




Article

Children's Participation in the Design of Smart Solutions: A Literature Review [†]

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Abstract: Smart solutions are widespread and diversified. Smart cities and smart objects are example of smart solutions. Their design usually follows certain patterns so that they can detect events and react accordingly. As future citizens, children are expected to interact with them in their daily lives. It is thus crucial to provide children with the tools for understanding, creating, and possibly programming them—in short, designing them. This paper presents a literature review of workshops involving children in designing smart solutions. The review coded a total of 25 papers that met the inclusion criteria. The discussion draws a research agenda using the workshops organized by the authors, the Roobopoli workshops for smart cities and the SNaP workshops for smart objects, as reference. Whereas smart cities and smart objects are usually addressed separately, this paper binds and compares them in order to investigate what, in different settings, enables children to be part of the design of smart solutions.

Keywords: smart city; smart object; workshop; children; design; programming; ideation; prototyping; toolkit; in presence; at a distance



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1. Introduction

The smart city concept refers to “the search and identification of intelligent solutions which allow cities to enhance the quality of the services provided to citizens” [1,2]. Many authors give more central importance to information and communication technology (ICT) stating that smart cities are grounded on the ICT usage [3] and rely on an intelligent network of physical objects with computing capabilities, a.k.a., smart objects [4]. In general, smart cities and smart objects sense the state of the surrounding, reason on the input and understand external conditions, and take action to solve a given problem [5] by leveraging on the architecture of the so-called Internet-of-Things (IoT) [6,7]. Smart cities and smart objects are also referred to as smart solutions in a general and unified view.

While smart solutions are frequently mentioned in the news and political discourses [2], what they are and how they are designed are unclear for people without a technical background [2,8]. Recent research recognises the need to enable citizens to assume an active role in their design, e.g., [9,10]. That means exposing citizens to their technical components and working mechanism [8,11,12], and at the same time communicating complex concepts in a language clear to citizens without a technical background. Many methods have emerged to enable their participation, such as collaboratively creating public services by coordinating citizens and city authorities [13–15], ensuring early user involvement [16], guaranteeing inclusiveness of users with disabilities [17] through workshops, living labs, and online platforms [18].

When discussing citizen participation, it is often assumed that citizens are adults. However, children are an essential subgroup of the citizenry and should be sensitized to smart solutions and their design [2,19,20]. Children's involvement in smart design brings several benefits, such as competence-development, especially concerning computational thinking and programming [21], preparation for adult participation, and formation of children communities [22]. Such objectives go beyond the narrow idea of preparing more well-equipped programmers and engineers, as it is a broader approach to empower children's problem solving, creativity, communication, or abstract thinking skills [21]. It is imperative not only to train children of today in 21st-century skills but also to empower them towards designing and hence contributing to their own technological futures [23]. Children should be moved in the position of protagonists in design, who understand, critically reflect on, and drive innovation of smart solutions [24–26].

In the smart city and smart object design context, children are usually engaged in project-based learning based on (complex) tasks, challenging questions, or problems that require learners to design, experience problem-solving, and decision making. Project-based learning leads to the introduction of computational thinking, as children can learn through authentic scenarios, in an iterative approach of making realistic products with programming and robotics [21,27,28]. Hence, children are engaged in building, creating, and customising everyday objects to fulfil personally, and socially meaningful problems, fostering active and significant learning [21].

Project-based learning requires thinking about meaningful learning experiences for children, which trigger engagement [21,29]. It should thus encompass the entire design of smart solutions, which steps through diverse stages: an exploration stage for familiarising with what smart cities or objects are made of; an ideation stage for conceiving and conceptualising new smart ideas; a programming stage for programming smart solutions, made concrete during the prototyping stage [30].

This paper presents a literature review of workshops seeking to involve children and teens, up to 18 years old, in the design of smart solutions. Among them, 5 design workshops organised by the authors in the context of smart city and smart objects are also presented separately. In particular, the Roobopoli workshops that involved teens in programming challenges of smart cities and the SNaP workshops that involved children in designing their smart objects through ideation and programming. The review has the following goals:

- to understand the current situation related to the design of smart solutions by children and provide an overview of how such workshops take place;
- to articulate reflections on future directions based on this overview.

This paper is an extended version of the one presented at the workshop titled “Technology-enhanced learning for future citizens”, co-located with the “Methodologies and Intelligent Systems for Technology Enhanced Learning” conference (TEL4FC@MIS4TEL) [31]. While the TEL4FC@MIS4TEL paper focuses on the differences and similarities of the workshops organised and moderated by the authors of this article, this paper reports a literature review to explore how the literature addresses smart solution design with children, focusing on reflections for organising design workshops with children.

The paper is structured as follows. Section 2 describes the data collection process for performing the literature review and clarifies the inclusion criteria, related workshops in the literature for introducing children to smart city and smart object design. Section 3 overviews the collected articles and details the Roobopoli and the SNaP workshops, considered as reference workshops thanks to the full access to the workshops details. Section 4 compares key aspects of smart city and smart object workshops separately, while Section 5 thematically analyses and clusters reflections regarding the design of smart solutions by children. Finally, it concludes with observations and future directions.

2. Materials and Methods

This section clarifies the research questions, the data collection process and the inclusion criteria on the basis of the reported literature review.

2.1. Research Questions

The leading research questions (RQs) of the literature review of this paper are as follows:

RQ1 What is the current situation related to the design of smart solutions by children?

RQ2 What should be considered in future design workshops of smart solutions by children?

2.2. Data Collection

The literature review was conducted by in-depth reading, interpreting and categorising papers addressing the participation of children in the design of smart solutions [32]. The aim was to develop a comprehensive understanding and a critical assessment of the knowledge relevant to this topic. To be as inclusive as possible, the reported review considered studies that engaged any child or teenage participant up to 18 years old.

The search for the papers was carried out using the Scopus database because it is a comprehensive and yet accurate database of research papers in Child-Computer Interaction. Used keywords included smart city, smart object, design, programming, and children, and different variations of those. A search carried out in the Scopus database is as follows: (TITLE-ABS-KEY (“smart city” OR “smart cities” OR “smart object” OR “smart thing”) AND (design OR programming) AND (child* OR student* OR pupil* OR kid*)). It was further decided to limit the results in the subject areas of Computer Science, Engineering, and Social Sciences. Finally, results with conference review as document type were excluded. A total of 260 papers were found fitting these criteria.

2.3. Inclusion Criteria

In this phase, non-peer-reviewed papers, workshops, and posters were excluded, as well as papers with a topic that was not relevant for this review. Among the excluded papers were, for example, papers that presented projects with university students or projects involving only the description of artifacts designed for children. To be included in this review, the papers needed to contain empirical data from design workshops with children related to smart cities or objects. Taking these criteria into account, the number of selected papers was narrowed down to 25. Figure 1 summarises and schematically reports the exclusion and inclusion criteria considered during the selection process on the basis of this literature review.

Each paper was coded into a table featuring eight aspects as columns; design stages, materials used during the workshops, setting, modality, duration, number of participants, age of participants, and percentage of female participation. The coding was done by the first two authors of this paper collaboratively. The coding process was iterative, and all the materials were gone through several times to identify content in the paper representing these categories. After coding, the results were discussed to provide an overview of the understanding of the current knowledge in the area.

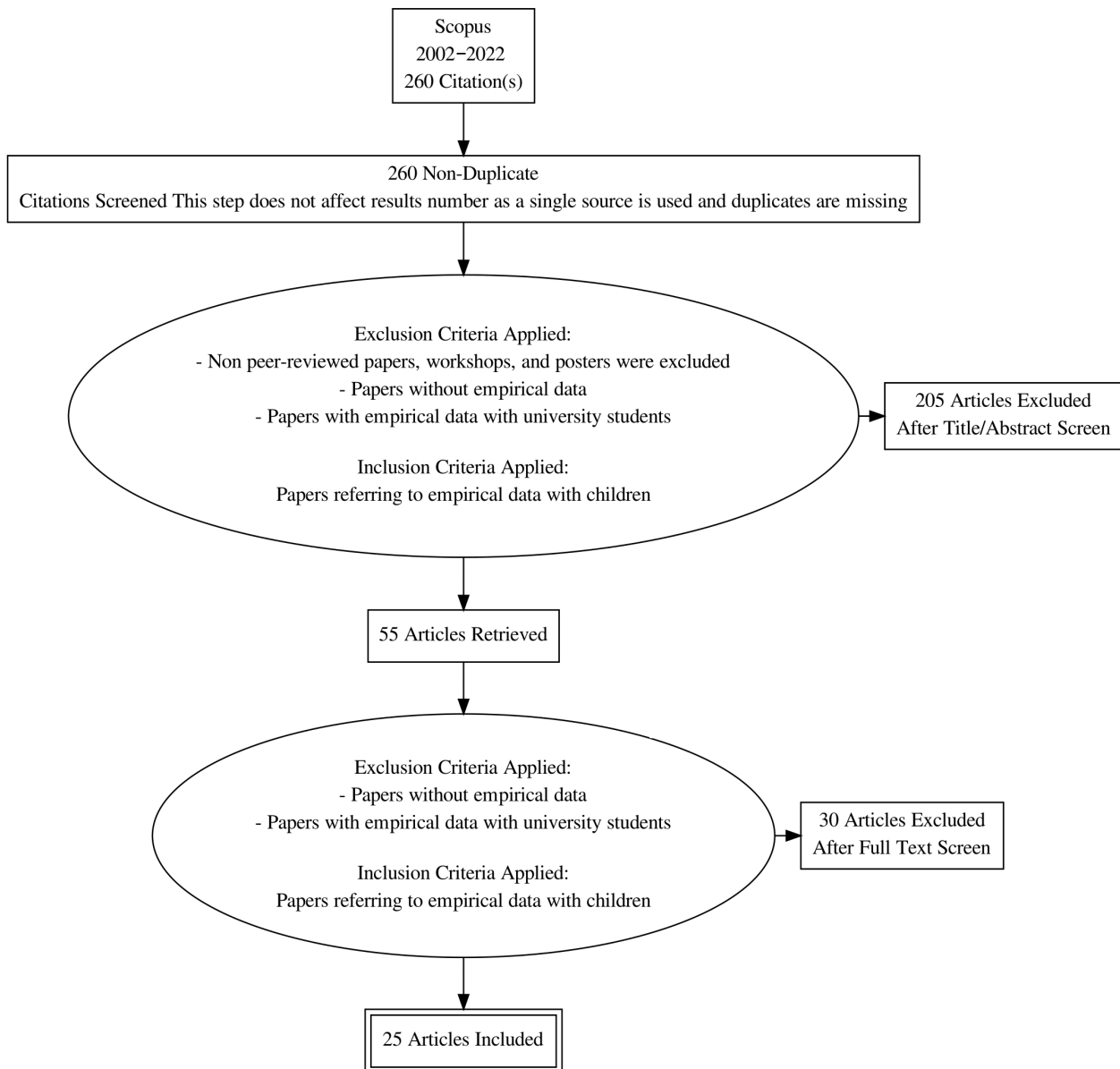


Figure 1. PRISMA chart describing the workflow on the basis of this literature review.

3. Results

This section overviews workshops proposed in the literature to enable children and teens to design smart cities and smart objects. Then, Roobopoli and SNaP are described in detail and used as a reference in the overview of procedures or settings to enable reproducibility and inspire future researchers in organising workshops in this context. Smart city and smart object workshops are recapped in Tables 1 and 2, respectively (the rows presenting the Roobopoli and SNaP workshops are shaded in gray). While the goal of the literature review is an overview of smart solution workshops in general, smart city and smart object workshops are presented separately due to the different approaches that organisers usually have in framing them.

Table 1. Summary of smart city design workshops with children.

<i>Study</i>	<i>Stages</i>	<i>Materials</i>	<i>Setting</i>	<i>Modality</i>	<i>Duration</i>	<i>Children</i>	<i>Age</i>	<i>Females</i>
[8]	(1) familiarization (2) city model (3) problem resolution	paper-based city model	formal	in presence	hours	21	12–14	40%
[2]	(1) familiarization (2) city model (3) problem resolution	interactive table	formal	in presence	hours	-	12–14	-
[21]	(1) brainstorming (2) idea exploration (3) programming (4) reflection	Scratch, MBlock, DOC MBot	formal	in presence	months	346	6–9	-
[33]	(1) familiarization (2) ideation (3) programming	virtual reality	informal	in presence	hours	30	6–10	60%
[34]	(1) exploration (2) programming	augmented reality, conversation agent	-	-	-	-	7–12	-
[35]	(1) programming	NetsBlox, Unity game	-	at a distance	-	-	-	-
[36]	(1) programming	Micro:bit	-	-	-	-	-	-
[37]	(1) exploration (2) algorithmic (3) programming	Roobokart	formal	in presence	days	300	13–18	30%
[37]	(1) exploration (2) algorithmic (3) programming	mBot	informal	in presence	hours	60	10–13	25%

Table 2. Summary of smart object design workshops with children.

<i>Study</i>	<i>Stages</i>	<i>Materials</i>	<i>Setting</i>	<i>Modality</i>	<i>Duration</i>	<i>Children</i>	<i>Age</i>	<i>Females</i>
[38]	(1) imagine & discover (2) make & prototype (3) test & present (4) reflect	physical computing devices, crafting material	formal	in presence	hours	>100	10–14	-
[39]	(1) design brief (2) field studies (3) ideation (4) fabrication (5) reflection	physical computing devices, 3d printers, crafting material	formal	in presence	weeks	>69	11–15	-
[40,41]	(1) ideation (2) conceptualisation (3) prototyping (4) refining & testing (5) evaluation	physical computing devices, crafting material	informal	in presence	months	5	6–8	20%
[42]	(1) storytelling (2) idea generation (3) mock-up creation (4) reflections	3d printers, paper-based material	informal	in presence	weeks	24	7–8	-

Table 2. Cont.

<i>Study</i>	<i>Stages</i>	<i>Materials</i>	<i>Setting</i>	<i>Modality</i>	<i>Duration</i>	<i>Children</i>	<i>Age</i>	<i>Females</i>
[43]	(1) exploration (2) programming	physical computing devices	informal	in presence	days	6	11–12	100%
[44]	(1) planning (2) scaffolding (3) building inquiry skills (4) teacher-child & peer-peer interactions (5) assessment/review	physical computing devices	formal	in presence	weeks	17	4–5	-
[45]	(1) exploration (2) ideation & programming	Tiles ideation toolkit, RapIoT, physical computing devices	formal	in presence	hours	44	14–17	-
[46]	(1) exploration (2) ideation	Tiles ideation toolkit	formal	in presence	hours	17	14–15	12%
[47]	(1) introduction (2) ideation (3) programming & prototyping	adapted Tiles cards, physical computing devices	informal	in presence	hours	21	10–11	52%
[48–51]	(1) exploration (2) ideation (3) programming & prototyping	physical SNaP toolkit, physical computing devices	informal	in presence	days, weeks	27	11–14	37%
[52,53]	(1) exploration (2) ideation (3) programming & simulation	digital SNaP toolkit	informal	at a distance	days	20	8–16	40%

3.1. Smart City Design by Children

Many countries, including Portugal [21], Belgium [18], Indonesia [5] are reforming educational curricula to introduce programming in schools since kindergarten to ensure early user involvement in smart city design.

Simonofski et al. propose a workshop to develop children's digital skills and their understanding of the smart city [8]. Their workshop is divided into three phases: (1) a theoretical introduction of the smart city concept, (2) the realisation of a city model with the children, and (3) the identification and resolution of urban issues on the model, with or without technology. It took place in a formal setting, at school, and lasted four hours split into two-hour sessions. The first session was dedicated to the first and second steps of the workshop, while the third step was conducted seven days later. During the first step of the workshop (approximately 30 min), children were challenged to link real-world services with smart city dimensions corresponding to environment, economy, mobility, public services, culture, living. The authors observed that students could accurately link the provided examples with the smart city dimensions. In the second step (approximately 1 h 30), children were challenged to create a smart city model, placing buildings on the model and reflecting on the performed choices with classmates to change their minds after the discussion. During this stage, children recognised the misplacement of the mall but disagreed on the new location. It resulted in a real-world problem corresponding to a voting system, implemented in the third and last workshop phase (lasting approximately 2 h). The authors analysed the evolution of their understanding of the smart city concept thanks to the insights gathered from the pre-tests and the post-questionnaire by the 21 children. According to children's opinions, a strong technological orientation was still present in

the smart city definition at the end of the workshop. However, it was clear to a wider set of participants that technology is instrumental for an explicit purpose to solve issues and improve citizens' lives.

Clarival et al. proposed a workshop split into two sessions, each lasting 100 min, retracing the same steps performed by Simonofski et al. with a different duration [2]. The first two steps take place over the first 100-min session, while the second session is fully dedicated to the third step. According to the revised version of the workshop, one of the major issues was insufficient depth in reflections around the city model, which is limited by its low interactivity [2]. When placing buildings on the model, children cannot ground their discussions on information concerning the expected impact of that placement. The debates were driven by children's personal preferences or by high-level questions such as the overall concentration of buildings. Clarival et al. addressed this issue by proposing a tangible collaborative interface to support the city model construction alternative to the paper-based approach. They envisioned the improved city model as an interactive table onto which an empty city map would be projected. The buildings placed on the table would then be recognized by a unique identifier, and data on its impact, such as road congestion or pollution, could be projected onto the city map to drive the discussion.

Gomes et al. proposed the Smart City Lab for Kids project to introduce computational thinking and creative computing in primary schools [21]. The project took place in a formal setting, at school, for three months, one or one and half hours per week. 346 participants joined the project, 44 belonging to the 1st and 2nd grades, and 302 belonging to the 3rd and 4th grades. The workshops explored the Scratch and MBlock block-based programming environments and the DOC and MBot robots. Participants explored computational thinking, tangible interfaces, and creative computing to design and represent solutions to transform their city into a smart city. A spiralling approach, based on Resnick's proposal, was followed. This is based on: (1) brainstorming, (2) idea exploration, (3) representing children's ideas through programming and robotics, (4) evaluation and reflection. All participants were administered a pre-test and a post-test, both with the goal of understanding their habits in terms of the usage of computers and robots. Observations and product evaluations served to analyse the process and validate the teacher-learning experience. As a result, authors state that paper mock-ups acted as a powerful tool to support algorithmic and programming. Moreover, programming tools and environments, based on more concrete interfaces as colored blocks, enabled to introduce children to computational thinking from an early age.

Stefanidi et al. [34] propose *MagiPlay*, an augmented reality serious game allowing children to manipulate and program smart environments. Children are provided with a handheld device that can be used to capture smart objects via its camera and create rules determining their behaviours via natural language through a conversational agent. Engagement is measured during the evaluation involving seven to twelve years old, and results are statistically significant.

Stein et al. explore robotics in a remote setting as a distance learning [35]. It implies experiencing several challenges caused by the physical access to hardware typically required by robotics. It uses the block-based programming language NetsBlox and a virtual environment used for simulation created in the Unity game engine to engage students regardless of programming experience with a simplified sensor network in a small smart city area and solve robot challenges. Challenges mainly concern traffic light programming and tasks connected to robotic behaviour programming. It reports experiments with students without detailing the participants' details and the evaluation settings. It results in a qualitative assessment concerning the satisfying task completion rate as all the participants completed the challenges and responded positively. However, some students with previous robotics experience said they preferred working with physical robots.

Prayaga et al. focuses on smart farms [36]. They exploit low-cost components, such as the Micro:bit and humidity sensor, and simple program languages to make the course content accessible to students at college and even school levels. No evaluation is explicitly reported.

Seraphin and Green mainly focused on tourism and stressed the crucial role played by drawing to enable children to communicate and show their point of views [33]. Their workshop lasted one hour during an off-school classroom session. 30 children joined the workshop, 6–10 years old, 12 boys and 18 girls. Firstly, moderators introduced the concept of smart city and provided participants with a sheet for briefly describing useful concepts. Secondly, participants were challenged to draw two sketches related to (i) the opportunity to use tablet technology to perform visit planning and dealing with arrivals and (ii) the use of augmented reality. Authors report that participants were satisfied to find their solutions independently, without adults' support.

3.1.1. Roobopoli Workshops

Roobopoli (Roobopoli website: <http://www.roobopoli.org> accessed on 20 January 2022) is an educational project that aims to make learners familiarise with smart cities and autonomous vehicles. It is designed by the Perlatecnica (Perlatecnica website: <http://www.perlatecnica.it/> accessed on 20 January 2022) non-profit association, with the technical support of the Bluenet company (Bluenet website: <https://bluenetita.com> accessed on 20 January 2022).

Roobopoli is a tiny smart city where the inhabitants' life is assisted by modern technologies. The town exhibits the same technology available in real cities, such as autonomous vehicles able to freely move on roads respecting traffic lights and road signs, reproduced in scale for educational, testing and simulation purposes. The Roobopoli city and the Roobokart set up tasks are considered an integral part of the Roobopoli workshops as an opportunity to practically experience smart city and autonomous vehicle components. Then, learners are challenged with missions requiring them to design and program a smart solution. Missions are designed to be well-known problems in this domain. They ask learners to experience real challenges and develop skills crucial for their (professional) future. Further details on the protocol follow.

Design Stages & Materials

Each Roobopoli workshop is organised in different stages: (i) an exploration stage to actively learn a smart city's components; (ii) a challenge requesting an algorithm, involving problem-solving skills; (iii) the programming stage, in which the algorithm is coded into an executable and working program. Each stage requires training, related to skills necessary for the goal of the stage. In terms of technical skills, participants are introduced to basic concepts of smart city and autonomous vehicle and practical aspects concerning their assembly. They are taught how to ideate an unambiguous high-level algorithm to solve the given mission, improving their problem solving skills. While problem-solving is a transversal attitude, coding and smart city design represent vertical skills (i.e., skills specific to a particular field). Each stage is separately analysed in the following.

Exploration stage: This stage enables participants to familiarise with what smart city and autonomous vehicles are composed of and analyse or construct them, according to their age and skills. It aims to make any participant familiar with components of smart cities and autonomous vehicles, such as sensors and actuators. At the beginning, Roobopoli can be presented as a disassembled city. Learners are first challenged to assemble it and respect constraints such as size, distances, road signs format, traffic lights mechanisms. The city structure is designed to be based on modular components that can be arranged according to the desired street configuration and the available space. Hence, less modules and a linear street can be used in case of demonstrations, where only limited space is dedicated to the city model, while city intersections and a bigger city model can be set up when a larger space can be dedicated to it, such as during learning activities. Figure 2 shows an example of the Roobopoli city at the end of the assembling phase.



Figure 2. Roobopoli city.

Once the city is assembled, learners might be invited to assemble and program city's vehicles, called Roobokart (Source code: <https://github.com/Perlatecnica/Roobokart> accessed on 20 January 2022, Demo: https://www.youtube.com/watch?v=g0307OEjOJg&feature=emb_logo accessed on 20 January 2022), displayed in Figure 3.

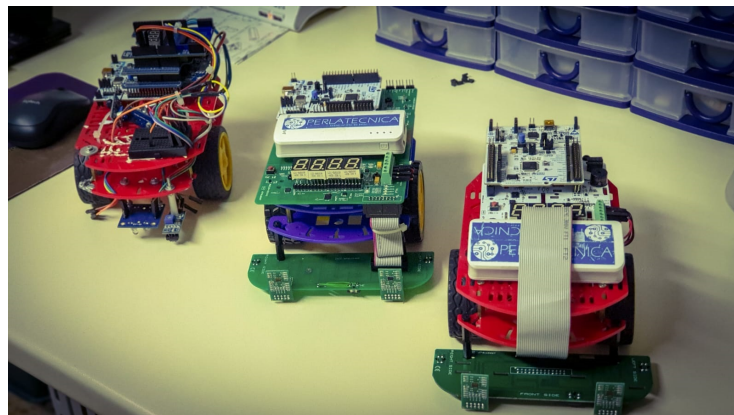


Figure 3. Roobokart.

Vehicles need to be programmed in order to move autonomously along the city roads. As in any smart city, Roobopoli and its vehicles are intelligent, i.e., they are equipped with advanced sensors and boards to sense data and behave accordingly. The boards are based on STMicroelectronics micro-controllers. More in details, Roobokart is controlled by an STM32 microcontroller mounted on a Nucleo F401RE board that is connected to a motherboard, equipped with accelerometers, gyroscopes, infrared sensors, colour sensors, and proximity Time-of-flight as sensors.

Algorithmic stage: This stage introduces participants to problem-solving for the chosen challenge(s) and related goals, presented as missions. They are reported in natural language, at a high-level, by splitting them into desirable objectives with unambiguous terminology. "Make the Roobokart able to autonomously move by following a line" is an example mission. During the resolution process, participants, organised in small groups (e.g., 4 members per group) deepen their problem-solving skills. In particular, learners have to decompose the mission into sub-problems and design an algorithm to solve them. Example sub-problems are "make the Roobokart able to perform line-following", "how to randomly turn at a cross". Missions are based on well-known problems in the smart city and autonomous vehicle domain to challenge learners to think about real world technical problems. In designing the solution, learners are invited to adopt unambiguous mechanisms, such as pseudo-code

or automaton modelling the vehicle behaviour at each input. This stage let participants develop problem-solving skills and unambiguous modelling solutions to a given challenge.

Programming stage: This stage ensures that participants become familiar with the basics of coding, such as, the concept of loops and conditions. Then, they have to implement their algorithm and make it into a working program, demonstrating how it can be applied in a real context.

Setting & Participants

The Roobopoli workshops took place from 2017 to 2019 and it involved two separate groups: a group of high-school learners, aged 13–18 years old, which stands for Roobopoli-1st workshop (a.k.a. R-W1); a group of middle-school learners, aged 10–13 years old, which stands for Roobopoli-2nd workshop (a.k.a. R-W2).

As shown in Figure 4, R-W1 worked in a formal setting, i.e., at school, during class hours for *Alternanza scuola-lavoro*, namely, hours devoted to the learning of skills for the job market, thanks to a collaboration between companies and schools. The workshop lasted 120 h in total, 4 consecutive hours per week. It involved 300 learners, around 30% females. Participants were encouraged to assemble Roobokarts and design solutions in C++ to pre-defined missions, e.g., “make the Roobokart able to freely move in the city and randomly choose the road to take at each cross-road”. R-W2 worked in an informal setting, after school hours, with children who voluntarily joined it. It lasted 16 h, 2 consecutive hours per week. It involved 60 participants, 25% females. Participants were provided with an already assembled robot and were encouraged to design solutions by means of a block-based programming language, i.e., the mBot programming language.

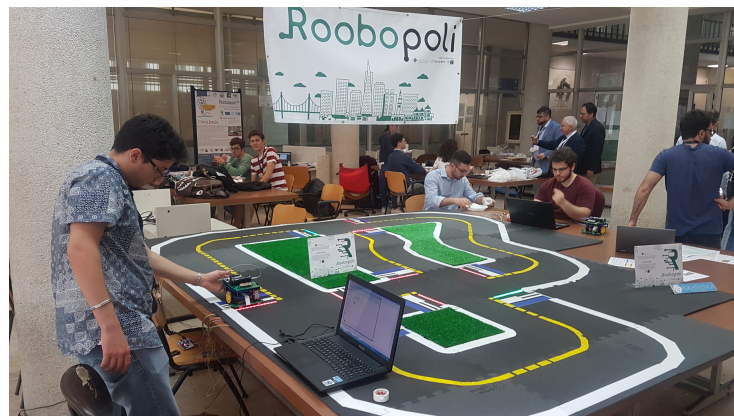


Figure 4. A Roobopoli workshop including the Roobopoli city and participants.

3.2. Smart Object Design by Children

The concept of smart objects is often difficult to be grasped by people not directly involved in the field, let alone children. Designing smart objects is usually a task reserved for experts with a background in electronics and low-level programming, e.g., [54]. This situation changed in the latest years, thanks to physical computing and microelectronic devices, such as Arduino, or specifically designed devices for children like Micro:bit [55,56]. Such devices make the design of smart objects possible for non-experts, such as children, as they facilitate micro-controller programming and standardise electronic assembly techniques.

Smart object design became an enabling process for shared, collective, and collaborative activities and an expression of creativity [42,47]. Smart objects have been used with children for educational purposes, as enhanced interfaces of physical learning objects, or as conduits to exploratory learning [57]. They have, thus, the potential to empower users by augmenting their understanding of technology and control of smart environments and stimulating their creativity [58].

Several approaches were made in the literature to involve children in the design of digital technology, such as smart objects. For their involvement, design thinking models are

very often used as a way to structure the process and transfer designerly methods and tools to children [59–61]. Bekker et al. for example, suggested a design-based learning approach through a framework [38]. The Reflective Design-based Learning (RDBL) framework is a way to teach digital literacy and design thinking to children in the school context. The framework includes suggestions on several components for framing design-based learning processes with children, e.g., regarding collaboration and reflection. Smith et al. developed a general framework, also used by other researchers, for framing a design process with children for digital fabrication [24,39]. Their framework organises design into a design brief and field studies, then ideation and implementation (referred to as fabrication). Several physical computing devices were used in the described workshops based on their framework, although not with a “tight focus on producing artifacts”. However, both of these approaches are not strictly designed around the concept of smart objects.

Frauenberger et al. instead, focused on the design of smart objects in design workshops with autistic children, as design partners [40,41]. Over several months, they engaged autistic children in a series of design stages to create their own individual smart objects with physical computing devices. Yavuz et al. also involved children in the design of new creative smart objects [42]. Children, however, did not use physical computing or other technological devices in their workshops but paper-based material. Their solutions were then 3d-printed as mock-ups by the participating designers. Their design workshop explored how designers can find inspiration for imagining our relation with smart objects, driven by the imagination of the children.

Seraj et al. involved 6th-grade female students in a non-formal workshop on smart object creation. Students were introduced to basic programming concepts and learnt how to apply them to turn a houseplant into a smart object. Their goal was to investigate how students’ attitudes and programming skills are influenced over time when they learn to program smart objects. Their results showed that students had high confidence regarding programming skills after the workshops, confirming some of the benefits that children can derive by their involvement in smart object design workshops [62].

Kewalramani et al. involved children in a design-based research method in which children were invited to build smart objects, in particular robotic toys [44]. Children used littleBits to conceptualise and create their artifacts with [63]. Findings through interviews with teachers and children showed that although novice in their own technological pedagogical knowledge, teachers engaged children’s play with the robotic toys and co-learned with the children.

Mavroudi et al. Gianni et al. and Gennari et al. engaged teens and primary-school children in the design of IoT objects by also supporting the ideation stages with a dedicated ideation toolkit [45–47]. In the latter two cases, the participants, using physical computing devices, conceptualised, programmed, and prototyped their solutions after familiarising themselves with their material. Results of these studies indicated positive outcomes for the participants, e.g., in terms of participant’s learning and engagement.

3.2.1. SNaP Workshops

The SNaP workshops are focused on smart-object design by children [64]. They are centred around the SNaP toolkit, a card-based gamified toolkit for children and young teens [65]. The main elements of the SNaP toolkit are cards and boards for conceptualising smart objects. The cards are divided into: mission cards (i.e., goals that smart objects should address), environment cards (i.e., objects related to a park or a school classroom to be made smart) and technology cards divided into input and output cards (i.e., sensors and actuators). Technology cards are matched with the physical computing toolkit that children will later use for prototyping their ideas (e.g., [56,66]). Boards serve to organise cards and conceptualise smart objects. The SNaP toolkit comes into two versions, a physical one (see Figure 5) and a digital one (see left of Figure 6). They have both been used in workshops with children, in presence and at-a-distance described in [48–51] and in [52,53] respectively.



Figure 5. Boards and cards of the physical SNaP.

The SNaP toolkit supports children or teens in the entire design workflow, by, firstly, enabling them to familiarise with smart-object components (e.g., sensors, actuators) and, secondly, it guides them in ideating novel smart objects by conceptualising them on boards. What is more, the digital version of SNaP (Digital SNaP website: <https://snap.inf.unibz.it/play.php> accessed date on 20 January 2022) automatically generates programs for the submitted smart-object ideas with an unbounded loop and a simple conditional (see right of Figure 6). The generated programs contain blocks of MakeCode for Micro:bit boards [56,67]. From this point onward, children can further elaborate on the generated programs and evolve them.

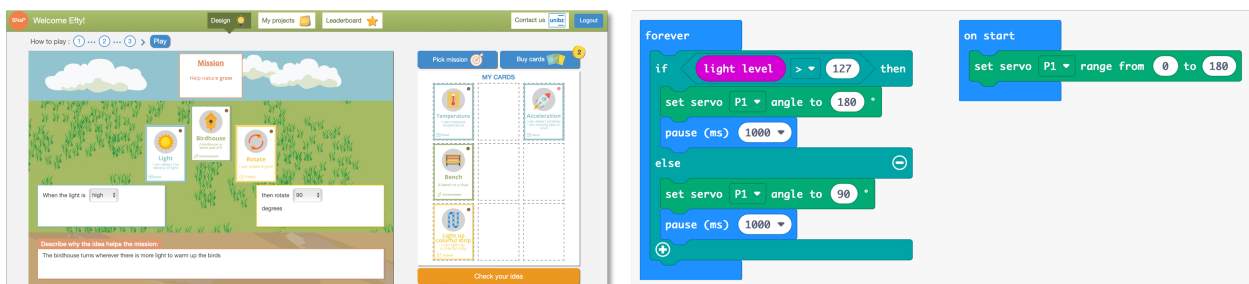


Figure 6. The environment of digital SNaP (left) and a SNaP-generated code for MakeCode (right).

Design Stages & Materials

The SNaP workshops start with the exploration stage, continue with the ideation and conclude with the programming and prototyping stage.

Exploration stage: This stage serves to give children the basic tools and experience for continuing on the next design stages as independently as possible. It also consists of guided exploration and tinkering with micro-electronic kits, input and output cards of SNaP and programming environments for children.

Ideation stage: The ideation stage continues the design process and, later on, it can be interleaved with the other stages. It starts by using the SNaP toolkit, which enables children to conceptualise ideas on their own and share them with others.

Programming and prototyping stage: In this stage children are programming their smart object ideas. They either expand the SNaP-generated program in case they used the digital SNaP, or they start from scratch in case they used the physical SNaP. In in-person workshops, they are also given the input and output devices that correspond to the chosen input and output cards used in their SNaP boards. Subsequently, they move on creating a physical prototype of their smart objects. In case workshops are held at a distance, prototyping is not conducted “physically” but only simulated in the MakeCode environment. The stage can interleave with the other stages.

Setting & Participants

Different SNaP workshops took place in 2019 and 2020, both in presence and at a distance. The in presence workshops were held in a fablab facility of the Free University of Bozen-Bolzano (see also Figure 7). In the at a distance workshop children participated from their homes. The workshops overall involved 47 children, both females and males, of different ages (mean age $M = 11.85$ years, maximum age $max = 16$ and minimum age $min = 8$, and standard deviation $SD = 1.94$), with different sorts of expertise (with/without expertise in programming and/or smart object design). The duration of the workshops varied from 2 days long to 6 weeks long.

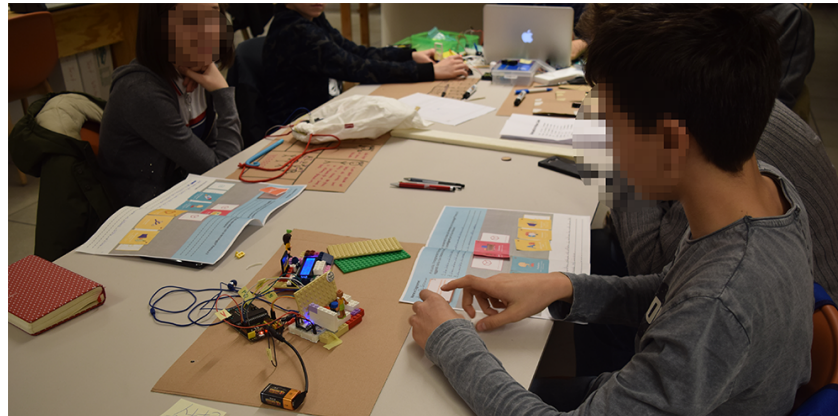


Figure 7. Children prototyping their smart objects in the in-presence workshop with the physical SNaP toolkit for school classrooms [51].

4. Overview of Workshops

This section answers RQ1, in relation to the design of smart solutions by children. It summarises key aspects that can be observed in the smart solution design workshops with children by overviewing smart city and smart object workshops as reported in Section 3.

4.1. Overview of Smart City Design by Children

Table 1 schematically reports smart city design workshops overviewed in Section 3 to enable their comparison. Main findings follow.

In smart-city design workshops it is noticeable that there is not a single or uniform structure for stages. However, the most common pattern is to start with an exploration or familiarisation stage to become familiar with smart cities and their components. Smart city design workshops heavily rely on prototyping, asking participants to create a city model, usually as an initial step of the entire protocol. Workshops rarely include a final stage concerning reflection to improve participants critical spirit. The ideation phase is practically absent in most of the workshops which mainly focus on well-known problems that participants are challenged to solve, such as city model assembling [2,8] or autonomous vehicles programming [35,37].

The interest in mainly focusing on the programming skill development emerges also looking at the adopted materials. In fact, used toolkits mainly concern the prototyping stage instead of the ideation one. They span from the more traditional approaches, such as a paper-based city model, to more innovative approaches, such as interactive tables and virtual reality. Participants can deal with either already assembled robots, such as mBot, or challenged to assemble their robot, such as in Rooboopoli.

Most of the reported workshops took place in presence, probably due to the strong accent on the physical prototyping stage and the strong requirement in accessing access to hardware typically required by robotics physically. They mainly took place in a formal setting, lasting hours, while longer workshops held in informal settings were rare.

It is interesting noting the effort invested in making very young children experience smart cities, as demonstrated by the age of the participants. They cover from primary to

secondary school in most cases. Rare are workshops involving high-school students, such as the experiment described in Roobopoli [37].

The lack of the explicit reference to the female participation underlines that researchers should more clearly report participants setting and put a wider commitment to encourage a wider adhesion of females to this topic. In fact, also in the workshops explicitly stating the female percentage, it represents the minority of the participants.

4.2. Overview of Smart Object Design by Children

Smart object design workshops overviewed in Section 3 are schematically reported in Table 2 and analysed below. Main findings follow.

Smart object design workshops with children are also commonly divided into stages for better structuring the design process. Offering explicit phases along the design process provides children with an understanding of the process and helps them to move on to the next stage of design with confidence [38]. The number of stages can vary among the several models. However, three main stages are usually addressed involving exploring, ideating, and implementing.

Most of the time, technological material is included in the process. The technology considered is varied: some authors refer to the usage of technology such as 3D printers for fabricating things, others refer to physical computing devices for children, e.g., Micro:bit [56]. However, sometimes they are used in a supportive and optional way for children's solutions, rather than as the main material to work with (e.g., in [38,39]). The SNaP workshops and the workshops by Gianni et al., Gennari et al. and Kewalramani et al., instead, were framed specifically around the usage of physical computing devices for children [44,45,47].

Involving technological material in the process requires children to be familiar with them before proceeding to the ideation, programming, and prototyping stages. For example, to be able to program their smart object solutions, children should be provided with basic programming scaffolds [68,69]. However, the process of scaffolding in programming is not always explicitly described in the reviewed workshops.

Often, paper-based materials and toolkits supported the ideation process, like in the case of Mavroudi et al. [46]. In the cases of Gianni et al. and Gennari et al. in particular, as well as in the SNaP workshops, the ideation toolkits also matched the physical computing devices [45,47]. In this way, children were able to ideate solutions with visual representations of sensors or actuators, easing thus the passage from ideation to the programming and prototyping parts of the design.

The smart object workshops overviewed in this paper were mainly conducted in the presence. However, by also considering the physical distancing restrictions imposed by the COVID-19 pandemic, alternative online and at a distance design approaches should also be considered [39,70]. Design at a distance may, for example, offer alternative opportunities for collaboration [71]. The design workshops focusing on technology and smart object design by children have not explicitly considered this dimension. Such an attempt was instead organised by the authors of this paper, with the support of the digital SNaP toolkit.

5. Discussion

This section answers RQ2. It stems from the above comparison of smart-city and smart-object design workshops and proposes a research agenda to guide future researchers and workshop moderators in organising workshops in this context. It thematically analyses and clusters reflections into four main topics, starting from preliminary reflections reported in [31]: design stages; materials; settings and modalities; participants. Some of the reflections reported below can be applied in other technology-related activities with children as well.

5.1. Design Stages

According to the performed literature review, smart city workshops are more focused on algorithmic and programming skills. For instance, the Roobopoli workshops focus on technologies that future citizens may experience during their lives, such as autonomous vehicles. They propose an imaginary smart city with pre-defined smart objects. They encourage participants to analyse possible behaviours that these smart objects may have, expressed as missions, in which participants should propose an algorithmic solution that may creatively solve a standard and well-known problem and program it. The same pattern is also observed in [35] that focuses on robot challenges, and in [36] that focuses on smart farms and the humidity control aspect. Hence, the general pattern observed in smart city workshops focuses on well-known problems and common challenges and encourages participants to develop algorithmic and programming skills to solve them. These workshops are mainly programming-oriented and enable participants to delve into advanced programming challenges.

The strong accent posed on the programming stage constrains the participants' age. Looking at Table 1, teens usually join these workshops as preliminary programming skills are required to contribute to the workshop actively.

Moreover, the overviewed smart city workshops usually sacrifice the ideation stage, which is extensively explored in the smart object design workshops. For instance, the SNaP workshops are focused on the active role which future citizens may play in proposing and designing original and novel smart objects and reflecting on them as part of a complex ecosystem. Through their missions, participants need to use their imagination and creativity to ideate their smart objects according to their preferences and make them concrete by programming them. Their respective protocols highlight this main difference: Roobopoli includes an algorithmic stage, while SNaP proposes an ideation stage even though this embeds a programming pattern via its game mechanics so that children are led to conceptualise ideas that are feasible to program.

The same trend can be observed in the other workshops, compared in Tables 1 and 2: smart city workshops are mainly focused on the programming stage, spending more time on developing programming skills than focusing on ideation stages. Participants are rarely challenged to create their own smart city versions by conceptualising new solutions. Such workshops, thus, do not offer the chance to children for a more critical and reflective stance toward technology [24]. Introducing a wider phase dedicated to proposing novel behaviours in the smart city might encourage learners to think about innovative services and out-of-the-box proposals by leveraging their creativity.

On the other hand, smart-object design workshops usually focus on specific objects. Participants can, thus, easily lose the perception of the entire ecosystem surrounding the designed object which can lead to de-contextualised by the environment solutions. Hence, smart object-based workshops might encourage participants to design novel objects, stressing their role in the entire smart city ecosystem.

What is more, a reflection stage is rarely performed or only partially covered in smart-city workshops. As a consequence, participants miss developing critical thinking skills and informed debate [2]. Moreover, they mainly work in isolation, without taking the best from the teamwork and the comparison with others (as analysed in a qualitative evaluation based on observations during the SNaP workshops, actually under review). By dedicating more time and effort to let participants reflect on their proposals have the potential to improve future citizens' critical thinking, let them discuss alternatives and suggestions to improve ideas, and learn how to defend an idea through informed and data-driven debates, as encouraged in [2].

5.2. Materials

Workshop materials must be carefully considered according to the age range of the participants and their experience in programming to avoid disengagement and frustration. For example, while text-based programming languages are well-suited for older and

experienced participants, younger participants require scaffolding by toolkits that guide them in programming stages step by step. As an example, the Roobopoli workshops mainly adopt text-based programming languages, such as C++, suitable for high-school learners to encourage them to develop technical skills in advanced programming languages. However, it requires abstract reasoning capabilities and algorithms, programming languages, and coding constructs. Instead, a block-based environment, such as mBot, can be easily adopted with 10–13 years old participants.

Card-based design toolkits, such as SNaP, have the potential to engage children from younger ages in ideation and simple smart-object programming. SNaP workshops guide children step-by-step in each stage, making them thus suitable even for younger participants or for those without former experience in programming, to such extent that children aged 8-years old or older successfully participated in SNaP-workshops. Nevertheless, the digital SNaP was perceived as a limitation for the oldest participants who wish to acquire more advanced technical skills and independence. In fact, a quantitative analysis on children's engagement during the SNaP workshops showed that all the participants were highly engaged [53]. However, the oldest participants suffered the limitations imposed by the block-based interface and asked for a similar workshop where they might be free to use also textual programming languages, such as Python and JavaScript. Such results show that participants were positively impressed by the workshop as they asked for opportunities like this, but it is crucial to identify design environments meeting participants' age, expectations, and background.

5.3. Settings and Modalities

Ecological settings, such as classrooms and playgrounds, are ideal areas for research involving children, which aims to consider context-dependent factors [33]. While smart objects and smart city workshops usually take place in presence, with the possibility of exploiting collaboration and teamwork to design solutions, COVID-19 forced researchers to revise the way design workshops are organised. Such choice affects the prototyping phase, as it is complex to provide participants with toolkits (it takes time for the distribution and requires additional costs for the material and the shipping), and restrictions imposed by the pandemic require avoiding not-sanitised material exchange among participants. In this context, the SNaP workshops, held at a distance with digital tools, can still organise smart-object design [52,53]. On the other hand, moving smart city workshops at a distance requires a shift in the design stages, as they mainly invest in the prototyping phase, which requires physical interaction. Stein et al. proposes a smart-city workshop held at a distance [35]. However, even if a satisfying task completion rate is reported in their study, as all the participants completed the challenges and responded positively, some students with previous robotics experience said they preferred working with physical robots.

As a general comment, children, above all younger ones, are not generally familiar with remote learning settings. They have difficulties in following instructions at a distance, dealing with multiple web pages, and sharing material. Moreover, their concentration can be strongly affected by their working setting, usually their homes, which offer several distractions [70]. It requires carefully selecting moderators as their expertise and experience are crucial mainly during remote workshops where both the moderator and the observers could not always be vigilant of children's mood, mostly due to at-a-distance interaction issues and children's inexperience with meeting tools, primarily designed for adults [70,71]. Moreover, remote settings require revising the protocol to iteratively enquire participants to deal with technical issues and avoid disengagement and frustration.

Whether in the presence or at a distance, the modality strongly affects the workshop schedule and its organisation. In informal settings, workshops can be compact and last a few days, resulting in focused activities. In formal settings, the school's organisational constraints affect the schedule, e.g., class hours are organised per subject in a day. Thus a workshop can only take a few hours per week, within certain subjects, and it usually needs to be consistent with the requirements of the subjects, leading to a fragmented activity.

Fragmentation requires to consider the necessity of organising the workshops accordingly, e.g., with material that progressively leads participants across stages and reminds them of the previous stages over time, as in the case reported in [72].

5.4. Participants

A crucial point in children's participation is to identify aspects that may encourage higher involvement of females [73]. Only in a few cases, the percentage of females is greater than of males when both genders can join the workshop, such as in the workshop organised by Seraphin and Green [33] (as reported in Table 1) or in the one held by Gennari et al. [47] (as reported in Table 2). It is interesting to notice that this mainly happened with the youngest participants. As highlighted by many researchers, the middle school period seems to be the crucial phase in which females lose interest in technology and computer science (e.g., [74]). Embedding programming with a design activity that solicits different skills and gives programming a purpose may encourage their participation [75].

The recruitment strategy may also highly influence participation. Workshops organised as a formal activity at school usually experience the greatest number of participants as reported in Tables 1 and 2. As an alternative, learners can join informal and non-mandatory courses to deepen their knowledge and awareness on topics relevant for their educational and job careers [76]. It may be an option to exploit schools and formal institutions to encourage participants to join external activities in informal settings. Mandatory activities in formal settings ensure inclusiveness without discriminating people by gender, socio-economic conditions, disabilities. On the other side, they involve both interested and not interested people, while workshops in informal settings deal with motivated and interested volunteers. Hence, organisers may rely on participants' interests and backgrounds to conduct the proposed workshops in informal settings. It is worth noting that this comment is general-purpose and can be considered in any activity involving children.

6. Conclusions

Despite the popularity of smart cities and smart objects, what is behind them is unclear to people without technical expertise, especially children. As these concepts are already part of our daily lives and future citizens will have to deal with them in the near future, there is consistent interest in proposing initiatives and workshops to familiarise learners with them. This paper overviewed different workshops that introduced children and teens to smart cities, in general, and smart objects, in particular. This paper presented their goals, protocols, settings, and achieved results. Smart city and smart object design are usually dealt with separately, despite their close relations, e.g., smart objects are components of smart cities. Hence, this paper discusses what can be shared among the described workshops, so that smart city design workshops are enriched with the smart object design workshops and vice-versa. For instance, smart city design workshops mainly focus on the prototyping phase limiting the possibility to invent novel services and think out-of-the-box solutions. By introducing a wider ideation phase, smart city design workshops can also improve participants' creativity and critical thinking. On the other hand, smart object design workshops usually neglect the contextualization of the proposed objects in the smart city ecosystem. Consequently, young participants may not be able to see the interconnections among the objects proposed by other participants in the given context. Further efforts should be invested in standardising design workshops concerning smart cities and smart objects to provide future citizens with further empowerment opportunities.

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