Impact and Challenges of Design and Sustainability in the Industry 4.0 Era: Co-Designing the Next Generation of Urban Beekeeping

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Abstract In the era of Industry 4.0, designers are expected to use new tools and approaches to innovate the design of products and services. From this perspective, the integration of design practices and technologies of the 4.0 transition can have positive implications for sustainability. Several current issues can be addressed and among them, honeybee death is relevant. Honeybees are fundamental to the ecosystem and human life. Nevertheless, their lives are extremely at risk due to exposure to several disease factors. After conducting expert interviews, the paper presents a conceptual model of intelligent beekeeping to monitor the health status of honeybees. Furthermore, after user research, the paper proposes a co-design model for urban beekeeping, scaled up to a condominium dimension, to allow condominiums and expert beekeepers to be part of an integrated design model. The critical proposition of this model is to raise awareness of the problem of honeybee death to achieve 3 out of 17 United Nations' Sustainable Development Goals: Good Health and Well-Being, Sustainable Cities and Community, and Life on Land. Early results report positive values of acceptance of the urban beekeeping practice by users and the use of IoT in managing beehives and their health status by expert beekeepers.

Keywords Urban beekeeping · Industry 4.0 · Industrial design · IoT technology · Design for sustainability · Co-design

United Nations' Sustainable Development Goals 3. Good Health and Well-Being · 11. Sustainable Cities and Community · 15. Life on Land

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M. Barberio et al. (eds.), *Architecture and Design for Industry 4.0*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-3-031-36922-3_21

1 Introduction

The industry 4.0 paradigm is moving forward quickly, increasingly changing our world and the way we live and work [1]. This digital transition provides tools to address urgent issues with the help of new and emerging technologies.

The 4.0 model affects the way designers *design* as in any industrial revolution. The exponential development of digital technologies is certainly increasing the virtual component of our experience [2]. In this ever-changing scenario, design can indeed gather input, tools, and procedures that can be used to solve critical issues.

In the twenty-first century, designers must think of products and services differently from their ancestors. In Industry 4.0 enabling technologies such as the Internet of Things (IoT) provide new design opportunities to empower people and enrich their daily lives, in real-time and smart connecting people.

On the other hand, the impact of Industry 4.0 on sustainability and the way it can contribute to sustainable economic, environmental, and social development is increasingly gaining attention [1]. The 4.0 paradigm may offer opportunities for sustainability, by helping to achieve the United Nations' Sustainable Development Goals (SDGs) outlined in the 2030 Agenda. This document provides a set of guidelines for sustainable development, adopted by all United Nations member states to promote effective design for sustainability.

Thus, the paper aims to stimulate 4.0 awareness for designers who must solve real and compelling issues related to this era. Also, the paper defines the role of design in the 4.0 paradigm to achieve and disseminate innovative solutions and projects according to the 17 United Nations Sustainable Development Goals.

The honeybee can benefit from this digital 4.0 transition with the help of design, and its well-being can have positive implications for sustainability. Indeed, honeybees are the most effective pollinators of crops and are crucial in order to achieve sustainable development [3, 4]. Since the end of the twentieth century, honeybees are suffering from increasing stress factors, leading domesticated colonies to die or at least be less productive [5]. Also, several factors including parasites, bacterial and fungal infections, and pesticides [3] have been identified as drivers of honeybee death and this phenomenon triggered the need to rethink beekeeping and its tools.

Many plant species would become extinct without them, and current levels of productivity could only be maintained at great cost through artificial pollination. Domestic and wild honeybees are responsible for about 70% of the pollination of all living plant species on the planet and provide about 35% of global food production.

The future of beekeeping is to implement smart 4.0 beehive management using automated and remote tools for monitoring honeybee colonies along with beehive control mechanisms to safeguard honeybees' well-being and improve colony productivity [6].

There is also a growing awareness of beekeeping, particularly in metropolises and cities [7], called *urban beekeeping*. This practice of raising honeybees in an urban environment is blended with the co-design perspective and the creation of communities of experts and non-experts for the safeguarding of honeybees. We use co-design in a broader sense to refer to the creativity of designers and people not trained in design working together in the design development process [8].

Not all the reasons for honeybee death are fully known, and as a result, it is essential to obtain all possible information on the environmental conditions surrounding the beehives [9].

The digitalization of beekeeping first involves systems from the field of the IoT, with the development of sensors to collect and transfer honeybee-related data [5]. Then, data analysis comes into play, providing models that connect the data with the biological states of beehives. The speed and scale of IoT provide new design opportunities to empower people and enrich their everyday lives [10].

Thus, in this paper, we want to address the following Research Questions (RQs):

RQ1. What is the urban beekeeping' acceptance level of users?

RQ2. How IoT can be an appropriate tool to help beekeepers in managing and control beekeeping systems?

Through semi-structured questionnaires, we surveyed a sample of 463 participants to figure out their knowledge and awareness about beekeeping and honeybees' safeguard and to survey their acceptance of the urban beekeeping model. Also, we conducted expert interviews with expert beekeepers to survey their needs, knowledge, and acceptance of 4.0 tools for beekeeping.

The remaining paper is structured in four sections. The first describes the state-of-the-art related to smart monitoring systems for beekeeping. The second describes the methods adopted to answer the RQs. The third relates to the discussion about the role of design within the 4.0 era and its potential to reach three sustainable development goals through the conceptual model. Lastly, we report our conclusions and future works.

2 Related Work

Beekeeping has a huge impact on all agricultural field, as honeybees are the main insect pollinators and plays the important role in whole crop production and the survival of plants [11].

Recently, urban beekeeping is a rapidly developing model, involving beekeeping *in*, *of,* and *for* the city [12]. Beekeeping *in* the city concerns the importation of traditionally rural beekeeping practices into urban spaces on behalf of the beekeeper. Beekeeping *of* the city describes beekeeping consciously adapted to the urban context, often accompanied by (semi)professionalization of beekeepers and the formation of local expert communities (i. e., beekeeping associations, and communities). Beekeeping *for* the city describes a shift in mindset that addresses beekeeping for civic purposes beyond the beekeeping community itself.

Beehive monitoring is fundamental to monitoring different parameters, such as the temperature and humidity levels inside the beehives and the weight, sounds, and gases produced, which can generate important information. For example, these data can inform whether the beehives are swarming based on the temperature, whether any action is required from the beekeeper, whether the honeybees are affected by any disease, or even whether the beehives are affected moving. This last application is very useful in areas where beehives can be stolen.

Different technologies can be applied to monitor the beehives [9]. A smart beehive is a connected beehive with some intelligence, for example, a beehive capable of diagnosing health issues [5, 13].

Phillips et al. [14] encouraged the "Bee Lab project" that blends citizen science and open design with beekeeping. Their objective was to enable participants to construct monitoring devices gathering reciprocal data, motivating them and third parties. They used design workshops to provide insight into the design of kits, and user motivations, promoting reciprocal interests and addressing community problems.

Murphy et al. [15, 16] developed a fully autonomous beehive monitoring system. Their objective was to use Wireless Sensor Network (WSN) technology to monitor a colony within the beehive by collecting image and audio data and developing a multi-data source beehive monitoring system. WSN technology includes sensors, low-power processing, mobile networking, and energy harvesting. In this way, the beekeeper will obtain recorded information about in-hive conditions (e. g., during the night, winter months, etc.). The contributions of this work also include the unobtrusive monitoring of the beehive during times when the beekeeper is unable to open it.

Zacepins et al. [6] introduced and analyzed different bee colony monitoring and control systems and their combinations within the ERA-NET ICT-Agri project 'ITAPIC'. Also, they presented their vision for the implementation of Precision Beekeeping together with the smart apiary concept system based on temperature, sound, and video monitoring.

Gil-Lebrero et al. [9] designed a remote monitoring system for honeybee colonies (i. e., WBee) based on a hierarchical three-level model formed by the wireless node, a local data server, and a cloud data server. WBee is a low-cost, fully scalable, easily deployable system for the number and types of sensors and the number of hives, and their geographical distribution.

Lyu et al. [17] designed an intelligent beehive system with a real-time monitoring function of the status information of the inside and outside of the beehive (e. g., weight, attitude, etc.). The beekeeper can check the status of the beehive in real time in the monitoring center. The system reduces beekeepers' labor and improves the quality of honey.

Kontogiannis [18] developed a holistic management and control system for the apiculture industry called the Integrated Beekeeping System of holistic Management and Control (IBSMC). This system allows honeybee living conditions regulation, aiming at minimizing honeybee swarm mortality, and maximizing productivity. Within the proposed system architecture, additional security functionalities are implemented for honeybee monitoring, low energy consumption, and incident response.

Existing beehive control and management systems allow for critical thinking and rethinking of smart beehive models thanks to design approaches and 4.0 technological tools.

3 Methods

Beekeeping can be innovated and conceived as a co-design activity that can involve not only expert beekeepers but also ordinary citizens. By broadening the knowledge about beekeeping to the urban level, a series of actions can be performed that can benefit honeybees and cause benefits, combined with IoT technology.

The two research questions were explored through user research and expert interviews to answer needs, expectations, and problems and subsequently formulate a model.

3.1 User Research

We analyze the context of use by investigating the user awareness concerning honeybee importance and their behavior. Thus, we create a questionnaire using Google Forms distributed to a sample of potential users for 12 days ($n = 306$; 59,3% female and 40,7% male). The questionnaire provides quantitative data about user knowledge and user behavior regarding honeybees through 13 open and closed questions. As an interesting result, the user analysis demonstrates that most of the users are aware of the phenomenon of honeybee death (82,8%). Also, many users know that honeybees are fundamental to human life and sustainability (84%), but most of them have never heard of urban beekeeping (58%). A mere 30.1% have observed a beehive up close previously and most are unaware of the possibility of being able to adopt a beehive (68%) and monitor its health (82%).

Interestingly, most of the users would like to have a condominium beehive to raise honeybees in their condominiums ($M = 6$; $SD = 0,4$ on a 7-point Likert scale).

In addition, users were asked about their agreement related to the listed requirements to have a condominium beehive using a 7-point Likert Scale. The results were compiled into a graph (see Fig. 1).

3.2 Expert Interviews

We conducted expert interviews to gain information about beekeepers' IoT adoption and explore their knowledge and expectations. Expert interviews are a widely used qualitative interview method often aiming at gaining information about or exploring a

Fig. 1 Condominium beehive requirements preferences according to users on a 7-point Likert Scale

specific field of action [19] (i. e., beekeeping). Those were semi-structured interviews based on the use of a questionnaire covering the following topics:

- Generic knowledge:
  - Threats to traditional beekeeping: climate change, immoderate use of pesticides, lack of food due to excessive plowing and extensive monocultures, and spread of beehive diseases (e. g., Varroa).
  - Actual problems of urban beekeeping: swarming. For the urban environment, swarms can become a nuisance and a fright for the citizens, both for citizens' lack of knowledge about them, but also the inconvenience concerning the places where the swarming families decide to settle (e.g., inhabited places, schools, etc.).

- IoT beehive adoption: according to the expert beekeepers, there is not a wide knowledge of commercially available smart beehives and their possibilities for the environment. In their opinion, if technology could help beekeepers to manage their beehives, intelligent beehives equipped with sensors are useful. Helping beekeepers manage their beehives more conveniently, quickly, and effectively is an advantage. For example, those beekeepers with lots of beehives could optimize their intervention time and be able to intervene while helping their honeybees grow and thrive. Expert beekeepers will be willing to use intelligent beehives, based on two dependent variables: costs and ease to use.

Also, beekeepers expect IoT-intelligent beehives to:

– Remotely control the beehive's temperature, humidity, and weight to understand how the health status of the family from these parameters.
– Manage to predict swarming, and consequently avoid or control it. An abrupt decrease in weight indicates that swarming has occurred, but at that point, it is too late, at most, if possible, the beekeeper could intervene earlier to recover the swarm before it moves too far from the beehive.

The possibility of monitoring the health status of honeybees remotely, by a device (e.g., smartphone, tablet, laptop), would facilitate and improve the work of beekeepers.

- Urban beekeeping with a co-design approach: the idea of implementing smart condominium beehives as a co-design for beekeeping is very interesting according to beekeepers. However, there are some limitations and aspects to consider in the design phase:

  – Fear of condominiums.
  – Allergies of the condominiums.
  – Swarming: In the city, they can become annoying and even dangerous.
  – Distance From a legislative point of view beehives must be placed at least ten meters from public roads and at least five meters from the borders of the neighborhood, unless there is a natural barrier (e.g., hedges) or artificial (e.g., walls) at least 2 m high. In this case, the distance is nullified because the honeybees would be forced to fly above human height.
  – The non-training of condos.

  Also, the smart beehive will need to have several features:

– Anti-theft system.
– Honeybee health monitoring.
– Weight of beehives.
– Swarming prediction.

3.3 The Conceptual Model

User research and expert interviews allow us to collect useful data to develop a conceptual model of a smart beehive (see Fig. 2) and to predict from a co-design perspective a useful application for the communication between condominiums and expert beekeepers.

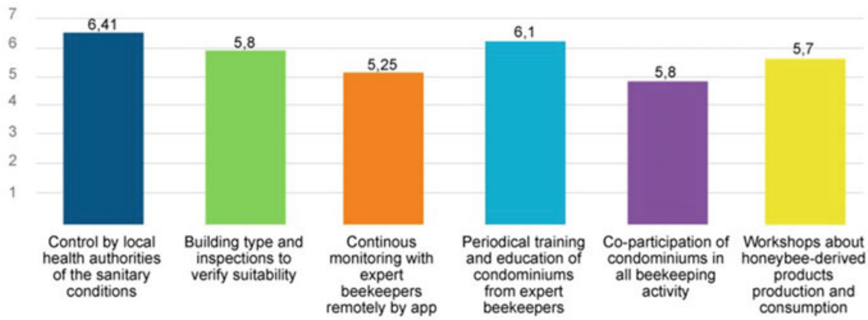

Fig. 2 IoT technology management. From honeybees to sensors, from the Internet to devices

Different parameters of the honeybee colony can be monitored: temperature, humidity, gas content, sound, vibration, etc. Continuous monitoring of some honeybee colony parameters is very challenging and not user-friendly, using it only for research purposes, not for practical implementation by the beekeepers [6].

3.3.1 Types of Sensors‘

In the IoT field, the choice of appropriate sensors is essential to produce a solid base before data analysis since sensors can capture beehive-related data [5].

The design of a wireless sensor network and IoT sensors involved in this are:

- Temperature and humidity sensors: honeybees need temperatures (90–95 F) and humidity levels (50–60%) to raise their brood optimally and promote overall colony wellbeing. Below 50% humidity, eggs won't even hatch because they dry out. Additionally, higher humidity levels significantly decrease Varroa mite reproduction levels and are desirable during the brood-rearing season.
- Accelerometer: registered data about frequencies and their variations in the beehive allow for to prediction of swarming phenomena [20].
- Weight: indicates the activity level of a colony and is a good indicator of honey flow evolution and flowering.
- Geo-localization: to localize the beehive to be reached by expert beekeepers and send data via the Internet to be visualized on the application.
- Anti-theft: a tracking device consisting of a GPS tracker, a battery, a SIM card, and a motion detector. It can be placed inside the beehive (e. g., at the lid, the bottom, the body, or even inside a honeycomb). The device will stay off, without draining its battery or disturbing the honeybees via cell phone radiation. With the slightest wiggling of the beehive, the device turns on and informs users with an SMS sent to their cell phones.

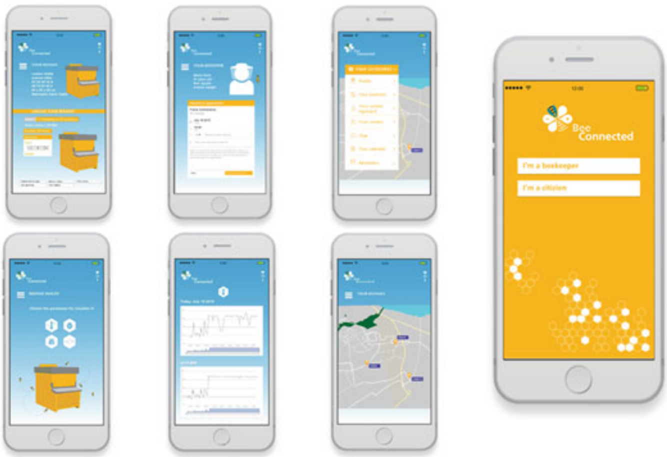

Fig. 3 Mockup of the mobile app from an expert beekeeper and condominiums point of view

All data about honeybee health could be transmitted to an application (see Fig. 3) through which users, both condominiums and expert beekeepers, can be informed about their health status and any urgent problems.

3.3.2 Co-Design Approach

Co-design is an approach to designing with, not for, people. Especially in areas where technologies mature, designers have been moving increasingly closer to the future users of what they design [8]. Co-design typically works best when people, communities, and professionals work together to improve something they all care about.

From this perspective, the co-design approach could potentially be extended to urban beekeeping. The process includes several parts and starts with "Build the conditions" (see Fig. 4) for the genuine and safe involvement of people (i. e. condominium requirements).

The reference community includes ordinary citizens grouped in condominiums, supported by expert beekeepers to carry out co-creation activities. The tools employed include IoT for controlled and shared co-design for the beehive management.

4 Discussion

Design plays a key role in achieving sustainable goals because, by leveraging design culture approaches (i. e., co-design approach) and Industry 4.0 transition tools (i. e., IoT technology), it can solve current critical problems.

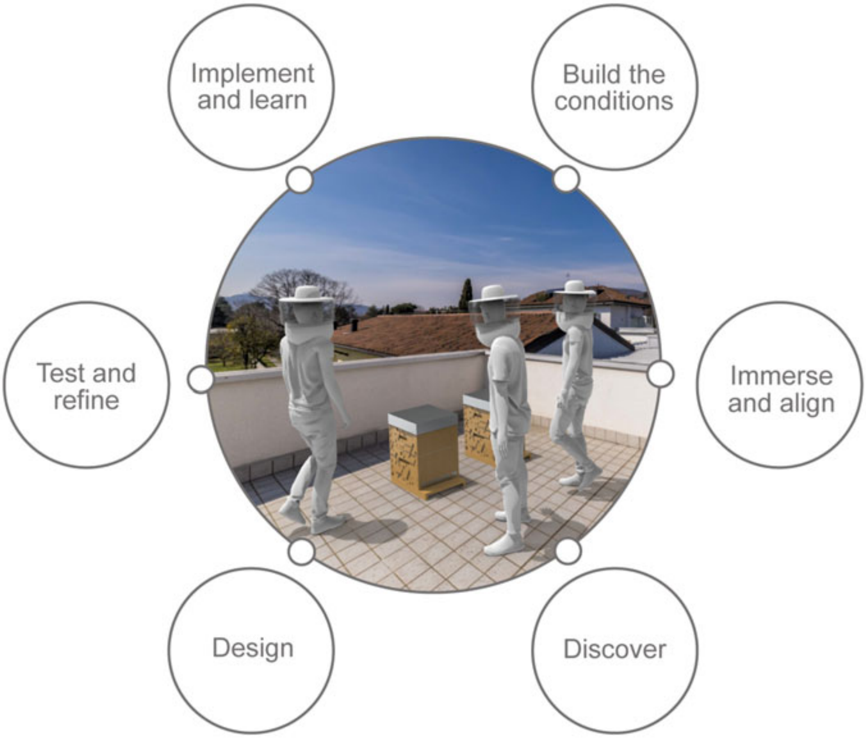

Fig. 4 The co-design process for the urban beekeeping

In this specific case, (e.g., the death of honeybees), the design allows for achieving three United Nations SDGs.

SD 3. Good Health and Well-Being

One of the sustainable goals relates to ensuring healthy lives and promoting well-being. The human being's health depends on the honeybee's health. This insect, thanks to pollination, enables new plants to be born and humans to breathe. Honeybees increase the possibility of a plant making more fruits and food for human beings.

The conceptual model developed allows for monitoring the health of honeybees in real-time, h24, to ensure their well-being, with positive implications for humans and the city. Intelligent beehives allow the recording of many variables such as:

1. Honeybee ecological variables

   - Colony life history: health monitoring, collapse events, requeening events (e.g., swarming), beekeeping tasks.
   - Colony dynamics: colony size, brood area, drone brood area, food reserve mass.

- Resource use: harvested pollen species composition, honey-embedded pollen species composition.

2. Environmental variables

- Floral resource phenology monitoring.
- Land use monitoring.
- Climatic data.

SD 11. Sustainable Cities and Community

The sustainable challenges cities face can be overcome to allow them to thrive and grow by improving resource use and reducing pollution.

Urban beekeeping would allow environmental monitoring, particularly related to air quality in cities. It is necessary to constantly monitor the presence of air pollutants to allow honeybees to live and reproduce in city environments. By observing the behavior of honeybees, it is possible to evaluate the presence of heavy metals, microplastics, and fine dust in the atmosphere. All these substances are as dangerous as they are unfortunately present in the air we breathe in large and small cities.

SD 15. Life on Land

From an ecological perspective, honeybees provide a source of both direct and indirect food to a whole host of organisms, including humans [15].

Protecting the population of honeybees worldwide and enabling them to maximize their productivity is an important concern [16] since they are fundamental not only for their well-being but also for humans and vegetation.

5 Conclusions

Design is constantly evolving and using new tools and approaches to design useful products and services to solve current problems. This paper shows how a relevant problem such as honeybee death could be addressed through the integration of the 4.0 paradigm and design.

User research shows that acceptance of urban beekeeping is high among many users (RQ1). This finding is important and encouraging for the development of conceptual models scaled to the urban dimension and, more specifically, to the condominium dimension. In addition, co-design could be a potential approach to innovate the practice of beekeeping, making it accessible not only to the expert beekeeper but also to the ordinary citizen.

Interviews with experts show that IoT is an appropriate tool to help beekeepers in the management and control of beekeeping systems (RQ2). Although there is no established knowledge of smart systems for beekeeping, there is a great interest in adopting technological systems to facilitate several tasks for beekeepers.

The first step in the future would be to set up the model and design in a real beehive to see how the system responds in a real-world deployment. Future tests would also provide valuable real-world data from the beehive, which can be used for further beekeeping research.

Furthermore, it is important to test the dimension of the co-design approach within one or more apartment buildings to collect data on their involvement in activities, and use of the mobile app and the IoT management model.

Acknowledgements We would like to thank the beekeepers Nicola Ignomeriello and Cristian Scalise involved in the project DontBEEScared—stai sen'APEnsieri which concerns urban educational beekeeping in Bari, Italy. They helped us recruit participants for the expert interviews and allowed us to discover the world of urban beekeeping deeply.

Also, we would like to thank the industrial designers Federica Gentile and Adriana Romeo for their valuable effort, who developed the concept together with their colleague, Marina Ricci, during the Master's degree course in Industrial Design at the Polytechnic University of Bari (2019/2020).

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