Stop and Smell the Chalk Flowers: A Robotic Probe for Investigating Urban Interaction with Physicalised Displays

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ABSTRACT

HCI researchers have begun to more systematically study non-digital transient approaches for displaying information in public space, for example, in the form of chalk infographics. These approaches provide several benefits compared to digital displays, such as: ad-hoc deployment, barrier-free interaction, and being more sustainable. However, one limitation is their hyperlocal scale and impact. Speculating on urban robots as agents for scaling up physicalised displays, we describe the exploratory design and deployment of Woodie, a slow-moving robot that draws on the ground using conventional chalk sticks. We deployed Woodie for three weeks in a quiet laneway situated within a highly urbanised area. Data collected from observations, video logs and interviews revealed that Woodie successfully attracted people's attention and acted as a facilitator for collaborative, creative placemaking. Furthermore, Woodie provoked emotional responses and was perceived as a living being. Findings are interpreted to describe opportunities urban robots provide for the design of future pervasive urban displays.

Author Keywords

Pervasive displays; human-robot interaction; physicalised displays; urban robotic displays; urban media; urban probe; design.

CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI);**

INTRODUCTION

The pervasiveness of digital technology is fundamentally changing society, including the way we act, interact, perceive and structure our daily lives in cities. Governments, organisational institutions and tech companies around the world are not only collecting and analysing data, but increasingly turning to urban robots for automating processes and services, with the aim to make cities more efficient and productive [48]. However, the development of so-called smart cities also triggered heated debates among thought leaders and scholars, with some arguing that the matter of productivity should be dissociated from speed and efficiency and instead questioning how to make cities more liveable and healthier for their inhabitants [52]. Foth and Guaralda refer to the "slow cities" movement, which instead of arguing against the use of digital, smart technology in cities, makes a case for genuine placemaking as an alternative to focusing on utilitarian objectives, such as "growth, efficiency and productivity" [19]. They suggest to use digital tools and grassroots activities to deepen the connection between people and space, thereby regarding people as co-creators instead of simply consumers.

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Figure 1. Boy drawing a humanoid robot with chalk on the ground next to Woodie.

Designing digital technologies to facilitate civic awareness, public participation and community engagement has also found increasing interest within the HCI community [11,14,20, 37]. Researchers emphasised the importance of community engagement being inclusive and situated, reaching a wide range of people in their immediate urban vicinity [6, 21]. Due to the increasing availability of digital screens in urban environments, researchers have often employed them as a community-supporting platform [42], for example, for urban polling [28, 56], to visualise maintenance processes in the city [35], and to raise awareness of environmental, sustainability and civic issues [8, 62]. However, several studies also investigated the use of non-digital, or *physicalised*, public displays and hybrid digital-physical input and output channels [6, 9, 21, 33, 34, 45, 57]. This approach can provide several benefits, such as: lowering the technical burdens of interaction to engage a broader audience [21], providing material affordances and transient qualities that can attract attention and appreciation (e.g. previously explored for chalk [34]), and inverting the fast-paced qualities of digitally updated content

Figure 2. Manually updating non-digital physical displays by a research team was reported to drive more engagement around public visualisations. Image credits: [34], [45].

to create anticipation and reflection [45]. Research in this area has also reported that the updating process itself – for example, a research team manually updating visualisations – creates additional engagement with the researchers acting as facilitators [33, 45]. However, a major and commonly acknowledged limitation that comes with the nature of such non-digital public display deployments is the issue of maintenance costs, therefore limiting the scalability and impact of such approaches.

Our research aims to address these limitations and investigates how urban robot technology could be appropriated to replicate the qualities of non-digital public displays, while their basic characteristics – being mobile and autonomous – provide the foundation for scalable deployments. Further, we are interested to what extent urban robots can function as a facilitator or 'spark' [8] to affect people's engagement with public displays and to foster social interaction among people. As robots are increasingly being tested in real-world urban contexts – mainly to complete mundane tasks – our aim was to investigate their potential for triggering urban reflection [49], "getting lost" in cities [19] and "slowing down" [52].

To investigate these questions, we designed and deployed *Woodie* (see Figure 1), a self-moving robot which can draw with a conventional chalk stick on the ground. Capable of drawing various predefined designs, Woodie uses the public space as a large horizontal canvas, producing simple line drawings at a slow speed: each drawing takes around ten minutes on average. Woodie's appearance is dominated by its round-shaped low-resolution (low-res) lighting display, which is integrated in the outer shell made of polypropylene plastic. The low-res screen renders expressive light patterns, using coloured and moving lights, to encode various internal states (e.g. drawing, moving) and Woodie's direction of movement.

We deployed Woodie as an urban probe for 17 evenings in a quiet laneway situated within a major business and residential district. The paper makes two novel contributions to the field of HCI. First, it creates an account for how the qualities of non-digital public displays, for example, in the form of chalk drawings on the street, can be created through a robotic device. To our knowledge, it is the first study of a drawing robot for creating a public display in an urban space. Second, the study contributes to an emerging strand within HCI that investigates the application of research-through-design as an exploratory method for the design of human-robot interfaces and autonomous systems.

RELATED WORK

Our study builds on and contributes to the field of pervasive displays, which has been extensively studied by the CHI community – as a field that takes computing into the urban space through digital screens that can be either interactive or non-interactive. We further build on studies of non-digital public displays that use physical material such as chalk for manually composing information representations, often employing the urban environment as a canvas. Through our study, we more specifically investigate the use of digital mechanisms to increase the hyperlocal scale and impact of non-digital displays. We refer to this approach of automating the process of creating information representations with materials such as chalk, as "physicalised public displays". In this section, we describe how previous work carried out across pervasive digital displays, non-digital displays and physicalised public displays informed our study design and contribution.

Pervasive Digital Displays

Compared to smartphones, pervasive displays enable a "push-based distribution" of content that is addressed to the public instead of individuals [13]. However, several works reported that passers-by tend to ignore digital screens [32, 47, 50]. Therefore, researchers investigated how to overcome so-called display blindness, for example, through adding layers of interactivity [63, 66] or aiming for the design of more relevant content [8, 28, 56, 62]. Vande Moere and Hill propose the concept of situated urban visualisations, which distinguish for example from conventional advertising screens, in the sense that the displayed information relates to its immediate physical environment and provides informative value for the local community [46]. Reporting on field observations, researchers elsewhere have concluded that also physical properties and contextual constraints such as position, location and prominence of a display within a public space, as well as restrictions posed to the flow of people through the display, can affect awareness of the display and its contents [25, 50].

From an architectural point of view, conventional digital screens are often criticised for their compromising factor on the architectural landscape [67] and for their fast-paced cinematic content failing to reflect more gradual contextual changes [46], such as socio-cultural shifts, spatio-temporal changes and natural processes occurring in cities. As a consequence, architects began to incorporate alternative display materials into their own practice, for example, in the form of low-res media façades or physical kinetic display elements [24]. Inspired by those works from architecture, arts and design practice, the CHI-community has shown increased interest on the integration of display technology into the built environment [12] and qualitative displays relating to the physical world [38]. Further, a substantial body of work has been carried out to understand the spatial configuration [17], user roles [53, 54] and trajectories [66] around large-scale displays and, more generally, interactive performances in public space [59].

Non-Digital Public Displays

Several studies also investigated and documented the use of non-digital displays [33, 34, 45, 57]. Koeman et al., for example, used chalk spray stencils to display urban visualisations on the pavement (see Figure 2, left) [33]. The data was collected through tangible voting devices distributed over several shops to visualise people's opinion on community-related questions. Based on their studies, the authors outlined several qualities [34] of non-digital public visualisations capable of leading to additional engagement. For example, they reported that textures and materiality, as well as the horizontal position of content on the pavement, attracted passer-by to approach (and touch) the visualisations. Further, the transient nature of the visualisations made people aware of their finite lifetime, resulting in additional appreciation of the content. In a similar vein, the delayed update cycles were reported to create additional anticipation in the community, whose pace, the authors argued, was better matched by periodic instead of real-time content updates. These findings are similar to those of Vande Moere et al. [45]: after deploying chalkboard-like signage for comparative energy feedback on the façades of residential houses, they reported that the manual update process carried out by a research team created additional engagement between residents and the researchers acting as facilitators (see Figure 2, right). Other relevant qualities of the non-digital physical displays adopted in those studies are the low skill requirements for their usage, and the lack of physical barriers or explicit digital user interface for people to create and extend content. Yet, although those studies suggest that non-digital physicalised displays can address some of the socio-technical pitfalls related to digital urban displays, their hyperlocal scale and impact remain unaddressed limitations, particularly in regard to what is left for the local community once the research projects are finished [58].

Physicalised Public Displays

The emergence of novel display technologies and distributed sensor networks has enabled the visualisation of data in context [44] and in a blended form [7]. As a consequence, various frameworks and taxonomies to unify these approaches also started to emerge. Willet et al. [65] introduced a conceptual framework on embedded data representations, including visual and physical representations that are deeply related to the physical spaces or entities the data originates from. They distinguish the spatial proximity of the representation to its referent, i.e. situated or embedded, and the form in which the data is manifested, i.e. purely visual or physical. However, they acknowledge that the range between visual and physical displays is continuous: likewise, chalk drawings on the ground provide virtual as well as physical qualities. Hoggenmueller et al. [29] developed a taxonomy that classifies current approaches of pervasive display based on two dimensions: (a) the level of physical integration of content into the surrounding environment (attached, blended, physicalised), and (b) the levels of mobility of the display technology (fixed, portable, self-moving). Both works point to novel technologies, such as drones and urban robots, as holding the potential of distributing digital content in a highly physicalised and ubiquitous form, due to their ability for dynamically positioning themselves in space, as well as manipulating the physical environment.

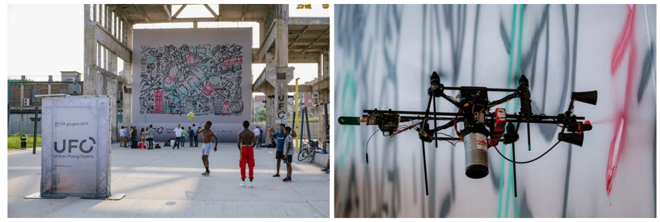

Figure 3. Novel technologies, such as drones and robots, pave the way towards emergent pervasive displays, where digital content is replicated in physical form and situated within the built environment, here explored in the context of a participatory art project. Image credits: ®CRA-Carlo Ratti Associati (Photos by Andrea Guermani) [2].

One recent example of putting this vision into practice comes from the design office CRA-Carlo Ratti Associati (see Figure 3) [2]: during a two-day event, they deployed a swarm of drones to spray-paint a collaborative artwork on a vertical large-scale canvas. Following a submission process open to the general public, a committee of artists selected proposed designs for exhibition. However, while this example illustrates well how robots can be used to create physicalised displays, the intervention falls short from fully replicating core qualities of non-digital public displays [34], such as enabling barrier-free and tangible interactions, and using the immediate physical environment (e.g. the ground) as a canvas. Aiming at overcoming such limitations, and to put to test the hypothesis of using robots to facilitate the emergence of non-digital public displays, we designed a field study in the form of an urban intervention, where we deployed our chalk drawing robot, Woodie, in an urban neighbourhood.

METHODOLOGY

Research through Design (RtD) is described by Zimmerman et al. as the generation of new knowledge by creating "a product that transforms the world from its current state to a preferred state" [68]. While there have been voices in the design community criticising the endless stream of design artefacts and pointing out a lack of standardisation in RtD, Gaver argues for the generative power of artefact examples that should be annotated by theory rather than being replaced [22]. In human-robot interaction (HRI), where so far the majority of research focuses on usability factors, an emerging area within the CHI community is to also apply RtD methods to the design of robotics [39]. As our aim is to explore how the qualities of non-digital physical displays can be scaled-up through a robotic design artefact, this exploratory and generative approach fits well with the speculative nature of our investigation. We also aimed to create a design artefact that questions in which new ways urban robots can be used in public space apart from completing utilitarian tasks and services, thereby following Gaver's definition of RtD providing the ability to "create multiple new worlds rather than describing a single existing one" [22]. To investigate how people would interpret, adapt to and appropriate such a non-utilitarian system, we designed Woodie as a lightweight and provocative urban probe for readily deployment in public space [51]. In this vein, we generate new knowledge through the design, construction and deployment of a conceptually rich artefact, thereby presenting theory as annotation of the design example [22].

Design Process and Rationale

From the outset, the design goal was to create a robotic device which could render digital drawings in a physicalised form, deeply integrated into the existing urban environment. One requirement was to design a 'plug-in system' [26] that could be deployed "anywhere" in public space, in and out, without the need for additional infrastructural support, such as a canvas or a stationary power source. As sidewalks and public plazas are ubiquitous in cities, publicly owned and used as a stage for social interactions, we decided for a self-moving, autonomously powered platform which uses the ground as a large canvas. This also implements recommendations from previous research suggesting that positioning content and interfaces on the street can successfully attract passers-by [16, 27, 34].

Early in the design process, before defining the actual design of Woodie and selecting a platform, we considered which material or substances to use for creating the content. As we planned to deploy the robot in an ordinary, functional urban environment, one requirement was that the material used to render content could be easily removed and provided the transient qualities of non-digital public visualisations [34]. We found these material characteristics in chalk. Admittedly, there are shortcomings when compared to alternative solutions, such as spray – for example, drawing with chalk on uneven surfaces can be challenging and there is a need for a mechanism to continuously 'feed' the chalk as it is consumed by the act of drawing. Yet, we decided for the use of a conventional chalk stick for two reasons: (1) Although it is often emphasised by artists and designers that they rely on sustainable solutions [2, 15], spray-paints are still more harmful to the environment compared to chalk, both in terms of production and removal. (2) As we intended to engage people in extending the drawings created by the robot, it made sense to adopt a solution which was both easy-to-use and safe, especially for children.

In the long history of drawing machines [43], their focus has mainly been on the drawing process and the outcome itself. In other words, the machine – even though in some cases spectacular – remained a technical means for the creation of content. With the design of Woodie, we followed a more holistic approach, where the robot itself becomes an important element of the intervention. As Woodie was aimed to act as a facilitator to engage people in collaborative and creative placemaking, the design of Woodie, including its appearance and behaviour, was an integral part of designing the intervention. The limited research to date on the design of urban robots suggests that people do not necessarily prefer an anthropomorphic design [18]. Given the non-utilitarian nature of our investigation, we considered incorporating ludic design elements to the intervention, such as presenting familiar objects in an unfamiliar context [23]. As people increasingly accommodate service robots such as automated vacuum cleaners in their homes, we posited that taking a robot to the street might evoke curiosity in people. Therefore, basic design characteristics of those products, such as dimension and shape, inspired our early design exploration phase, in which we created sketches and renderings (see Figure 4).

Figure 4. Early renderings of Woodie.

Design Considerations and Decisions

The points identified in the previous section, coupled with considerations regarding intuitiveness and the robot's scale within the urban environment, informed important design decisions, as listed below.

Shape. In line with our goal of enticing curiosity by depriving Woodie from any obvious association with preconceptions about how a robot should look like, we decided early on not to give it anthropomorphic features. Instead, we opted for a circular body, thus allowing the robot to move in any direction without the constraints of having to reposition its "face".

Size. Woodie should be large enough to be noticed by passers-by, yet small enough not to become an obstacle to them, and not to obstruct visibility of its own drawings. After testing a few different dimensions, and also taking into account the available options for off-the-shelf robotic platforms, we settled on a diameter of about 60 centimetres for Woodie's body.

Speed. Slowness emerged as an important feature for Woodie, as it should move sufficiently slow to allow for thoughtful appreciation by the public, as well as not to compromise the free movement of pedestrians in the public space.

Information visualisation. The information visualised through the robot's drawings – representing an instance of the physicalised public display – had to be aligned with the environment and its physical and temporal context. Given that Woodie was located in a laneway, we aimed to use visualisations for activating the space, implementing digital placemaking principles [61] to connect people with the space and with each other. We further aimed to align the visualisations with the theme of the light festival taking place in the neighbourhood at the time when Woodie was deployed, which was "love, peace and harmony". These considerations led us to the use of simple shapes, such as flowers and hearts. An important aspect at this prototyping stage was not only to decide for the "right" type of content, but also to explore the characteristic style of the drawings. After several tests drawing on various grounds, we realised that highly geometric vector graphics convey the impression that the drawings are imperfect when "rendered" on rough terrain, while less geometric, hand-sketched drawing styles worked well with Woodie's limited drawing accuracy (see Figure 5).

Information communication. In addition to creating a public display through drawing on the ground, Woodie should also have communicative features itself. Following recommenda-

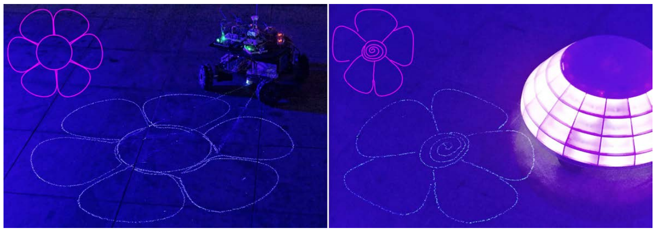

Figure 5. Two different drawing style explorations (with the actual vector graphics in purple): geometric flower (left), sketchy flower (right).

tions from research on autonomous vehicles [40], suggesting the use of visual signals for communicating a vehicle's intent to people around the vehicle, Woodie should be capable of visually representing its internal mode. We chose a low-res LED lighting display solution given their established aesthetic qualities [30].

Behaviour. Woodie should be fully oblivious of people around it, enacting its behaviour without requiring its operator's attention. Rather than directly responding to them, we were interested in what indirect interactions might emerge from the robot sharing an urban space with passers-by and spectators.

Absence of interface. To prevent any false affordances and discourage people feeling tempted to touch or directly interact with the robot, we deprived it from any kind of features that might resemble traditional interfaces.

Absence of feedback. Following on from the decision not to include any interface elements, we decided that any feedback to people around Woodie would be minimised and restricted only to communicate internal states related to the robot's operation, such as it started to draw, was resting in between drawings, or got caught up on cracks in the pavement.

Implementation and Construction

In the following we briefly describe the final implementation of Woodie. We used an off-the-shelf robotic platform with four omni wheels, which are powered by stepper motors. The stepper motors are controlled via an Arduino board, running Grbl [1], which is a freely available and open-source gcode-parser. Grbl is mainly used in computer-aided manufacturing, for example to control 3D printers and laser cutters. The Arduino board receives the motion commands from a Raspberry Pi 3, which is Woodie's core unit running the Java-based software to start drawings, move the robot and control the LEDs of the low-res lighting display. A linear motor attached to the center of the robotic platform lifts and lowers the chalk stick. This is necessary for 'feeding' the chalk and to make sure that Woodie is only drawing intended lines when it is in motion. The robot is powered by a 12 voltage / 12Ah Lithium rechargeable battery, which lasts up to 2 hours when Woodie is constantly moving.

Woodie's shell and its structural parts were custom-made and developed at our school's workshops following a process of iteration and testing. The shell served three main purposes: (a) it concealed and protected the robot's internal hardware; (b) it diffused the LED lighting, thus not only improving its aesthetic, but also enhancing the low-res character of the display; and (c) it gave Woodie its final distinctive shape. To achieve those three features, the shell was made from polypropylene using a vacuum former. For giving the shell a unique shape, we created a purpose-built mold from polystyrene.

[1] https://github.com/grbl/grbl, accessed September 2019

In-the-Wild Evaluation

We deployed Woodie for three weeks in a major business and residential district, around 10 kilometres away from the centre of a global city in the Australasian region. The deployment was part of a large-scale annual festival, which includes outdoor light installations, music events, and public talks and debates. The festival takes place in several districts around the city, attracting more than 2 million attendees in total. As described above, the festival and its theme informed our choice of visualisations created through the robot. Different to other light installations, we further conceived Woodie as an urban probe from the outset. For example, this meant that instead of telling people about the work, we left it to them to explore Woodie and its functionality.

Location Description & Deployment Duration

Woodie was deployed at Mills Lane, a narrow backstreet connecting a cultural centre and two large shopping malls. The lane, however, is usually not very busy due to the limited number of restaurants located there, compared to the larger main street, running in parallel. During the day, the lane is mainly used for the delivery of products to a nearby warehouse, however, during the time of our intervention the lane was pedestrianised and closed for traffic. The designated area in which Woodie was drawing on the ground was roughly 15 metres in length and 5 metres in width, however, due to the slow movement, Woodie's drawings would not cover the whole area during the course of an evening. The drawing area was illuminated by 6 high-power ultraviolet (UV) lamps (300 wattage each). As the intervention took place in winter evenings, the drawings were created with luminescent chalk sticks, for greater visibility at night and increased aesthetic perception of the space.

As we were concerned about understanding how the design of urban robots shapes the experiences people develop with them, rather than investigating technical details, implementing Woodie to act fully autonomously was not a chief concern. Instead, we developed a simple mobile application, which we handed over to festival volunteers monitoring the installation during the festival. Through the mobile application, the volunteers could instruct the robot to start a new drawing or, if necessary, move Woodie to different positions. Due to the slow movement, the interactions with the mobile application only needed to happen occasionally (approx. 3-4 commands per hour). We also briefed volunteers on the fact that Woodie did not need to constantly draw, but could also "rest" now and then. Most of the time, volunteers would just stay in the background, intervening only in case people approached them for questions, or when someone posed a risk to Woodie. Thus, we could make sure to sustain the intended ambiguity and curiosity around the object, leaving it up to people to conjecture about Woodie's actual level of autonomy.

To allow people to add their own drawings on the ground, most of the evenings we provided chalk sticks around the installation. We laser-cutted a little holder for the chalk sticks from white perspex, however mostly people left the chalk sticks on the ground or handed them over to others, an interesting finding we discuss in more details further below. In order to compare the effect of people drawing on the ground on their behaviour around and interactions with Woodie, we decided on two evenings not to provide any chalk sticks.

Woodie was deployed at Mills Lane for a total of 17 evenings. As it was not designed to be entirely water-proof, we had to keep it inside when heavy rain was forecast, which was the case for 6 out of the 23 evenings of the festival. On weekends, Woodie was deployed for 5 hours, starting from 5.30pm until 10.30pm. During the weeks, the intervention ended earlier at around 9.30pm. This adds up to a total of 81 hours.

Observations, Video Recordings & Photographs

During the 17 evenings Woodie was deployed on Mills Lane, on 11 of those evenings at least one researcher was on-site to observe the interactions of people with and around Woodie (a total of 53 hours). The researchers took observation notes on how people approached the intervention, movements around Woodie, reoccurring interaction attempts (e.g. touching the robot), comments that people made to others as well as 'special incidents' (e.g. one evening a girl tried to skate on Woodie). On 10 evenings, we additionally took video recordings with a GoPro camera. The camera was placed at a nearby building approximately 3 metres high, and recordings were done in superview mode in order to cover the whole area. The video recordings were later used to verify our observation notes and the participants' statements during the data analysis. Further, we took photographs on-site, mainly of the drawings that other people added on the ground, thus gathering, overtime, snapshots of the co-created non-digital content emerging from the intervention.

Interviews

Throughout the intervention, we conducted 21 semi-structured interviews with individuals and groups. As people are usually in a rush in public space, we kept the interviews short, between 3 and 5 minutes. The interviews were conducted just before people left the location, and after having observed and/or interacted with Woodie in some form, for example, by drawing on the ground. The interviews included questions regarding their engagement with the intervention, aesthetic perception of Woodie and the surrounding space, and their general opinion towards the deployment of robots in urban space.

FINDINGS AND INTERPRETATIONS

We transcribed our interviews and conducted a thematic analysis [4] of both the interview data and the notes from our field observations to identify common themes across all data points. Video recordings were used to gain further insight into particular observations and to add contextual data to comments made in interviews. After an initial analysis, three researchers collectively reviewed the data and cross-referenced the data sources to refine the themes. We use the themes that emerged from this process to structure our findings in this section. We also offer interpretations to explain specific findings. These findings and interpretations form the basis for the discussion of future directions in the next section.

Types of Engagement

Based on our observations and interviews, we identified several types of engagement, initially related to curiosity evoked by the robot, followed by a process of sense-making: when **approaching** the location and taking the decision to stop by and contemplate, people were mainly curious and started **speculating** about what *"the robot is doing"*, the drawings on the ground, and other people interacting with and around Woodie. When recognising Woodie as a robot, which was mostly based on the movement (*"I saw the movement, and could tell it's a robot"*), people started to speculate on its task. Relating to the drawings on the ground and its resemblance with the home cleaning robot Roomba, many people thought in the beginning that Woodie would be *"wiping the floor"*, so that *"other people could draw again"*.

If the intervention successfully evoked people's attention, then this initial state of being curious would transition into a more in-depth phase of **observing**. People who were more interested on the performance itself, started *"walking around, and observe [Woodie] from different angles"*. At this stage, people often realised that Woodie was drawing, which was sometimes not immediately visible due to the prominent drawings made by humans. Interviews confirmed our observations from on-site visits and video surveys, that people often stayed at least until a drawing was done, in order to see *"how long will it take for [Woodie] to finish a drawing"*. Recording the drawing process with a smartphone additionally enticed people to wait until the drawing was completed.

The opportunity to manually draw on the ground successfully engaged people in actively **participating** in our intervention. People appreciated the *"feeling of belonging"* and that *"[the intervention] includes everyone"*, referring to the lane as a *"graffiti place that makes you feel relaxed"*. While drawing on the ground was particularly popular among children, we also observed many adults adding drawings, which was also reflected in the interviews (e.g. *"I admire this creation, because as I mentioned before, [...] adults and kids can interact at the same time. And in my case, I'm interacting. I did my drawing, I like my Mickey Mouse."*). Actively participating in the intervention was also another reason why passers-by ended up **dwelling** rather than rushing away from the precinct, further **exploring** the scope of possibilities offered by the intervention. One interviewee who stated to have spent more than 20 minutes at the site, reasoned: *"You get to look around at everything, draw, add to things and see what other people are doing."* – which is evidence of the intervention achieving its aim of connecting people with the space and with each other. Importantly, this retention of passers-by in the space seemed to be driven not by any of the isolated design elements – e.g. Woodie's presence alone, or the availability of chalk sticks to draw on the pavement – but rather by the possibility of engage in a playful activity, in public, facilitated by an urban robot. In other words, the possibility of **co-creating** with Woodie emerged as a compelling driver of participation. As one participant expressed, *"I like the fact that it's kind of a*

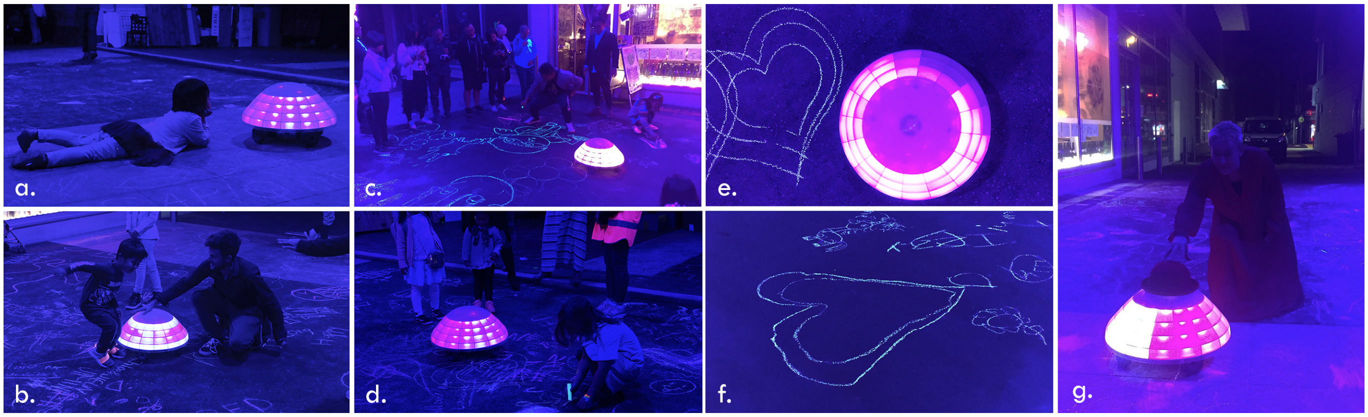

Figure 6. Interactions observed around Woodie and excerpts of drawings: (a) girl sitting on the ground and observing Woodie drawing, (b) boy trampling in front of Woodie, (c) man making a series of drawings next to Woodie while being watched by a group of people, (d) girl drawing stacked hearts next to Woodie, (e) stacked heart drawn by Woodie and (f) replicated version drawn by a girl, (g) woman performing in front of Woodie carefully putting her hat on its shell.

mixture of something, let's say, non-tangible and tangible. So the combination of we can draw ourselves, but the robot draws as well, is a nice touch. It makes it more human, I suppose, than only a robot [drawing]."

A few days after the beginning of our intervention, we observed that also the staff members of a local Japanese restaurant in the lane took advantage of the participatory opportunities afforded by the intervention: they started using the chalk sticks to draw their menu specials on the ground, surrounded by arrows pointing towards their door, thus **appropriating** the intervention to advertise their business. This highlights the adaptability and the ability for appropriation of physicalised public displays; in this case enabling local businesses to connect with passers-by.

This capacity of physicalised displays for mediating interactions between people sharing the public space echoes findings from previous research on digital pervasive displays [27, 41], in which social triangulation [64] emerged as the relevant method driving social interactions. The mere presence of the robot on the lane set in motion a series of spontaneous actions and interactions leading to people making their own drawings, adding to previous drawings they found, handing over chalks to others, conjecturing about the robot's purpose and operation, or simply passively observing the actions by Woodie and other people. This finding is relevant for it means physicalised displays retain arguably one of the strongest potential qualities of pervasive displays, namely its capacity to serve as a pretext for members of the public to engage in mutual interaction and creative collaboration. Plus, since the interactions they afford are distributed across the public space, they can provide a safe space for all to enjoy simultaneously. In the words of one interviewee, *"it's good because adults and kids can interact at the same time."*

Drivers of Engagement

We identified a range of factors that encouraged people to visit and engage with our intervention. These can be roughly divided into two groups: (a) visual elements on-site that caught the attention of passers-by and invited them to approach and interact (a pattern we call the "Cracked Honeypot Effect") and (b) external motivators, such as word-of-mouth and media recommendations about the intervention.

The "Cracked Honeypot Effect"

On-site, Woodie itself successfully *"caught [people's] eyes"*, mainly due to the integrated low-res lighting display. In the words of one interviewee: *"I think the colour play is an important part [...] to attract the people to come and have a look."* Likewise, some also reported that they first saw the *"purple lights"* which *"create a very nice atmosphere for the robot"*. The slow movement of the robot, in contrast, was arguably less determinant in attracting people: *"You don't realise it's drawing. But the light attracts, and people come."*. In particular, when people spotted Woodie from a distance, they reported that they did not realise it was moving, rather perceiving it as a mere glowing object on the ground.

While the light from the robot itself was the primary aesthetic factor causing it to stand out from the surrounding environment and be noticed, towards the end of the evenings, it was taken over by the co-created content itself: with the combination of drawings, created both by the robot and previous participants, covering a large section of the lane, the physicalised display on the street, visible from a distance, started to lure people towards the site (e.g. *"I saw lots of drawings and scribbles"*, or *"I recognised the robot straight-away, but first saw the drawings"*). Finally, and similarly to what has been described by Fischer et al. [17], also in our case people acted as a display (e.g. *"first saw children drawing"*) and stimulated a 'honeypot effect' [5]. Here, however, the elements attracting passers-by evolve overtime from the robot (digital display) into the co-created non-digital content (physicalised display), and then into the crowd gathering around both, rather than only around the digital display, as in "traditional" urban displays. We refer to this pattern of interaction as the "Cracked Honeypot Effect" as it extends the metaphor conceived by Brignull and Rogers [5] and widely acknowledged elsewhere in HCI research [10, 31, 36, 60, 66], whereby in our case the "honey" (i.e. the content) spilled out of the "pot" (i.e. the digital display embedded on the robot's body) and into the surrounding environment, thus distributing the visual drivers for engagement. Depending on the situation, e.g. how much content was produced and the amount of people around, those various factors would hold different strength in stimulating passers-by to approach, observe and participate.

External Motivators

An additional factor, which played an important role in attracting people to our site, was the topicality of robots as a subject, and the general curiosity around a playful robot deployed in public space. This novelty factor was reflected by various quotes overheard among the audience (e.g. *"I told my parents that here is a robot"*) or captured in interviews (e.g. *"we read that there is a robot and were excited about"*). Likewise, the growing popularity of Woodie throughout the period of the festival resulted in it becoming one of the event's main draw cards, attracting considerable promotion in social and traditional media, and consequently a significant number of visitors despite it being tucked away in a quiet laneway.

Audience Behaviour and Grouping

Similarly to non-moving light objects on the ground [16], we observed that people who were just passing by the lane came surprisingly close to the robot, however without accidentally touching it. Often people seemed to be in a rush, some glimpsing at Woodie, however due to their fast pace obviously unable to register Woodie's slow movement. We often observed such a situation on occasions when the lane was less crowded. These less-crowded situations, however, also enabled an interesting common occurrence: small children touching Woodie. While most kids would stop near the robot or be held back by their parents, others would run towards Woodie, even occasionally jumping on it, or attempting to ride it like a skateboard.

When successfully engaged in longer-lasting engagement, we observed that some people, in particular children, tended to get very close to the robot, while others would keep a distance because they were *"worried to disturb Woodie"* and thus risk not being able to see the finished drawing. When observing Woodie, children, but also adults, would often bend down, or sit on the floor, in order to understand the mechanism whereby the chalk stick touched the ground. Interestingly, despite Woodie's spherical shape, looking similar from all sides, people were often readjusting their standing position to see Woodie from various sides. One explanation for this behaviour could be that, depending on which direction Woodie was drawing, the chalk stick which was pulled behind could be more visible and better observed. In this longer-lasting engagement situations, we could observe two types of audience groupings, depending on the availability of chalk sticks for the public: (1) in situations when chalk sticks were not available, and therefore only Woodie was drawing, we observed **focused** groups of people standing around it as if it were a street performer (see Figure 7, top). For small to medium-sized groups, Woodie was still visible from a distance by people approaching the site, who were then encouraged to join the group (e.g. *"robot caught my eyes"*). Larger groups, however, would obstruct the robot's view from afar, with people standing and sitting

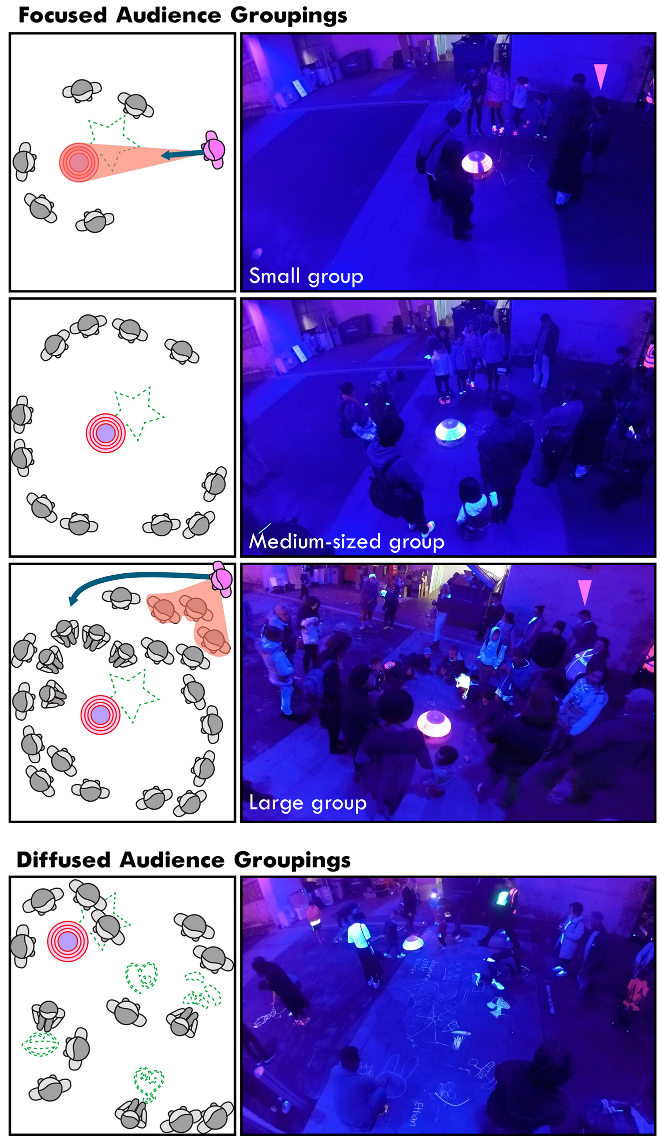

Figure 7. Difference in audience behaviour and grouping: focused audience groupings when only Woodie was drawing (top), diffused audience groupings when chalk sticks were provided to the public (bottom).

around Woodie in multiple rows. In those situations, the audience itself acted as a display, with new arrivals trying to find a free spot among those who were previously in the area. (2) Conversely, on the majority of evenings, when we did provide chalk sticks to the public, we observed a **diffused** distribution of people spread over the whole area (see Figure 7, bottom). This diffused distribution of people was enticed by what we previously referred to as the "Cracked Honeypot Effect": the emerging content created new display spaces, at which people stopped by, reflected on the existing drawings and added their own content. On the contrary, later in the evening, when Woodie's allocated zone was covered by drawings, people had to look after 'free' display spaces, which either resulted in people drawing over existing content or 'expanding' the canvas towards the adjoining street.

Emotional Response

Our data analysis revealed that people had a variety of emotional responses to Woodie. Many referred to Woodie as something *"cute"*, that they want *"to take home"*. One woman who performed in front of the robot – putting her hat on it – mentioned to the group of people around her: *"it's not interactive but it makes people interact, it responds to me like nature responds to me."* The pattern of relating Woodie to natural phenomena was also apparent in comments by other interviewees. For example, one female interviewee stated that the robot *"feels more like a living organism"*. While some people associated the robot to known living species on earth, e.g. a *"mushroom"* or *"jellyfish"*, others rather perceived Woodie as a creature *"from outer space"*. Sometimes people were also speculating about gender and character traits: for example, one elderly man, after observing Woodie for around 20 minutes, asked whether Woodie is a *"male or a female"* and if it's *"serious"*.

The behaviour of small children also reflected the perception of Woodie as a living being: they would often run towards Woodie, trample for a few seconds on the floor in front of it, laugh, and then escape again. This behaviour, which we mainly observed for children aged around 3 years and under, strongly resembled the behaviour of children chasing animals in public space, such as pigeons. Another behaviour that we observed among small children who were just learning to walk, was to lean on the robot by spreading their arms around and hugging it similar to a cuddly toy. However, the intention to touch Woodie was not only observed among children: adults also often approach the robot and tenderly stroke it. One of the volunteers who was on-site for several nights stated that despite the non-existent interactivity, *"[the intervention] is very close and personal"*. Indeed, we also observed a boy apologising for kicking the robot, saying it felt bad for it, and people regularly saying *"Bye, Woodie!"* upon leaving the lane.

Appropriation & Learning

The fact that Woodie was particularly popular among children was apparent not only throughout our on-site observations, but also from the interviews we conducted with parents. One mother who was visiting the site with her 10 and 7 years old girls, commented while her children entertained themselves by observing Woodie drawing: *"For my girls it's fantastic because they could spend one hour being entertained by something like that. So to me that's fantastic."* During conversations we had with other parents, it emerged that some were coming to see Woodie because their children *"are going to coding classes"* and having projects at school where they learn about robots: *"They're doing a mechanic unit at school right now. They've been learning all about robots and robotics. [...] So we don't know anything about it, but she [is] delighted by something like that."* At some stages, when we conducted interviews and children recognised us as "the designer", children were beginning to ask questions about the functionality and implementation of Woodie, which lead to passers-by commenting: *"I love that they wanna know how it works"*. Reflecting about children as potential early adopters of urban robots, a father drew the following insightful remark: *"Six years ago, when my eldest son was just a couple of months old, his first word was 'iPad', besides mother and father."*

We also observed evidence of emerging learning and creativity among children, manifested through watching, and then copying and adapting, some of the patterns drawn by the robot. For example, we noticed in one of our video recordings that a little girl, after had drawn the figure of a heart on the floor, and then seeing a draw of three stacked hearts drawn by Woodie, then also added additional hearts to her own (see Figure 6). Likewise, in various instances, inspired by the sheer presence of Woodie, children would start drawing their own interpretations of what robots look like, often based on humanoid depictions of robots in popular culture (Figure 1).

DISCUSSION & FUTURE DIRECTIONS

From the outset, we designed Woodie as an urban probe, with a relatively open scope, and with the objective of gaining a greater understanding about the relevant features of physicalised urban displays. We were interested on how they would differ from traditional (digital) pervasive displays, and in gauging their implications for encouraging people to strike interactions with a robotic device in public spaces, as well as with their surroundings and each other. Our findings and interpretations above point to particularly relevant aspects that, we would argue, are characteristic of physicalised public displays, and which could inform the design of future similar interventions.

Lessons Learnt

Using the ground as a canvas. Rendering visualisations on the ground attracts people, as the content becomes visible in their immediate physical environment. A visible rendering device moving on the ground, in the form of an urban robot, entices people to shift their gaze to the floor and pay attention in order to adjust their walking accordingly, which in turn causes them, at least momentarily, to slow down. Using an urban robot to print content in a physicalised form allows to arbitrarily increase the 'display area', which is merely restricted by physical rather than technical constraints. As a consequence, the "catchment" area for passers-by spreads way beyond the robot itself, and in spite of it. After slowing, and in order to fully appreciate the chalk drawings on the floor, people need to walk around, turn in different directions, and reposition themselves in space in response to others around - which, then, sparks mutual acknowledgement and, often, social interactions.

Implication of deployment setting. Our study emphasised how urban robots – being mobile and autonomous – can turn arbitrary urban spaces (e.g. a laneway) into display areas with only little infrastructural support required. However, designers and local authorities need to consider safety aspects when planning such interventions. Even if the intended area for operating of the robot is closed for vehicles, people might extend the display area towards adjoining streets. Depending on the deployment location and the context, urban robots such as Woodie, might in particular attract small children who can not estimate the robot's stability and stiffness. Therefore, designers need to implement safety measures in order to not harm children, but also avoid damages to the ground robot.

Urban robots as a facilitator. For making people dwelling on a space they would otherwise just have walked past, physicalised urban displays could also become a powerful strategy for placemaking and community engagement [21, 26, 27]. In that sense, we would argue that Woodie successfully acted as a facilitator for participatory, creative placemaking. Firstly, the integrated low-res lighting display attracted people to approach the intervention site and explore the chalk drawings on the ground. Secondly, the curiosity triggered by Woodie's presence, fostered social interactions among people, such as talking about the robot and the content itself. Previous work reported that researchers manually updating content functions as a "spark" for social interaction [8, 34, 45], which is non-existent with digital public displays. Therefore, we argue that urban robots, visibly creating physicalised displays, can replicate this role.

Slow pace urban media. Early studies reported that delayed, periodic update cycles can create additional anticipation around urban data visualisations [33, 45]. Slowing down the rendering process itself, we found can further increase the dwell time of people and entice them to "come back to see the finished drawing". Future research needs to investigate the influence of speed levels on the interventions' temporal trajectories [3, 66], such as people's disengagement and reengagement with it.

Characteristic style. Our study confirmed the attractiveness of non-digital physical displays in regard to their materiality and transient qualities (e.g. people touching the chalk). Additionally, the characteristic aesthetics of the robot's drawings in comparison to those made by people added another layer of implicit information to the content (e.g. *"We saw similar, precise chalk drawings, so we realised it must be the robot"*). Further, the unpredictability of movement due to the surface of the ground can add analogue aesthetics, however needs to be considered in the chosen drawing style.

Exploratory Design Research in HRI

The majority of research on human-robot interaction (HRI) focuses on usability factors, however an emerging trend within the CHI community is to also apply exploratory design research to this field [39]. In our study, the open-ended approach revealed interesting insights, for example in regard to people's emotional response to Woodie and some people treating the robot as a living being. This was remarkable in two ways: a) Woodie lacked any actual resemblance with humanoid or anthropomorphic features, provided no forms of feedback on human's presence and behaviour, nor any sort of interface for establishing mutual communication. Also, the movement was constant and not inspired by animal movement models, which has previously been proofed to influence the perception of affect [55]. b) We did not confront people with preconceived assumptions, instead the findings emerged from observing people's behaviour in a natural setting and based on open-ended interview questions. Similar to what has been previously said about public displays [1], we argue for the importance of studying urban robots *in-the-wild*, in order to obtain more generative insights about people's behaviour around, and perception of, robots in a natural setting. Overall, the exploratory design and deployment of Woodie indicated novel opportunities on "what to design" robots for [39] apart from mundane tasks, or as one of the interviewee puts it: *"Why not being entertaining as well?"*.

CONCLUSION

In this paper, we described the design and field evaluation of Woodie, a chalk-drawing robot, which we deployed as an urban probe in a metropolitan laneway for a period of 17 evenings. The study contributes to the broad field of pervasive displays and specifically offers insights into how physical materials such as chalk can be used as an alternative to digital displays. It draws on the findings from previous work that highlights the benefits of such physicalised displays, such as the ability for ad-hoc deployment, offering barrier-free interaction, and being more sustainable. The evaluation of Woodie demonstrated that it is possible to use urban robots for increasing the scale and impact of this type of public display. Our findings highlighted a number of opportunities that offer avenues for future research on urban information displays, such as the ability of urban robots and their drawings to act as catalysts for social interaction, enable inclusive education and facilitate placemaking and community engagement, which we will further investigate through the deployment of Woodie as a tool for creating large-scale situated (real-time) data visualisations. The slow update cycles of the physicalised content were effective in persuading passers-by to slow down, engage in appreciation and, often, co-creation both with the robot and other people. The study also pointed to research-through-design as an effective method for the design of human-robot interfaces. To our knowledge, this is the first study of a drawing robot for creating a public display in an urban space. In light of the increasing pervasiveness of autonomous robotic agents in various sectors of our lives, physicalised urban displays present themselves as a viable strategy for emotionally meaningful creative collaborations between human and non-human agents in cities that, beyond smart, can also be social and affective.

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