strands completes the schema in Figure 4: next, moving counterclockwise, 2) Instrumented Places emphasize Real Life (or ecological validity) —another core idea in the original conception of living labs, which was later reinforced remarkably by the "in-the-wild" movement in the HCI research.

The other three strands seem to have been instigated by somewhat external waves that we symbolize in Figure 4 as dotted concentric circles. 3) The Instrumented People strand capitalizes on the advancing possibilities for pervasive sensing through mobile and wearable devices. This kind of living lab can be argued to be inherently more scalable than the others in terms of time and spaces of study, as well as the number of participants that can contribute simultaneously. 4) Lived-in Places aim to provide living environments that are also a site for interdisciplinary research. They particularly support research on topics that address human experiences within built environments. Relevant disciplines such as Architecture and Building Performance Sciences are the influencing factors in the initiation and development of this trend. Finally, 5) Innovation Space is distinctively motivated by the need for engaging users in the process of innovation—the line of thought that has been reinforced by the reemergence of participatory design movement in HCI.

In the following, we elaborate on each of the trends in a separate section and try to compare their attributes using some of the prototypical examples in the literature.

4.2 Visited Places

As built environments resembling typical living spaces (kitchen, living room, office, etc.) that are heavily equipped with sensors, Visited Places are still essentially laboratories for research, shaped and equipped to provide naturalistic test environments. Studies in Visited Places recruit human subjects to spend a limited period of time in the highly monitored designed environment while being exposed to one or several experimental conditions. These type of living laboratories provide a fairly controlled experimental condition with the price of strictly confining the spatial and temporal scope of the context they study. The participants have other habitual work and living environments that might not resemble to the test environment. Moreover, they may have to experience alternative conditions or technological interventions that are not necessarily relevant to their normal life, nor empowering them in their daily activities, or even be of their personal interest.

Aware Home of Georgia Tech [39] and PlaceLab of MIT [34] (in its initial form) are classic examples. PlaceLab is described as a real house where routine activities and interactions of everyday home life can be observed. Its interior is formed by 15 cabinetry components each containing a micro-controller, and a network of 25 to 30 sensors. The Placelab was designed for multi-day or multi-week observations of single individuals living alone. Visited Places were proposed as an in-between option that can be used to help migrate studies from the laboratory conditions to more realistic settings. The wave of ubiquitous computing and the need for evaluating ambient technologies at the place where they serve everyday activities have been the major motivating factor for this strand of living labs. Some of the other prototypical examples of Visited Places are Broadband Institute Residential Laboratory [51], the living room setup created at KU Lauven [43] designed to study TV gaming, and the R-House, a five-room house used for research on human-robot interaction and the design of domestic interactive technologies at Indiana University [16]. Such living labs are typically created on a university campus or at the site of a research institute, the urban area may be of substantial difference to the areas where the participants had built up their habits and organized their daily individual and social activities.

4.3 Instrumented Places

Instrumented places, unlike Visited Places, are not built to provide a research facility. They are real living environments with their ordinary inhabitants who agreed to participate in a study at their own homes or offices. Researchers instrument these places with retrofitted sensors and collect data for a certain period of time, spanning from a few hours to a few months.

Over the past decade, living lab as an Instrumented Place has been widely adopted by the HCI community. This may be, for a large part, along with the resurgence of "in-the-wild" approach, along with the particular values it has established. Nevertheless, a (thin yet significant) border is notable between research in the wild and conducting studies in Instrumented Places. There is a general expectation of living labs (within HCI) to use substantial sensing, with an emphasis on quantitative methods, which sets them apart from in-the-wild research—where the goal is typically to observe the genuine context within which human experiences shape and unfold. Moreover, the (often messy) installation of sensors in the environment and the continuous data collection in Instrumented Places can introduce a bias in the results of the study as they can modify the occupants' sense of privacy, natural perception of the environment, and consequently their behavior.

For example, Castelli et al. [18] observed 12 houses over three months to evaluate the usability and the appropriation of a visualisation tool they developed to display data from various smart home systems in an integrated fashion. In the description of the study the characteristics of households that participated in the study and the urban area of the houses are detailed, indicating the authors' attention to the importance of the broader context including family dynamics and life style—what would have been missed in a Visited Place setting. Kanis et al. [37] ran a study in two houses aiming at assessing an application that displays how smart home devices operate. The specific purpose of the application was to inform the elderly about how ambient assisted technologies function and how the collected data is used. In both of these example projects, quantitative and qualitative methods were used in complementary ways and the participants were occasionally engaged in a dialogue about the assessed technologies. Also, significant effort was needed to select and acquire the appropriate places that could host the studies. Similar to these two projects, many other studies particularly in the domain of smart home and IoT systems have adopted this approach to living labs (e.g. [3, 15, 30, 32, 36, 38, 48, 52]).

However, other than smart home and IoT systems, there are other good examples of research topics that can take advantage of Instrumented Places, namely questions surrounding the idea of Resourcefulness (i.e. "adaptation, modification, and reinvention of technologies in everyday life"). Kuijer et al. [41], in the context of conceptualizing Resourcefulness, proposed instrumenting artifacts with sensors to be able to capture when the same object is used as a different means, for a different purpose, within a different situation, etc. Studying resourcefulness—since it

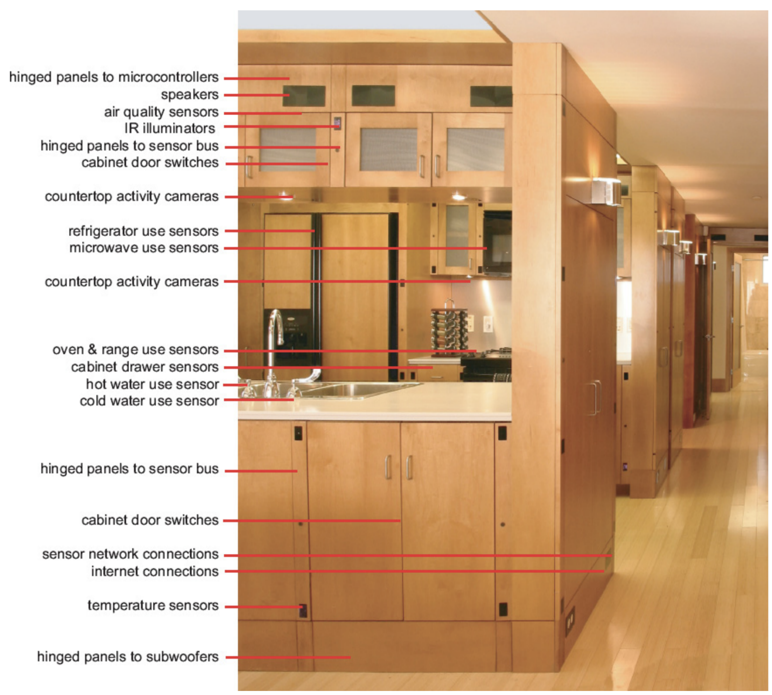

Fig. 5. The MIT Place Lab is one the earliest instances of living lab that can be categorized as a *Visited Place*. (Image taken from [34]).

requires a genuine ecosystem of artifacts, spaces, and people—exemplifies another class of research questions for which Instrumented Places can provide the most appropriate experimental setting.

Studies in Instrumented Places can produce outcome with high level of ecological validity, not only in comparison with studies in Visited Places, but also among all the five types of living lab. This is partly due to the fact that they retains the social and spatial context, but also for their specific ability to capture elements that develop over time. For example, the natural multidimensional binding between member of a family and their home—an influential element to the experience of smart home technologies—can only be captured at the place where such bindings have been constructed and established over years.

Instrumented Places, nevertheless, suffer from at least two limitations. First, it can only help studies that pursue understanding of experiences that are spatially confined within the boundaries of a certain place that has been instrumented. And second, the recordings are temporally limited to the times when the participants are at that place. However, many of our activities extend beyond one place (e.g. knowledge work being done at home, in public transport, in offices, co-working spaces, cafes, etc.), and even for the case of smart home systems many of the applications (e.g. home security system) must be able to operate independent of the user's location. The temporal boundaries are also meaningfully limiting, since even many of the localized experiences may be impacted by the user's experiences prior to the time of the observation. The model of the living lab that we describe in the next section, strives to address these two limitations.

4.4 Instrumented People

By recruiting a community of individuals who agree to carry a wearable device and/or install recording applications on their smartphones, this type of living lab provides researchers with highly scalable sources of data that are not necessarily bound to a physical location or limited to short lifespan activities. Compare to the other strands of living lab, scalability in the key advantage of Instrumented People, that is, they enable conducting studies with more participants simultaneously, and at the time and locations where observation by researchers may have been difficult if not impossible.

For example, Staiano et al. [63] recruited a group of more than 100 volunteers who carried instrumented smartphones in exchange for a monthly phone service credit bonus. A sensing system was installed on the their smartphones that logged communication events, location, and application usage, over six weeks. The objective was to combine the data collected from the smartphones and the surveys that the participants filled out everyday to render insight into the users' perception of their own online activities and the value of sharing information in digital platforms. Furthermore, one can find traces in the HCI literature suggesting that not only the new possibilities for living labs to take advantage of mobile and wearable sensing have been recognized, but also a new type of living lab has emerged, which capitalizes primarily on mobile and wearable technologies and can capture an extended version of the context beyond fixed locations. Hofte et al. [65], for example, in a workshop proposal to MobileHCI 2009, called for the necessity to broadening the discussion of "Mobile Living Labs" and envisioned their substantial contribution to the evolving world of living labs. Astrom et al. [8], in another visionary contribution, argued that what they refer to as "pervasive mobile participation" can shape the future of living lab methodologies for they enable addressing questions that entail connecting to multiple contexts.

It is worth noting that, other than new possibilities for data collection, the Instrumented People model creates opportunities for engaging users in addressing certain issues that may be situated in dispersed locations—what is commonly referred to as "situated engagement" [40, 57]. An example, at the urban scale, is to ask participants share their ideas about the design problems they notice in public spaces as they are at the location, and engage in the process of innovation and solution seeking through mobile applications designed for that purpose.

Fig. 6. Smart Living Lab in Switzerland is an example of the *Lived-in Place* model. The building hosts research labs and start-up companies with more than 100 occupants who use the building on a daily basis. Photo courtesy of Lutz Architectes.

The methodological and conceptual backdrop for the emerging shift in the HCI living lab literature towards the model of Instrumented People [20, 42, 56, 56, 63] is the main argument made; namely, that the study of human experiences using mobile and wearable sensors will be able to outperform fixed recording devices in terms of accuracy and completeness of the data. Considering the cost for the creation of Instrumented People living labs and their enabling power, arguably it is only due to technical immaturity of mobile sensors that other types of living lab can still be justified. The current mobile sensors are still susceptible to noise, are less accurate as they are constrained to be light-weight, and are less reliable in terms of functioning continuously since they depend on a battery.

4.5 Lived-in Places

Similar to Visited Places, Lived-in Places are built for the specific purpose of facilitating research projects. However, unlike Visited Places, they are functional built environments which are used as real apartments, offices, schools, and so forth. The occupants of the environment are the (almost) permanent participants of studies. Each study is typically longitudinal or may even be planned with no temporal constraints. Research conducted in Lived-in Places could be confined to collecting data from the daily activities in an unobtrusive way, or could entail the occupants' active engagement and commitment to giving feedback about a novel technology or experience they are exposed to. The occupants of Lived-in Places are aware of the fact they are contributing to a long-term research program and are informed about when, where, how, and why their daily activities are observed. The incentives for participation can be financial (low rental price), and/or being at the forefront of testing new design concepts, services, or novel technologies [15, 50].

For example, the Smart Living Lab in Switzerland [6, 68] consists of a an office building with private and shared office spaces, meeting rooms, and a cafeteria, hosting everyday more than 100 knowledge workers who are employees of start-up companies or members of university research groups. The constructed spaces incorporate various types of sensors and the building occupants are occasionally asked wear indoor tracking bracelets during the time they are in the building. The physical and social environment of Smart Living Lab has created practical opportunities for

Fig. 7. The Malmö living lab is an example for the category of living labs that we lable as *Innovation Spaces* strand. This living lab has been utilized to examine participatory design approaches and social innovation in the city of Malmö. Photo taken from http://medea.mah.se/malmo-living-labs/.

developing interdisciplinary projects where, for example, researchers from the domains of Architecture and Computer Science collaborate on topics related to human interactive experiences within smart built environments. Beside the current office building, a whole urban block is dedicated to this project and the plan is to extend the scope the living lab infrastructure to include also residential apartments, a hotel, as well as public outdoor spaces.

Lived-in Places are typically created in the framework of ambitious projects that include several research groups from various disciplines. By bringing the different stakeholders to the site of research, they aim for quicker transitions from research findings to design guidelines and policy-making.

Figure8, in four schematic illustrations, compares the methodological specificities of the four above described strands of living lab. The fifth strand in not included in this illustration because the ideas behind this model may be implemented in various types of spaces and take different shapes as we describe in the follwoing.

4.6 Innovation Spaces

In the context of industries' attempts to introduce novel products to the market, Innovative Spaces have emerged as a response to closed innovation environments and the limited interaction with potential markets [62]. They promoted the concept of "democratizing innovation" which was initially defined by management and innovation research to be achieved through providing easy access to production tools so that the lead-users and the new experts drive innovation. The vision of participatory design then complemented this vision by foregrounding the bottom-up long-term collaborations amongst diverse stakeholders and by introducing a shift from a product-centric view to a focus on socio-material working relations [12, 13].

Ideally, Innovation Spaces bring together companies, research organizations, individuals and civic sectors as stakeholders; they are typically in the form of workshop rooms (ideation or maker spaces); one could use stratification to recruit participants or take pre-existing communities of stakeholders; data collection include recording the dialogues, the process of co-creation, and the resulting prototypes.

Innovation Spaces, to our knowledge, manifest the dominant type of how the concept of living lab is perceived in the business and management literature. In the HCI literature, studies in Innovation Spaces are presented in relation to the need for engaging the users in the early stages of the design process of a technology whose usability would be evaluated in the practice of the same or a similar population. For example, Morgan et al. organized co-design sessions with the members of a large organization to explore the potentials of technological innovations that can encourage energy saving behavior among the office workers. The reasoning is that persuasive technologies, to reach their optimal capacities, entail the inclusion of nuanced user's routines, practical needs, and concerns. At the end, we would like to

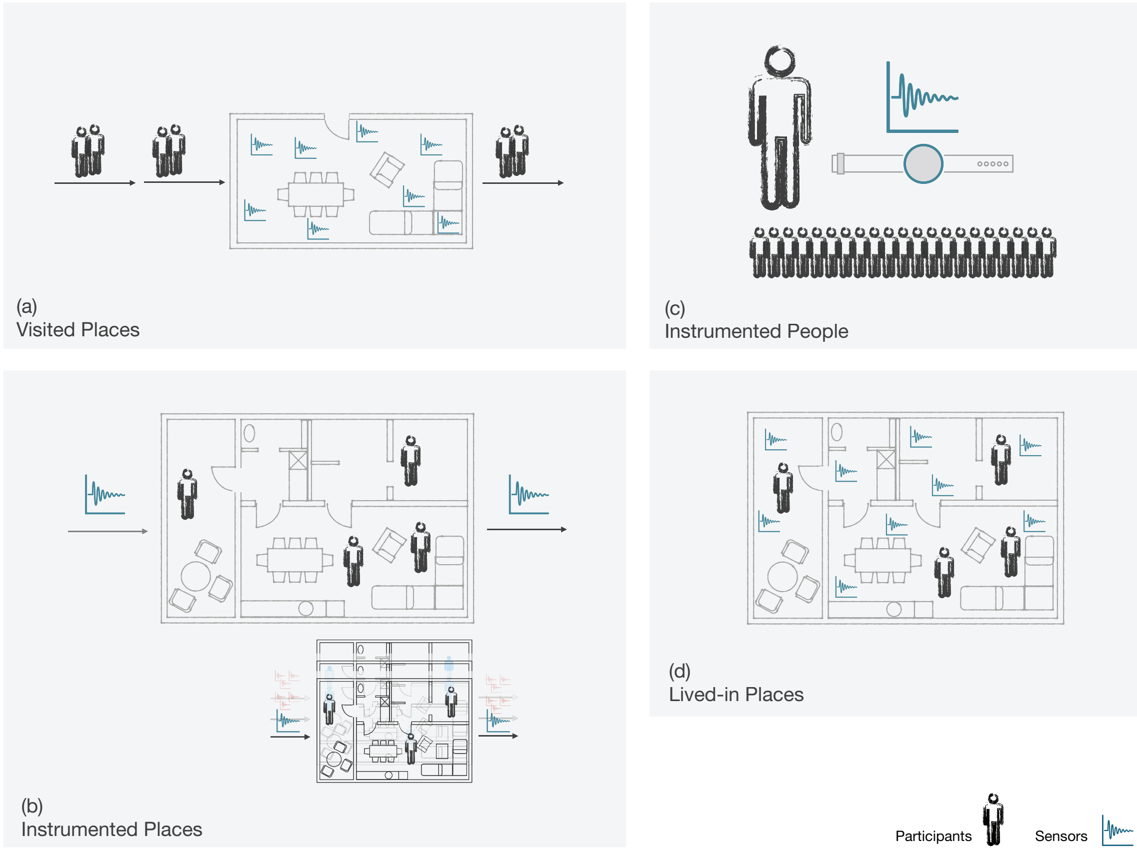

Fig. 8. (a) **Visited Places** are built environments that resemble a living space and are heavily equipped with sensors. Participants, in sequential sessions "visit" the place (live in the environment for a few hours to a few month and then leave). (b) **Instrumented Places** are real living environments that are used by their ordinary inhabitants and are instrumented with a set of sensors. Sensors are removed from the place after the study. Typically, several places are monitored simultaneously in a study. (c) In the **Instrumented People** model a group of participants carry sensors embedded in wearables or as smartphone applications. Many people in many places can be studied simultaneously. **(d) Lived-in Places** are built environments equipped with sensors (similar to Visited Places) and host permanent residents (similar to Instrumented Places). Various methods are used to incentivize such long-term participation. The **Innovation Spaces**, is not included in this figure because the ideas behind this model may be implemented in various types of spaces and take different shapes, with the common goal of creating a platform for stakeholders' active participation in the process of innovative design (as described in the Section 4.6).

remind that, in all of the other strands of living labs that we discussed in this section, the idea of involving users at the early stages of the (innovative) design process exists with varying extent. Innovation Spaces, however, in contrast to the other types, is first and foremost a social environment with a key aspect that is the capacity to simultaneously meet social needs, create social relations, and within that social atmosphere examine participation in innovative creation.

Table4 summarizes the main advantages and limitations, as well as the distinct features of each living lab strand in comparison with the others.

Table 4. Comparing the five strands of living lab in terms of their methodological advantages, main limitations, as well as their distinguishing characterestics.

	Main Advantages	Main Limitations	Distinct Feature
Visited Places	—High level of control on experimental parameters, design intervention, and data collection	—The created place might not match the participants' habitual living environments, thus low ecological validity.	—Essentially a lab setting (that resembles a typical living environment) —The initial conception of living lab in HCI
Instrumented Places	—High level of ecological validity —Simultaneous data collection	—Spatially limited to the places that are instrumented, and temporally limited to when those places are used	—Ephemeral living labs. The sensing equipment are removed from the place after the study.
Instrumented People	—Large number of participants —Simultaneous data collection —Can collect new types of data (e.g. physiological)	—Immaturity of mobile sensors (battery life, accuracy, reliability)	—Wearables and smartphones used for sensing —Location-independent
Lived-in Places	—Longitudenal studies —Fairly high level of control —Fairly high level of ecological validity	—Cost and resources needed for creating real living environments —Incentivizing participation to long-term and pervasive sensing	—Environments built as a real living place but also a research infrastructure —Ambitious and multidisciplinary projects
Innovation Spaces	—Studying people as co-designers (not merely users) —Direct impact on product development and policy making	—Open setting; not appropriate for evaluating a technology rigorously, or validating a hypothesis	—The provided space could be a workshop or an open space and does not resemble a living place.

4.7 Multiple Trends in One Project

To conclude this discussion, we would like to clarify that many combinations of the living lab strands are plausible in a project. While presenting conceptually distinct ideas, they are practically compatible. For example, it would be perfectly imaginable to complement the study of a smart home technology in the living room (Instrumented Place) with the data collected from the participants' smartphones as to how they monitor their home when they are away (Instrumented People) (e.g. [61]). In that case, we should refer to the situation simply as a combination of Instrumented Place and Instrumented People. The more carefully the combinations are planned the more productive the living lab project can be.

5 VISION AND AMBITION

In the previous section, we depicted the current state of the varied strands of living labs. In this section, we reflect on their future and aspirations from the standpoint of HCI.

5.1 The Persistence of Living Lab Concepts

The persistence, proliferation, and mutation of living lab ideas, in the early years of the current century, is a collective acknowledgment that there exists a growing space of opportunities for developing research methods that go beyond lab-based studies while emphasizing large-scale contextual data collection. This is the space that HCI has found the most suitable for researching embodied interactions of ubiquitous and social technologies [23], for better integrating participatory design with open innovation [17], and for contributing to interdisciplinary studies on interactive experiences with and within built environments [28].

No matter what we consider as the original development of the notion, our enquiry into the current trends of living labs exhibits a general perception that living labs, in the broad sense, hold the potential to become an increasingly influential player in the future of HCI research. The evidence is not limited to the steady growth of the number of papers that we see in Figure 9; many living lab projects are being launched all over the world and many research programs are being developed within those projects.

While admitting that the future trajectory of living labs is too complex to forecast, we would like to start an analytical discourse on the future of living lab trends, scrutinizing which ones will make no/less sense and which ones will take new shapes; what benefits HCI can gain from these evolving trends, and what lessons living labs can learn from the rest of HCI for their future directions.

5.2 The Aspiration of Living Lab Trends

Figure 10 shows the number of living lab papers in our sampled collection, along with their publication year, separated by trend. The apparent decrease in the number of published works on Visited Places matches our observation that this strand can no longer contain the ambitions of living labs. Even in the formulation of early projects in this trend, for example in PlaceLab [34], it was mentioned that portable sensors will be developed to be able to bring the studies from their "living laboratory" to inhabited apartments —forecasting a transition from Visited Place to Instrumented Place. With the advancement in sensing technologies, many of the studies that previously justified the creation of a Visited Place could be run in real living environments, with a clear advantage in terms of ecological validity. Nevertheless, in special cases, Visited Places may still carry a unique advantage. That is, when the technology to be evaluated is not compelling enough for the participants to try it in their daily life, either due to its immaturity or because of the experimental nature of the intervention. Only if a research project requires a number of such studies and running them in lab settings would meaningfully impede the validity of results might investing in the construction of a Visited Place be reasonable.

The vision of the Instrumented Place strand seems to be intertwined with the evolving worlds of Smart City, Smart Building, and the Internet of Things. The question is how far are we from a future in which every place is an instrumented place and every object is a connected object that can embody design interventions? In addition, the advances in artificial intelligence and more broadly data science has made possible the analysis of large volumes of data and eliciting the context where data is collected. Capitalizing on such classification capability, future studies of human experiences can investigate—in uncontrolled conditions of living lab—questions that previously needed to be studied in a controlled context. Instrumented People is a pioneer in that future, promising an expanding platform for pervasive mobile sensing and large-scale contextualized data collection. It is not by coincidence that, in our quantitative analysis, the distinguishing characteristic of Instrumented People appeared to be scalability. The same can be expected for the Instrumented Place strand: the prospect of a flourishing body of work on smart environments and connected objects is

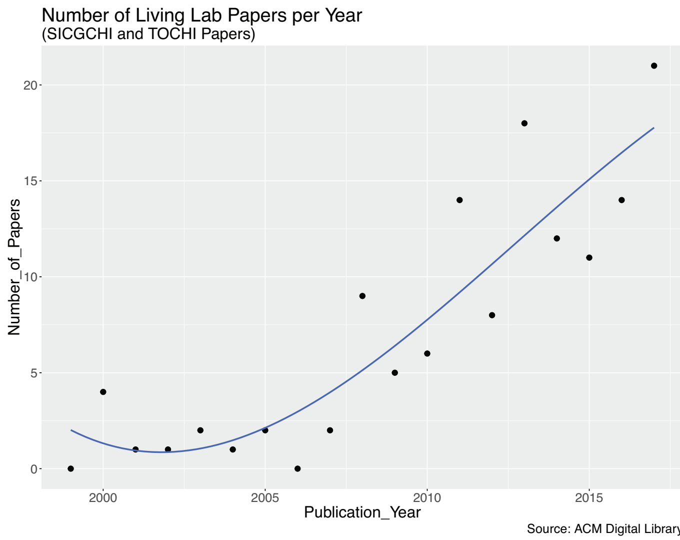

Fig. 9. Number of articles published in SIGCHI and TOCHI since 1999 that mention the term living lab. (The line is a third-order polynomial model of the data points.)

auspicious for the scalability of Instrumented Places where researchers will not need to equip every place that they plan to study by themselves. A complementary combination of Instrumented Place and Instrumented People, therefore, may provide an ideal future scenario. Between these two then, the balance would be determined by the type of required sensing, place-based vs. individual-based, depending on the research question at hand. Moreover, the combination of these two strands can provide a platform for research that, because of its scalability and pervasiveness, allows for replication of studies and validating the results across various parameters such as culture and geographical location.

Innovation Spaces and Lived-in Places are in quite a different situation; they are remarkably invested in by other research fields for specific purposes. The challenge for HCI researchers contributing to these projects manifests itself in resolving some of the methodological discrepancies and creating conditions that maximize mutual benefit for all the contributing fields. For the case of Innovation spaces, business and innovation sciences have reached out to the principles of participatory design examining methods of co-design and user engagement in the process of innovation to raise the success rate of products and services. We also noticed, in our literature study, that participation of stakeholders in the process of design is incorporated into many of the living lab projects that might be primarily categorized as Lived-in or Instrumented Place. We expect that, for HCI, this will be the dominant way of pursuing the ideas related to co-innovation (i.e. to be blended into others strands).

Lived-in Places, similar to Instrumented Places, aim to create a platform for contextualized large-scale data collection, and thus, their future should merge into the vision that relies on smart built environments (as described previously). But, that does not tell the whole story; Lived-in Places are often built to scaffold research on some of the contemporary concerns in the domain of Architecture and Urban design, namely, questions related to sustainable living, comfort, automation, agency, and so forth. These are also the topics of interest for an emerging branch of HCI that has started to offer notable contributions to the study and design of built environments. The emerging notion of Human-Building Interaction (HBI) [4, 5] is a framing attempt for this new branch of HCI that is considering a transition from the realm of artifacts to the realm of architecture. Lived-in Places, because of their interdisciplinary nature that involves a consortium of research groups, is a fertile ground for HBI research and design to develop a research agenda that is informed by the

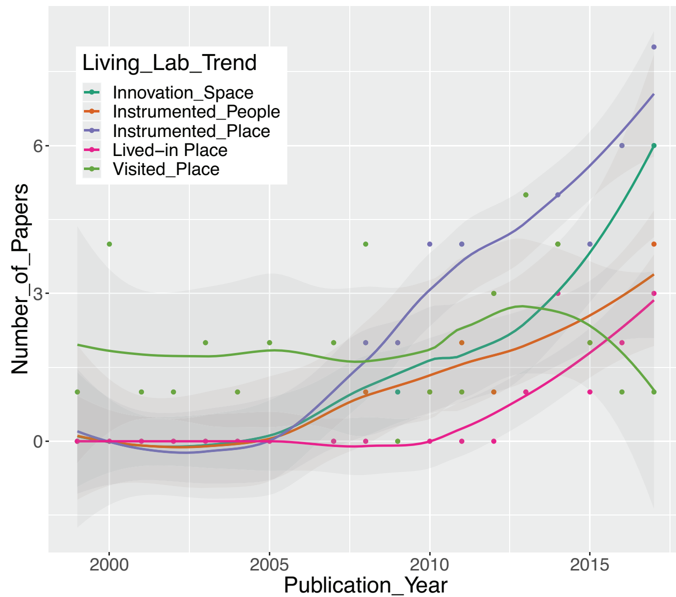

Fig. 10. Number of articles published in SIGCHI and TOCHI since 1999 that mention the term Living Lab(oratory), categorized into five types of living labs. (The line is a local polynomial regression model of data points with alpha=0.1)

constraints, challenges, and ultimate objectives of architectural projects, and thus be able to have a real impact on the future of built environments and the future of living.

5.3 From Participation to Partnership

Much of the reasoning we developed in the last section underlined sensing and data collection. Also, many of the papers that we reviewed emphasized exhaustive data collection in the form of place-based or pervasive sensing. The emphasis on data and quantitative methods is somewhat rooted in the notion of living *lab*; it is the thread that ties the future of living labs to the future of smart built environments, and defines the position of living labs within HCI methods, particularly against the in-the-wild approach. This, nevertheless, does not undervalue qualitative attempts in living lab studies, and it would certainly be naive to assume that the ubiquity of sensors embedded in smart environments will reduce the role of researchers to the quantitative analysis of data that stream readily into their databases. On the contrary, because of the extensive sensing, living lab researchers confront new critical challenges, particularly in terms of relations with the living lab inhabitants. Building trust through the means of transparency and awareness while implementing the measures of privacy protection, as well as offering the possibility for opting-out from the study, is a primary challenge, considering that the individuals are immersed spatiotemporally within the monitored environments. *Trust* is one element that the special attributes of living labs impose to the relationship between researchers and the subjects of their studies; *Empowerment* is another. Living lab interventions need to bring meaningful value to the users to be able to persist in real homes, offices, hospitals, or schools for a long time. Empowering living lab users can be accomplished in a multitude of ways and scopes, for example, by visualizing and bringing back the sensed data to the inhabitants(e.g. [61]), or through assistive solutions that, even though under examination, are mature enough to be enabling.

Trust and empowerment are two elements of an organic shift that we propose in the relationship with the subjects of living lab studies, a shift from what has been commonly practiced as *Participation* to what we start to envision as *Partnership*. In such a model, living lab inhabitants are considered as the engaged, informed, and proactive partners of a research program rather than passive or reactive participants of a study. It is still a work-in-progress for us in the HCI community to render the methodological nuances of such model. However, what we intend to offer through introducing the notion of Partnership is a means for HCI to follow its perennial mission to ensure that human values and priorities are advanced, that they are not compromised in the living labs' data collection pursuit, while supporting living lab studies in producing actionable and effective knowledge. This may be the imperative to prevent living labs from spiraling out of control.

6 CONCLUSIONS

We studied the evolution of living lab concepts over the past twenty years in the HCI literature. The qualitative and quantiative analysis of 152 SIGCHI and TOCHI papers uncovered five distinct trends of living labs in the HCI literature, which we labeled as "Visited Places", "Instrumented Places", "Instrumented People", "Lived-in Places", and "Innovation Spaces". We describe each trend of living lab and compare their methodological attributes using prototypical examples from the literature.

This contribution is an invitation for researchers to adopt the proposed classification in order to complement and clarify the future description of their living lab studies. We also hope that the presented attempt to analyze our collective ideas of what living labs are, coupled with the brief discussion of what they should become, help frame the challenges and open questions, as well as furthering critical discourses on the future role of living lab methods in HCI.

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