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ORIGINAL ARTICLE

Hybrid crafting: towards an integrated practice of crafting with physical and digital components

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Abstract With current digital technologies, people have large archives of digital media, such as images and audio files, but there are only limited means to include these media in creative practices of crafting and making. Nevertheless, studies have shown that crafting with digital media often makes these media more cherished and that people enjoy being creative with their digital media. This paper aims to open up the way for novel means for crafting, which include digital media in integrations with physical construction, here called 'hybrid crafting'. Notions of hybrid crafting were explored to inform the design of products or systems that may support these new crafting practices. We designed 'Materialise'—a building set that allows for the inclusion of digital images and audio files in physical constructions by using tangible building blocks that can display images or play audio files, alongside a variety of other physical components—and used this set in four hands-on creative workshops to gain insight into how people go about doing hybrid crafting; whether hybrid crafting is desirable; what the characteristics of hybrid crafting are; and how we may design to support these practices. By reflecting on the findings from these workshops, we provide concrete guidelines for the design of novel hybrid crafting products or systems that address craft context, process and result. We aim to open up the design space to designing for hybrid crafting because these new practices provide interesting new challenges and opportunities for future crafting that can lead to novel forms of creative expression.

Keywords Crafting · Hybrid · Physical materials · Digital media · Design research · Interaction design

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1 Introduction

Making and crafting have been interwoven in people's lives for a long time; originally mostly within professions but later also recreationally, people have turned to making both for functional reasons and for love of the experience of making itself. In our current mass-production society, there appears to be a turn back towards making [1, 2] which becomes evident in the existence and popularity of maker fairs and online communities with how-to resources and blogs of makers' experiences, such as 'Instructables' (instructables.com) and 'Make Magazine' (makeprojects.com). With the prominence of digital materials in our everyday lives, such as photographs, websites and emails, there have been repeated findings that people enjoy making and crafting with digital materials as well and that

self-made digital things can become 'cherished objects' [e.g. 3–5]. However, currently there are limited means available for using digital media in physical crafting practices and integrating these media in the landscapes of our everyday lives. Since both physical and digital means for making have their strengths, this paper focusses on the integration of making practices in physical and digital realms into 'hybrid' forms of making, for example, creating physical objects with the inclusion of digital media. Examples of such hybrid creations that are currently available are photo collages printed on canvas or commercially printed 3D models. However, despite the dynamic potential of digital media, the results of such hybrid creations are static: they do not react to someone interacting with them and cannot be changed or edited after they have been created, unless new versions of the objects are made.

We aim to inform and explore—with the goal of supporting the design of novel tools—the creation and facilitation of forms of hybrid making that result in interactive creations, which, for example, can respond to a person's interaction with them, can change or evolve over time, can be different in different situations—for example, when different people are present in a room—or can be edited as new media becomes available or as someone's interests or preferences change. This means that both crafting *process* and *result* will include both physical and digital elements. These forms of interactive hybrid making will be referred to as 'hybrid crafting'. We are interested in people's everyday crafting practices, rather than those of 'the certified genius' [2, p. 75], which is in line with Sennett's view that craft 'names an enduring, basic human impulse, the desire to do a job well for its own sake', which can be anything from playing a musical instrument, to teaching, to bricklaying and which goes beyond manual labour [6, p. 9]. Following Csikszentmihalyi's definition of creativity [7]—employed by Gauntlett [2] to address everyday making—we include in our notion of everyday crafting 'making [anything] which is novel in that context' [2, p. 76]. This includes creating something from scratch but also using existing materials or objects, physical or digital, in new ways. In fact, we are interested in how personal digital media, for example, photos or audio files—existing digital materials—may be used in hybrid crafting. As such, our definition of hybrid crafting is: '*everyday creative practices of using combinations of physical and digital materials, techniques or tools, to make interactive physical-digital creations.*'

To explore how we can design means to facilitate hybrid crafting, we developed 'Materialise', a building set for hybrid crafting that consists of physical building blocks which can be used for crafting physical constructions, but also allows for the inclusion of digital media. These media can be composed to form a meaningful integration with the physical components by using tangible building blocks that can display digital images or play audio files. As a means to create compositions from physical and digital materials, Materialise not only addresses forms of craft that include existing elements, but also answers to views in materiality research that consider composition a key factor in successful integration of physical and digital materials in design [e.g. 8–10]. A set of creative workshops was organised in which through hands-on experiences with the set, discussions and design activities we explored the following questions:

1. How would you go about doing hybrid crafting with personal digital media?
2. Is hybrid crafting preferred to crafting in only physical or only digital realms?
3. What are the characteristics of hybrid crafting?
4. How can hybrid crafting be facilitated through the design of an interactive product or tool?

This paper will address a literature review into related work in HCI and design in the areas of tangible interaction (which, relatedly, aims to combine physical interaction mechanisms and digital media) and crafting (Sect. 2), after which we will address the design and implementation of Materialise (Sect. 3), and the creative workshops done with a prototype of Materialise to explore notions of hybrid crafting (Sects. 4 and 5). This paper ends with a discussion and conclusions based on our findings (Sects. 6 and 7).

2 Related work

While crafting and making were originally mostly practised in professions and aimed at making functional artefacts for everyday life, for example, blacksmithing, bricklaying and carpeting, nowadays people turn to crafting and making for recreational purposes and results of crafting do not have to be functional. For these forms of recreational crafting and making, the process is often more important than the result, and this process can be a personal, reflective activity, for example, composing photo albums or scrapbooking [11–13]. Apart from material practices of crafting, such as painting, jewellery making and sculpting, people have also turned to digital forms of crafting, that is, making new creations with digital media or augmenting digital media, for example, making websites or digital photo collages. Apart from dedicated tools, such as image or video editing software, people appear to be creative in finding their own ways of making and personalising digital media files. For example, Odom et al. [4] found in their study about the value of digital possessions that the teenagers they interviewed engaged in the personalisation of metadata, both individually and

collaboratively, which can be seen as a form of craft. Similarly, Petrelli et al. [5] found that digital things that are special are often self-made, such as PowerPoint presentations, animations and photo montages. The authors argue for the development of new digital archiving tools that can support new practices of selecting and composing digital media in ways similar to making albums or scrapbooking. These results have shown that crafting and making with digital media can make these media more special or cherished, and, in fact, being self-made or augmented appears to be one of the main reasons people cherish their digital possessions [e.g. 3, 14]. Crafting and creativity with digital media may further provide a means for selectivity by carefully reflecting and choosing which media to keep and discard, and as Gauntlett argues: craft and creativity may offer a 'positive vision to making and reusing' and an alternative to accumulating more stuff that does not positively contribute to well-being [2, p. 57]. Including digital media in craft practice, as is included in our notion of hybrid crafting, is therefore an important underlying motivation for the exploration of designing for hybrid crafting. This section will address HCI and design work in the area of craft, as well as related work on crafting platforms and tangible interaction with a focus on crafting and making—after all, tangible interaction focusses on the combination of interaction through physical and digital materials, as hybrid crafting does. We will end this section by addressing interesting questions regarding designing for craft and outlining which questions we focus on in this paper.

2.1 Craft in design and HCI

Addressing craft from the perspective of cherished objects, Csikszentmihalyi has taken a broad perspective on craft, defining it as everything that is made by someone rather than being a 'conveyor belt product' [15]. In HCI, this understanding of craft has further been taken up by Rosner and Ryokai who summarise craft to include a 'partnership between people and technology for the creation of personally meaningful things' [16, p. 195]. Within HCI, craft-oriented research has also been identified as a strand within materiality research, which brings to the discussion the communicative dimensions of materiality—for example, by communicating traditions, material choices and processes of making through the material [17]. Crafting in everyday life, as addressed in this paper, is strongly linked to the DIY tradition which has previously been defined as: 'an array of creative activities in which people use, repurpose and modify existing materials to produce something. These techniques are sometimes codified and shared so that others can reproduce, re-interpret or extend them.' [18, p. 4824]. Similarly, Gauntlett draws on Csikszentmihalyi's definition of creativity [7] to define everyday creativity as follows: 'Everyday creativity refers to a process which brings together at least one active human mind, and the material or digital world, in the activity of making something which is novel in that context, and is a process which evokes a feeling of joy' [2, p. 76]. In his book about creativity and making in the digital realm, he includes examples ranging from game avatars to YouTube videos, which illustrates the great variety in which people can be creative in crafting things with digital materials. Crafting with digital materials or tools can also be seen in, for example, CAD design [e.g. 19] or rapid prototyping technologies [e.g. 20, 21]. Since the processes and/or results of these forms of making are not hybrid and/or not interactive, they do not fall under our notion of hybrid making and are thus outside the scope of this paper. Craft has recently started to gain interest from the HCI community, and over the past years, a number of studies have looked at craft practice to inform design or have developed ways to combine technology with more traditional means of crafting to support new craft practices with digital technology.

2.1.1 *Informing design through the study of craft practice*

In this category, some studies aim to *extend notions of craft in the context of design*. Kettley [22], for example, argues that craft should be seen as something fluid that has the ability to shift between transparency and reflection and that looking at craft thus can provide a promising model for tangible interaction design that is both metaphorically meaningful as well as useful. Kolko [23] introduces a new notion of craftsmanship centred on empathy through narrative, prototyping and public action, and inference, for situations in design in which the 'material' to work with is not a traditional material, such as paint or clay, but instead related to service design or interaction design. Robles and Wiberg [24, p. 137] use the design and crafting of an Icehotel to introduce the term 'texture', 'a material property signifying relations between surfaces, structures and forms' to argue for a focus on the similarities and extensions of physical and digital rather than the differences, within and beyond the realm of crafting. Tanenbaum et al. [25] look at the Steampunk movement and how, through the concepts of design fiction, DIY and appropriation, Steampunk maker practices can inform design. They argue that such practices introduce new models of values and meanings, and as such construct new models of craftsmanship, functionality and aesthetics, in which creativity and resourcefulness are encouraged and designers act as 'bricoleurs'. Future craft [26] introduces a design methodology that aims at the use of digital tools and processes, such as digital fabrication and open-source communities, to

create designs that are socially and environmentally sustainable, through the application of principles of public, local and personal design. And finally, Nimkulrat has used her own practice-based research in textile craft to explore how craft can inform practice-based research and how research can inform craft practice [27].

Other studies have looked at *specific craft practices* to illustrate how the design of technological products may benefit from taking into account these forms of making. Meastri and Wakkery [28], for example, look at the repair and reuse of objects in the home as a form of everyday creativity and 'everyday design' and argue for the employment of a framework of resourcefulness, adaptation and quality to overcome the barriers of repairing and adapting digital technologies. Also addressing repair, Rosner and Taylor [29] studied bookbinding practices and use antiquarian book restoration to illustrate the material practices of restoration for HCI, highlighting the making of authenticity through careful use of materiality and designing for longevity by integration in social practice as means for designing more meaningful and lasting technological products. Bardzell et al. [30] have interviewed elite craft practitioners to enrich understanding of notions of quality and provide insights into interacting with integrity, self-expression through interaction with materials and socio-cultural positioning of creative work, in the light of designing products with socio-cultural relevance and value. Lindell studies the practices of programmers within design processes to argue that code can be seen as a material and programming as a craft [31]. Goodman and Rosner [32] look at the practices and use of information technologies of gardeners and knitters to argue for a framework of handwork that can inform design that goes beyond the distinction of physical and digital, by focusing on extending, interrupting and splitting up physical practices with digital technology. Again drawing on craft practice, Rosner [33] further argues for designing technological products that allow for tracking provenance, for example, by replaying traces of production, foregrounding traces of breaking and extending traces of ownership. Similarly, Broken Probes aim to give new life to broken and worn-down objects by digitally associating stories with marks of degradation [34]. Finally, Wallace's work [e.g. 35, 36] uses examples of jewellery making to illustrate how aesthetics and beauty, and enchantment, can arise from the process of making, through empathy and sensibility towards felt life, and the relationships between maker and wearer, and maker and materials.

2.1.2 *Combining technology with traditional means of crafting*

In the second category, the first large group of enhanced or 'mediated crafts' [37] are *textile-based crafts*. Buechley and Eisenberg [38] designed new means to attach off-the-shelf electronics to textiles to make this so-called 'e-textile craft' available for crafters and hobbyists. Perner-Wilson et al. [39] take the approach of a 'kit-of-no-parts' as a means for supporting the building of electronics from a variety of craft materials, illustrated by the development of a number of textile sensors, hereby bypassing the constraints that modular, pre-determined building blocks in traditional construction or electronics kits may have. Embroidered Confessions [40] is a collection of QR codes associated with digital confession stories from the internet embedded in a quilt. Rosner and Ryokai's Spyn [41] is a mobile phone software tool that allows needle-crafters to associate specific locations on physical garments with digital media to enrich the meaning of these garments as gifts and the relationships between maker/giver and receiver. A second well-employed material appears to be *paper*. Freed et al.'s I/O stickers [42] provide children with a means to craft personalised remote communication interfaces by combining the crafting of greeting cards with the use of networked sensor and actuator stickers. Zhu [43] looks at paper-craft, such as writing, drawing, folding, cutting, gluing, and presents two supporting technologies to allow the building of paper-computing systems around three themes: the ubiquity of paper-craft, the flexibility of paper-craft as a means to control digital data and displaying digital information through changes in the paper. Cheng et al.'s Tessela [44] is an interactive origami light that encourages creative, poetic interaction through changing light patterns. And finally, Saul et al. [45] propose a number of interactive paper devices, construction techniques—for example, cutting, folding, gluing—and materials—for example, paper, copper tape, gold leaf foil—and a piece of software, which support a DIY design practice for users to build their own paper electronics.

2.1.3 *Tangible interaction and crafting platforms*

A number of existing Tangible interaction systems can be considered platforms that support making or crafting. Some of these have looked *repurposing and employing existing means* to novels ends, such as the use of open-source hardware as a means to support creativity [46, 47], the role of hacking and DIY in tangible interaction [48] or creating objects that can be used in home crafting projects with such hardware, such as Rototack [49] and a programmable hinge [50]. Inspirational Bits [51] further aim to expose material properties of technologies that can inform a design process and design sketches, although they are not intended as prototyping means. Other platforms are *prototyping tools* that allow for the quick assembly of electronics in the design phase, but the use of which can extend to creative practices of users, such as Voodoo I/O [52, 53], LittleBits

[54] and .NET Gadgeteer [55]. A third category is formed by *systems aimed at children* and which allow them to create their own toys and tools for storytelling, such as Plushbot [56], Craftopolis [57], e-textiles [58], kidCAD [59] and Telltable [60]. Finally, some studies have looked at the use of *craft materials and crafting as augmented input* for digital technologies or creative interaction with digital technologies, for example, claying [61] or sketching [62].

2.2 Design questions for hybrid crafting

Despite the wealth of HCI and design work in the craft area, none of the addressed studies has looked at hybrid crafting in the form addressed in this paper, a physical-digital making process that results in interactive physical-digital creations. Interesting questions arise from considering hybrid crafting as a direction for design, and based on a review of the related work described above, a literature review into craft (which lies outside the scope of this paper), and our own research interests, we formulated design questions about the inclusion of digital materials and tools in crafting. These questions lay in the following areas:

1. Social aspects, such as: 'Would people like to craft collaboratively using digital means?' or 'How can the results of crafting with digital means be communicated and displayed in more suitable ways?'
2. Materiality, such as: 'How do people use the different affordances of various digital media in hybrid crafting?' or 'How can we provide a sense of materiality in working with digital materials?'
3. Process, such as: 'To what extent would people allow for creations with digital media to be edited by others?' or 'How can people develop specific ways of working with digital materials?'
4. Result, such as: 'How can the ability of digital means to evolve and grow change the perception of a creation?' or 'How can the process of making be shown in the result?'

These four areas arose from our set of design questions and were merely used to categorise the questions, rather than as a framework for design or analysis. Early in the design, research process ideas were generated around each of the design questions, and these questions further led to refining our definition of hybrid crafting. The design direction we eventually decided to pursue focuses mainly on the Materiality area and aims to explore how physical and digital materials may be integrated in crafting practice; what the value of this integration is; how we can design for this integration; and how characteristics of physical and digital crafting apply to this hybrid form of crafting. In the next section, we will address the design and implementation of a research probe we developed to explore these questions.

3 Materialise: a design for hybrid crafting

One of our early design ideas was a building set that allowed for the creation of a customised media cube by connecting six physical building blocks, which could each hold one specific digital media type, for example, a photo, an audio file or a text message, as a novel form of making customised gifts. Based on this idea, we developed 'Materialise', a design research probe which was the result of an iterative design process. Materialise employed the tenets of the described early idea but was developed into a much more flexible and open-ended building set for hybrid crafting. The set contains physical building blocks that can also include personal digital media, but rather than the goal being to build a gift-cube, now physical and digital components can be combined in various ways, and many possibilities for creative applications and additions are present, due to the provision of building blocks in different shapes and materials which can be connected in various ways and orientations. To support the integration of the digital media files, a software application was implemented that allows the users to start composing how the digital media will be integrated in the physical creation, by showing digital representations of the physical building blocks that can be dragged, rotated and connected in much the same way as the actual physical blocks. Digital media can then be dragged and dropped to the digital representations of the blocks and displayed as it would look in the final creation. In this way, Materialise supports a hybrid crafting *process*—including both physical building and composing the digital media on screen—and *result*—ending with a creation that is interactive (more about this in the next section) and includes both physical and digital materials.

A prototype was implemented of Materialise (see Fig. 1) to be used in a set of creative workshops to explore notions of hybrid crafting. The set of building blocks consists of a number of 'active blocks' which can contain digital media files, and a large variety of 'passive blocks' that are not interactive or contain digital media but can be used to build physical structures.

3.1 Active building blocks

Two different types of active building blocks were implemented. The first type had a touch screen and could display digital images (see Fig. 2a). This type of block could display a series of images and provided interactivity by allowing the user to press the 'next' and 'previous' buttons

Fig. 1 The prototype of 'Materialise'

on the screen to change to image, or it could automatically display a sequence of images by activating a slideshow on the touch screen. The second type of building block could, when a speaker or headphone was attached, play digital audio files (see Fig. 2b). It could play a sequence of sounds by pressing 'next' and 'previous' buttons on the block. Three active blocks were implemented for the prototype, of which two were of the image type and one of the audio type. Further, a separate speaker was provided. All active blocks were implemented using the .NET Gadgeteer platform for prototyping (netmf.com/gadgeteer/) and had, apart from either a touch screen or an audio module, Wi-Fi capabilities and a micro SD card reader. Casings were designed and produced using rapid prototyping. Wi-Fi capabilities were used to download media content wirelessly from a webserver, which was the dedicated place for the users to place media they wanted to upload to the blocks. Media content was downloaded and saved on the micro SD card and consequently displayed or played back. Each block further had a 'reload' button which could be used to reload media files from the server if the content on the server had been updated by the user. Wi-Fi capabilities were further used for communication between active blocks. Whenever content was changed on one block, either because a slideshow was activated or because by user input, the filename of the new media file that was displayed or played was passed on to the other blocks wirelessly. The other blocks then checked whether their file lists contained media with this file name and whether this was the case displayed or played that media. This allowed the users to associate multiple related media files and display them at the same time, for example, two photos taken at the same event, and an audio file related to that same event. This function provided interactivity for the hybrid creation; apart from being able to easily change the physical composition, digital media on the blocks could be easily changed and updated by the user to alter the hybrid end result.

3.2 Passive building blocks

Passive blocks did not have interactive functions but could be used to enhance the physical composition. Most passive blocks were made of wood and included: four cubes painted white that could serve as whiteboards; four cubes that were painted with blackboard paint; nine bar-shaped blocks; a frame; four rings; two blocks with hooks. Further building blocks were as follows: a pin board; a clip; two magnet boards; and magnetic transparent sleeves. All building blocks, including the active building blocks, were equipped with a number of magnets to allow for them to be connected in different ways. To provide more flexibility in how blocks could be connected, metal connector strips were also provided of different lengths and with different angles. See Fig. 3a for an example of some passive blocks

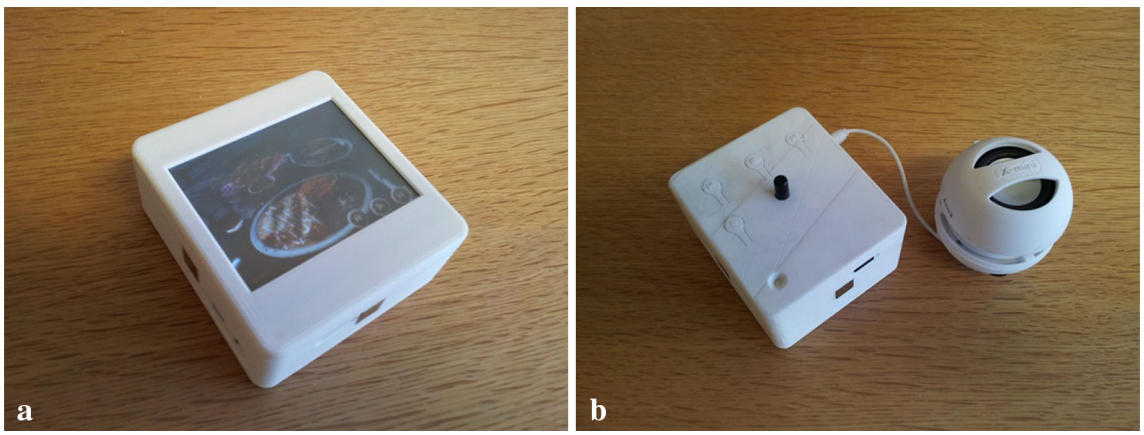

Fig. 2 The active blocks: **a** image building block; and **b** audio building block with a speaker

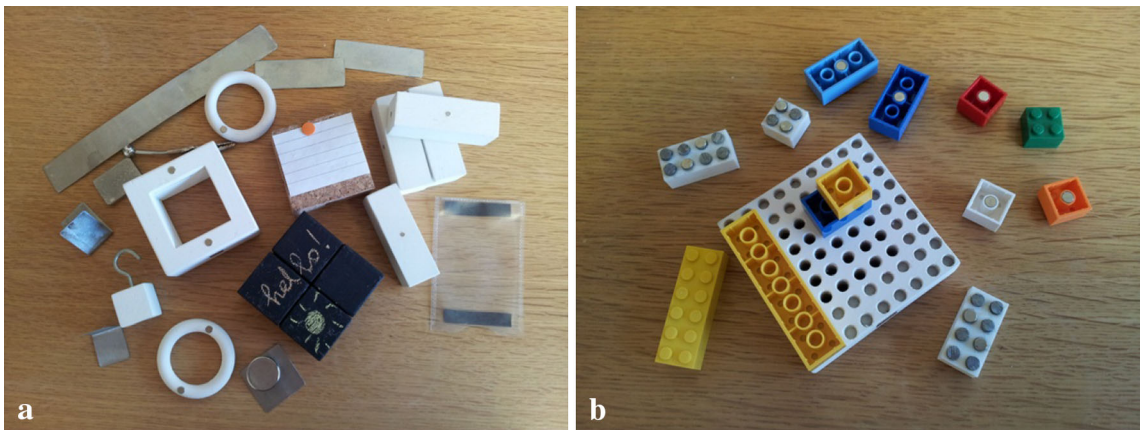

Fig. 3 **a** Examples of passive building blocks and connector strips; **b** Lego connector blocks and adapted Lego bricks

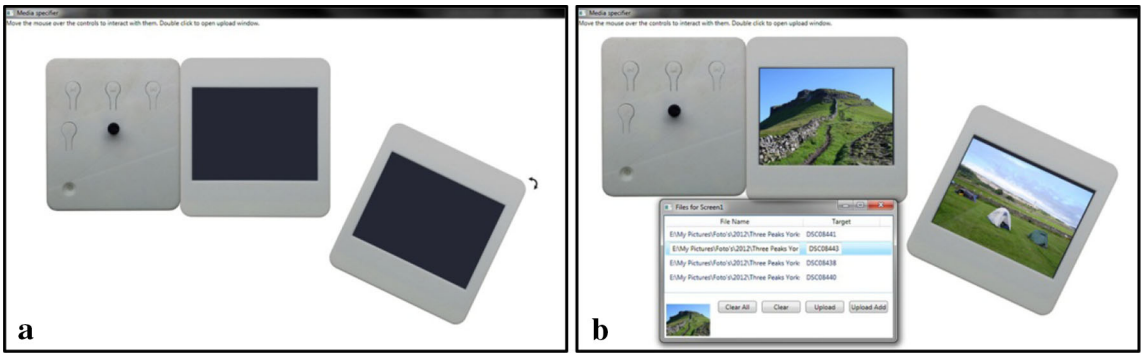

Fig. 4 Screenshots of the user software: **a** representations of the physical building blocks that can be dragged and rotated; **b** a pop-up window could be used to drag and drop media content to the media blocks and display these

and connector strips. Furthermore, whiteboard markers, chalk, paper and pens, scissors and pins were included to allow users to write and draw and attach notes to the creation. Finally, a variety of Lego bricks were provided which could be connected to the other building blocks in a number of ways: some Lego bricks were equipped with a magnet on the underside; other Lego bricks were adapted to have magnets and small metal discs on the top; and a wooden block was provided that had holes in which Lego bricks could be clicked for further building flexibility; see Fig. 3b for the Lego connector blocks. The passive blocks and connector strips in combination with the Lego bricks were expected to provide the users with great flexibility to execute their ideas about what they wanted to create physically and in addition provided means to bring in additional materials—for example, magnetic objects—beyond the set.

3.3 User software

A software application was created that allowed the users to start exploring the hybrid composition digitally and which helped them with the uploading process. By clicking a digital representation of an active building block (Fig. 4a), a pop-up window would appear which would allow the user to drag and drop media content from a directory on their computer to the block. Image files could then be seen on the illustration of the block to give the user an idea of what it would look like on the physical blocks, and thus, how this may be incorporated in a physical creation (Fig. 4b). After selecting media and dragging these to the desired blocks, the user had the option to change the target file name of each media file in order to be able to link related media on the active blocks. After renaming, media could be uploaded to the webserver, from where they were downloaded by the active blocks, which each had their own dedicated directory on the webserver.

Restrictions of this first version of the user software were the absence of built-in image editing possibilities, such as rotation, resizing and cropping images, and audio editing possibilities, such as clipping a section of audio, and changing the bitrate. Because these functions were important for accurate functioning of the active blocks—images needed to be adjusted to fit the screen resolution and the audio bitrate needed to be 128 kbps or lower for smooth audio feedback—some preparation of media files

using other software applications was needed in the workshops.

3.4 Other envisioned functionality

Because of technical limitations in the .NET Gadgeteer prototyping platform, and time restrictions, only a limited number of functions were implemented in the prototype: displaying images and navigating through the image sequence; a slideshow; playing audio files and navigating through the audio sequence; and wireless communication to download media and enable communication between blocks. However, other functionality of the blocks was envisioned which was communicated to the users to get them thinking beyond the current possibilities. Other envisioned functionality included: downloading content from Facebook, for example, displaying a Facebook photo on one block and the comments with that photo on another block; live feeds from the internet, for example, Facebook status updates or Tweets; playing movies; easy ways to load web content to the blocks; and text content, for example, email or forwarding text messages from a mobile phone to a block.

4 Creative workshops

The prototype of Materialise was used in a set of creative workshops to explore notions of hybrid crafting through hands-on experience with this form of hybrid crafting, discussions and design exercises. Four two-hour workshops were done in the UK, each with three or four participants. The workshops were held with small groups because participants had to collaborate in the workshops using the one-off prototype and a laptop. The first workshop was held with a group of designers, the second with a group of parents, the third with a group of teenagers, and the fourth with a group of crafters. Each of these groups was considered to be able to provide useful comments either from the perspective of creators and makers to consider design implications for hybrid crafting (the crafters and designers) or from the perspective of potential target users (the parents and the teenagers). The group of designers consisted of professional designers and postgraduate researchers in interaction design. For the crafters group, the definition of who may be considered a crafter was deliberately kept open to include anyone who liked to make things either recreationally or professionally. All participants were recruited from the personal and professional networks of the researchers through e-mail adverts and verbal explanations of the study. The workshops took place in a meeting room at the research institute, with the exception of the designers' workshop, which took place in a meeting room at the designers' own place of employment. Participants were paid a small incentive (£20.00) for their participation. In each workshop, two researchers were present: one facilitator and one other who was in charge of audio and video recording and taking photographs.

4.1 Method

Because Materialise focusses on the use of personal digital media in hybrid crafting, as a preparation to the sessions, participants were asked to select from their own media, search online or create 5–10 digital images that were interesting, meaningful or beautiful to them, such as personal photographs, digital artworks or screenshots from online content. They were further asked to select, search online or create 1–5 audio files that were in one way or another related to one or more of their images, for example, a song that reminded them of a holiday of which they had included a photograph or a recorded narrative about an image. Participants were asked to bring their selected media to the sessions or email them to the facilitator beforehand.

The sessions themselves were started with welcoming and introducing participants, researchers and the topic of the workshops, followed by three parts: 1—a demonstration of the prototype and software; 2—hands-on experience with the prototype and software; and 3—a group discussion about potential use, improvements and extensions. At the end of this section, we will describe how each of these parts informed our research questions.

The first part, the demonstration, included showing the participants the physical building blocks, the software and the functionality of the active blocks, as well as introducing envisioned other functionality, in order to get them to think about what they would like to make. The demonstration was done by showing the uploading of media with the software and showing a photo of a physical creation built around these media. This example showed a relevant integration of digital media and physical construction, namely a series of images of cartoon and movie characters headshots (e.g. the Men in Black, the Muppets, Wallace and Gromit, the Blues Brothers) and the associated theme songs, coupled with the creation of physical bodies for these characters (Fig. 5).

For the second part, the hands-on experience, all tasks were collaborative because there was only one prototype of the building set available. Participants were first asked to perform a small, specific task to familiarise them with the set, which started with composing and uploading a provided set of images and audio using the software. After these images and audio appeared on the physical blocks, participants were asked to build something that was related to these media. The media used in this example were a set

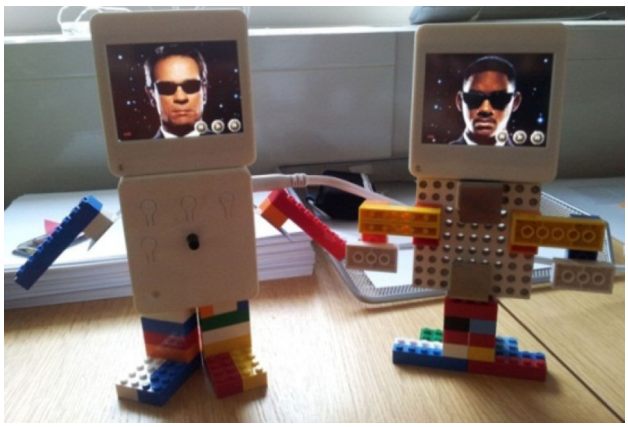

Fig. 5 The demonstration example used in the workshops: while the physical body was static, the digital images showed different examples of cartoon or movie duos that were linked and thus displayed at the same time. The examples were further linked to the theme songs of the movies or cartoons, which played at the same time as the images were shown

of images related to Jamaica and reggae music; a set of images of London; a set of images of Paris; a set of soundscapes of cities, for example, traffic and crowds talking; the sound of beach and waves; and a Bob Marley song ('Three little birds'). It was estimated participants would either choose the Jamaica theme or one or both of the cities for their creation. After a short break in which the facilitator prepared the participants' media, that is, resized images and changed the bitrate of audio files for reliable functioning of the prototype, participants used a laptop to select media from what they brought into the sessions, again in a collaborative activity, and used the software to compose and upload images. Further, there was the opportunity to create new content, for example, audio narratives, or sourced online. Additional software that was available was the freeware Audacity (audacity.sourceforge.net/) and iTunes (apple.com/itunes/), and Microsoft Office Picture Editor, for which custom user manuals were created to support users who were not familiar with these applications. Apart from this digital exploration, participants were asked to upload the digital content to the physical devices and create physical constructions using the building set and other available materials. It was anticipated that participants would switch between working with the digital media and physical building and that they would try out multiple combinations of physical and digital creations. We were also interested in seeing how participants would negotiate between adapting the physical to the digital content or vice versa, which was why the digital and physical creation phases were introduced simultaneously and participants were free to determine which to do first and to switch.

In the final part, the group discussion, we aimed to gain some insights into the participants' opinions on Materialise, as well as explore potential use, improvements and extensions, in order to derive ideas on how these answers may be applied to hybrid crafting in general. The discussion was centred on the following questions: 1—What is the participants' general opinion on the building set? 2—What would they like to use this set for? What physical blocks are suitable or desired for this? What would they do with the result? 3—What digital media would they like to use? In what way? Would they use it for static creations and with existing media or would they value dynamic, streaming media, such as Facebook feeds? 4—What other building blocks can be thought of? For this question, participants were given a sheet of paper with template sketches of blocks to design their own extensions 5—What would they change or add to the software? What would be interesting digital extensions?

Data analysis focused on the research questions about hybrid crafting posed in the introduction of this paper and aimed to answer these questions specified to Materialise. The different phases of the workshop informed each research question as follows. Question 1 (How would you go about doing hybrid crafting with personal digital media?) was informed by the observations in the workshop, particularly about how participants went about selecting and using their personal media, and how physical constructions were built around personal media. We watched the video recordings of the workshops and we thematically categorised interesting observations that informed this question. Question 2 (Is hybrid crafting preferred to crafting in only physical or only digital realms?) was mainly informed by the group discussion on participants' general opinions, possible use of the set, and which physical and digital components they would value. We thematically categorised answers and—although we are aware we cannot draw objective generalizations based on the findings for Materialise and the novelty of the set will have influenced participants' opinions—we aimed to provide insights into the value of hybrid crafting. Question 3 (What are characteristics of hybrid crafting?) was informed by observations, particularly in the area of integrating physical and digital components, how these were selected and what the processes were of working with physical and digital materials, which were again thematically organised. And finally, question 4 (How can hybrid crafting be facilitated through the design of an interactive product or tool?) was informed by the design activity within the group discussion, as well as by a more general reflection on our findings regarding the four research questions. The Results section will be focussed around answering these research questions and will, through further reflection, aim to reach a more

general feel for hybrid crafting and derive guidelines for designing for hybrid crafting, in the Discussion.

4.2 Participants

In total, 13 participants took part in the workshops (3 men, 10 women, ages ranging from 17 to 56; average age: 34), of which 3 were designers, 3 parents, 4 teenagers and 3 crafters. See Table 1 for an overview of the participants. All the designers knew each other through work; two of the parents were also work colleagues; the teenagers were a group of friends; and two of the crafters had met each other before. Because a comparison of groups was not the aim of our study, the results for these groups will be addressed together.

5 Workshop results

The thirteen participants together brought in 121 images (ranging from 5 to 25 per person, 9 on average) and 45 audio files (ranging from 1 to 7 per person, 3.5 on average), and all participants brought at least one set of related media; either an audio file related to a photo or two related photos. The majority of the images were either unedited photos or downloaded from the internet, but mostly taken by participants themselves (e.g. of nature scenery, participants and their families and friends, and specific events such as a graduation), and only two images were self-created: an electronic self-portrait, and a photo of a participant and her partner that was edited into a black and white 'pop art' representation. Most participants indicated to have chosen images that were somehow representative of different aspects of their lives, such as photos of people, or of things they had made themselves, but there were also instances in which participants carefully constructed combinations of images and music, such as one participant's example of her photo of the Berlin wall in 1989 coupled with the music from the movie 'The lives of others' set in Berlin around that time. Audio files were less personal and were more often downloaded from the internet to fit with images or to provide a diversity of examples, for example, ambient sounds of crowds, cities and nature, voices and laughter (19 files), and music (16 files). However, there were also personal examples, such as a designer's file of a radio interview with his grandfather and a teenager's recording of her talking to her father in a restaurant when she was a small child.

5.1 How did participants go about hybrid crafting with personal digital media using Materialise?

In the first task of the hands-on part of the workshop, in which one prototype of the set was available to the group of participants, a number of example themes and related media were given. In this task, participants could focus on getting to know the prototype after deciding on which theme they were going to use. The second task, however, in which they were asked to use their own personal digital media appeared to be 'pushing creativity' much more. Participants selected media to use collaboratively by going through their files and telling each other what they had brought, how their files were connected, and the stories behind these files. Because media were so diverse, finding

Table 1 Gender, ages and backgrounds (profession or craft) of the participants

Designers	Crafters
Female, 31. Occupation: postgraduate researcher, interaction designer	Female, 51. Occupation: legal secretary
	Craft: knitting, embroidery, sewing, spinning
Male, 42. Occupation: interaction designer	Male, 53. Occupation: information security
	Craft: jewellery
Female, 31. Occupation: postgraduate researcher, interaction designer	Female, 40. Occupation: senior tutor and jeweller
	Craft: jewellery
Parents	**Teenagers**
Female, 25. Occupation: youth worker	Female, 17. Just finished college (secondary school)
Parent of: female, 7; male, 3	Female, 18. Just finished college (secondary school)
Female, 56. Occupation: researcher (sociology)	Female, 17. Just finished college (secondary school)
Parent of: female, 16	Female, 18. Just finished college (secondary school)
Male, 46. Occupation: researcher (user experience)	
Parent of: female, 16; female, 13; female, 11; female, 7	

a common theme in their media proved challenging to participants. However, all groups managed to find a theme in which they could include media from different participants and build a physical construction around this, such as the 'urban theme' chosen by the designers, around which they built an 'urban diorama' consisting of a 'Banksy-inspired' graffiti piece, pillars and piles of rubble, created in the prototype briefcase, which was meant to be 'provocative, not beautiful!''; see Fig. 6.

Participants went through phases of *exploration and experimentation* with both digital media and physical building blocks, and in some cases, the participants never indicated they were finished, continuing building until time restrictions required moving on. Participants appeared to enjoy exploring the possibilities with the prototype and brainstormed potential things to make, such as 'Bob Marley's 14 kids' or 'a real-life model of Bob Marley', and one designer sped off to his office to bring in his Lego model of a VW-van and asked whether he could use it as part of the creation. Other participants became fascinated with exploring how they could make constructions move by using the attracting and repelling powers of the magnets; see Fig. 7. Also digital media were changed often, even after having downloaded it to the active blocks, and participants talked about what they could make with certain combinations of media files. However, in most cases, the actual physical building took place after participants had decided on a theme and had decided the media that should feed into that theme. In the final phase before building, participants eventually selected relatively few files to upload to the blocks, 1–5 images per block, and one or two audio files; and the audio files were generally linked to one or two images, while about half of the images were linked to another image or an audio file. In several groups, the construction was not considered complete without sound: while the designers kept playing the Bob Marley song 'Three Little Birds' while building, one teenager commented, after finishing their beach scene: 'We've lost the sound'; after activating the sound of waves to go with their construction, in unison: 'awwww'.

Fig. 6 The designers' urban diorama: a 'Banksy-inspired' graffiti piece, pillars and piles of rubble, created in the briefcase

Apart from sharing stories behind their media and finding a common theme, other *social dynamics* could be observed. In each group, one participant took responsibility for managing the laptop, often after asking the others whether this was okay. This role changed after the first part of the workshop, often encouraged by the person who did it before who wanted to give someone else the opportunity, for example: 'Does anyone else want to do the mouse? I don't want to be the mouse dictator'. Apart from feeling 'in charge' of the laptop, participants often also each felt in charge of an active block because in most groups there were three participants and three active blocks. This can be illustrated by the following exchange between a designer and the person controlling the laptop: 'Don't I get any pictures?'—'Oh, you want a picture? What do you want?'—'A Jamaican one!' In all groups, it was common for participants to build elements separately, which were then combined completely into a joined composition or merely put next to each other; see Fig. 8.

Looking at *what was built* it was interesting to see that in both hands-on tasks of the workshop, most physical creations were concrete representations of scenes or objects related to the images and audio, such as the palm trees, the bird from the 'Three little birds' song, the model of Bob Marley, the waves, the toilet and the model of the college. While the designers' 'urban diorama' (Fig. 6) was less concrete than these examples, the only truly abstract representation was created by the parents around the Berlin wall theme and included the 'windmill of change' and a 'balance thing' to indicate the skewed balance of the situation, accompanied by music from the movie 'The lives of others' (see Fig. 8b). This abstract representation was mostly initiated by one participant and also repurposed elements from the parents' earlier experiments with creating moving parts. The teenagers decided on a college theme, having all just finished college, and used images of friends that reminded them of their college time and the Britney Spears' song 'I'm not a girl, not yet a woman'. Their physical construction around this consisted of a scale model of their college; see Fig. 9. After the construction was finished, they played the song and one teenager commented to the others: 'This is about you guys', and another

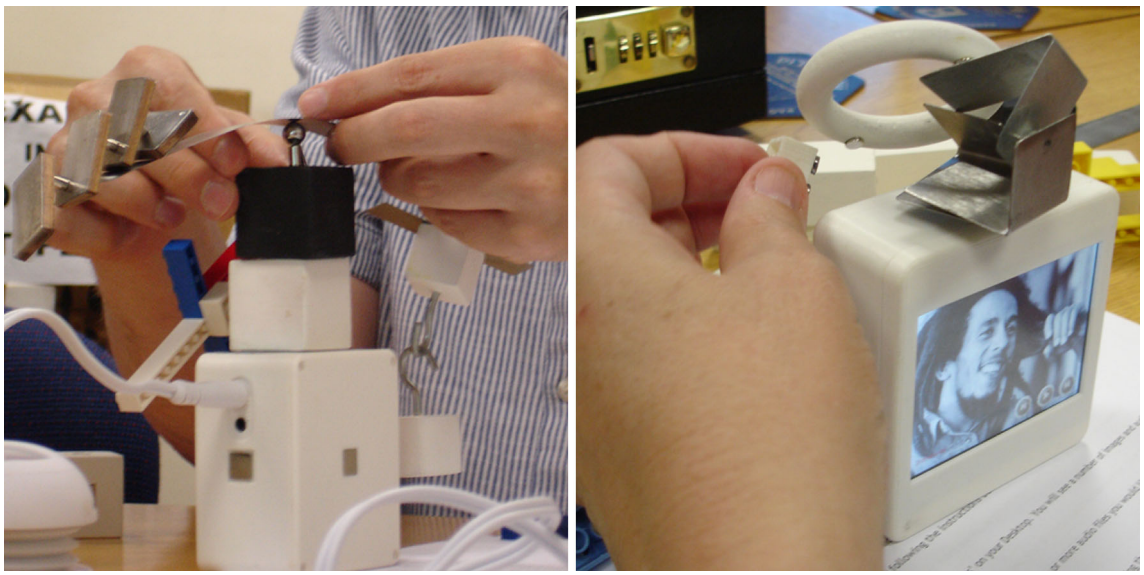

Fig. 7 Participants experimenting with the attracting and repelling powers of the magnets to creating moving parts

Fig. 8 Examples of creations built separately by participants and then joined: **a** city buildings and a car that remained separate constructions; **b** a fully integrated abstract representation around the theme of the Berlin wall: the right side of the construction—looking at a thematic stained glass window through a window, the left side—obscured vision of what is behind, because of the wall, and the top part—'a balance thing' (to indicate the skewed balance of the situation) and 'the windmill of change' (change caused by the wall coming down)

girl teased one of the others: 'Are you getting sad now?' The current set-up of the set thus mostly triggered thinking about concrete physical representations. It is likely this was influenced by the limited time the participants had to come up with something to build and the collaborative character of the workshop—we anticipate abstract creations may require more reflection and thought for which there was limited room.

5.2 Is hybrid crafting with Materialise preferred to crafting in only physical or only digital realms?

In the group discussion after the hands-on part of the workshop, the participants highlighted two areas of the building set that they considered interesting and novel: the linking of media files, (dis)playing them at the same time and the separate, wireless uploading of media, on the one hand; and the building of physical constructions around digital media files, on the other hand. Particularly, this last point sets Materialise apart from either using only digital or using only physical materials or tools. Participants envisioned creating something that could be used as an enhanced music playlist by linking images to music, which was particularly attractive to the teenagers, who wanted to link their images to their favourite music—both when going through their photos and when playing their music. Further, participants envisioned using it for personal reminiscence; as a thematic media display; sharing media with others in more natural photo sharing situations, using physical means; or using it as a remote awareness system, both outside the home and across different rooms in the home. Another suggestion was to have one block per

Fig. 9 The teenagers' college-themed creation: a model of their college with the piazza, the 'yellow umbrellas' and the 'trees where the freaks hang out'

family member, and the blocks and physical constructions around them were considered more interesting than digital photo frames as media sharing and displaying devices, because of their interactive qualities. Looking at the possibilities of linking dynamic, interactive information to the physical blocks, the teenagers liked the idea of Tweets showing up if they were related to images or photos, using hash tag information, and the idea of having a Facebook photo on the one block and the comments about that photo on another block. All in all, while much enthusiasm was displayed building the physical constructions around personal media, and participants saw value in having digital media files linked and displayed in interactive ways, they also indicated to struggle envisioning how they would use a set like Materialise in everyday life.

5.3 What are characteristics of hybrid crafting with Materialise?

For the hands-on hybrid crafting experience with Materialise in the workshops, we had anticipated participants would switch between phases of physical and digital building and iterate several times. Although this happened to some extent, *iterations in the process of making mostly took place within the digital phase,* whereas the physical building came second and was a more linear process. In most cases, participants finished the selection and composition of digital media before starting to build something physically. This was in part caused by the instruction for the first task, in which participants were asked to select media first and then build something related; it is likely participants extended the same procedure to the second task, in which they were free to choose their own procedure. However, we also observed that while participants did upload different media to the blocks, in most cases, they did not start building until they had a good idea of what they wanted to make. On the other hand, when left without instruction, such as during the initial demonstration and even during the breaks, the participants explored the physical building much more and came up with creative objects, such as the creation of a tea pot. This seems to indicate that participants felt freer to explore when they did not have to stick to a theme in their media and build something around this, which was coupled with more thought and planning.

Despite this, we observed that it was easier to *start the crafting process from digital media* and build something around these media, rather than start by building something physical and choosing the digital media to go with this. This appeared to be at least in part caused by the fact that the digital media already provided concrete handles to start from, such as an event or object displayed in an image, while the physical building blocks left the possibilities for creation open and as such were more difficult to use as a starting point. On a related note, participants did not create or look for any new media online, which could have helped them if they had chosen something to build physically first and select media after, which may well have been caused by time limitations and the expectation that they were required to use the media they had brought in. Given more time and freedom to explore—which was difficult to achieve to full extent in these workshops—we estimate participants would iterate more between modes of digital and physical making and explore more in both phases: proceeding to trying out different physical constructions, and starting from these, rather than only talking about them.

Further, obviously this building set provided participants with a *predetermined set of blocks* they could use, rather than providing the unlimited possibilities of a raw material, such as wood or clay. This was the case for both physical materials and digital materials (using existing media files). However, while participants did not search or create digital media to fit their needs, they proved to be very creative in overcoming some of the physical limitations, such as using the bended connection strips to provide connection points where they required them. Extra magnets were further provided, which were used often by participants to fortify connections, make parts move, or connect the metal connection strips to each other. In fact, for some participants, these extra magnets, which were small cubes and spheres, were the most interesting parts to play around and experiment with. Finally, some of the provided materials were used in novel, creative ways, such as the use of pins, intended for the pin board, for a representation of barbed

wire, the use of chalks in the urban diorama as pieces of rubble and the use of the scissors to hang over the pieces of rubble as a sort of car claw in the urban diorama.

Participants finally tried to negotiate the *dynamic possibilities of the digital with the static physical constructions*. While in the first task the slideshow function was used often to scroll through different images in one of the example themes, for example, Jamaica, within a creation, in the second task in most cases, one file was chosen for each block to be displayed statically, or played, and which was used to build something around. This difference was mainly caused by the lack of more images that clearly fit a certain theme within the participants' own media, because media of different participants were so diverse. For this, it could again be beneficial if participants have more time to find or create more media that fit a certain theme or can work individually. Despite this challenge, all final creations in the second task consisted of images as well as audio. In some cases, the audio was directly linked to the creation (e.g. in the case of the parents, teenagers, and designers), and in other cases, it was more of a background sound (in the case of the crafters who use the sound of laughter with their nature scene because they just liked that sound).

All in all, it could be said the characteristics of hybrid crafting with Materialise, as found in the workshops, are as follows: 1—iterations in crafting mostly take place with digital media, while the physical materials invite more exploration when left without a specific task; 2—physical materials are used around digital media and support those, rather than the other way around; 3—physical materials are used creatively and 'bent' to serve the participants' needs while digital materials are taken more 'as-is'; and 4—dynamic possibilities of the digital are used to a limited extent when coupled with the static physical counterpart.

5.4 How does the design of materialise facilitate hybrid crafting?

In facilitating the inclusion of both digital and physical materials, and providing digital and physical tools to craft, Materialise facilitates hybrid crafting as defined in the introduction of this paper. However, the workshops served to illustrate how the design of Materialise, in a way, *defines* the process of hybrid crafting, and how the building set, or any other design for hybrid crafting, may be adjusted to facilitate hybrid crafting better. These, and other themes, will be further addressed in the Discussion, in which we explore further how hybrid crafting may be designed for.

First, we can address the *dynamic functions* that allowed to link media and activate a slideshow. As mentioned in the previous section, the negotiation of the dynamic possibilities of the digital and the static physical construction meant that a hybrid creation mostly included static display of an image on each block and choosing one audio file to have associated with these images. This made the linking of images and audio files less relevant, and it can be argued that because the physical element is static, there will always be a limited number of media files associated with any one creation. However, as was seen in the first task, participants did use the linking of files and used the slideshow function to synchronise (dis)playing-related media at the same time in the same physical creation, as long as there was enough media related to a theme available. We envision more use of the linking and slideshow functionality if there is enough related media available, as will be the case in people's own home media archives, for example, images of the same event, and as such the linking and slideshow functions provide valuable dynamic qualities on the digital side.

However, because the physical creations are static, the question arises to what extent the physical construction can truly be suitable to complement changing, dynamic digital media in meaningful ways. To support the integration of physical and digital in meaningful hybrid creations, we propose *the physical must be made less static* than is currently the case for Materialise. Physical building blocks or compositions should be able to change and evolve dynamically or be changed by simple user input—rather than rebuilding the whole composition. A simple example could be to include other physical building blocks that can change appearance synchronised with the changing media, such as one participant's idea of an ambient light block, or have blocks with moving parts—as participants tried to create themselves in the workshops.

Second, when discussing the use of the building set with the participants, it was discovered that there is a tension between the *playfulness and exploration of the building set, and the desire to craft something lasting* around one or more specific media files as expressed by some participants. While certain elements of the set, such as the Lego, allowed for quick assembling and disassembling, possibilities for creating something that can be left on display, and which also has an enduring appearance, were limited. When designing for hybrid crafting, it is therefore important to provide means for playfulness and exploration in the building process, but also means for creating lasting constructions, for example, by providing different materials to cover up the building blocks, for example, cloth, wood or leather, when a final creation is made. Providing more means for such final creations can further strengthen the link between the digital media and physical construction if materials or compositions are chosen that fit closely with the media that is (dis)played more permanently.

Finally, we observed that rather than having an integrated hybrid creation process, in Materialise *digital and physical phases of the creation process are quite separate*.

The digital phase happens entirely on the computer through the selection of media, experimenting with the composition and uploading media, while the physical creation happens entirely away from the computer. While the result is hybrid and physical and digital elements are involved in the crafting process, the issues addressed above led us to believe that the current building set could benefit from closer integration of physical and digital elements at the time of creation, which may, in fact, be the most important requirement for hybrid crafting. One element of closer integration is the digital representations of the physical building blocks in the software that allowed participants to already start exploring their composition on the computer. However, although participants said these representations were useful to imagine what their creation would be like, they did not use the possibilities of rotating and positioning the blocks on the computer to explore the composition. We believe this was partly caused by the active building blocks being the only blocks available as digital representations, which made the focus shift to the uploading of media rather than exploring the composition. By making digital representations of the other physical blocks available as well, exploring the complete composition would be more encouraged. Moreover, however, the physical and digital phases of creation should be closer coupled by making interaction with digital materials similar to interaction with physical materials and across the same platforms: on the computer (through the use of digital representations of physical blocks), and away from the computer, by making digital media files as readily available as the physical building blocks. We envision expanding the interactivity of the physical building blocks to support the use of digital media files in the physical exploration phase. This can be done, for example, by including media control buttons on separate building blocks, but also by providing media editing functions through physical interaction with the blocks or changing the blocks or their composition, for example, cropping media by breaking pieces off a block, resizing media by folding or unfolding flexible blocks, or copying media from one block to another by connecting them. In this way, physical crafting becomes much closer coupled with digital media, which will benefit the hybrid exploration of physical and digital materials.

6 Discussion

In this discussion, we will use our findings from trying out hands-on crafting with the building set Materialise to reflect on the characteristics of hybrid crafting and, moreover, aim to provide guidelines for designing to support and facilitate hybrid crafting practices. When looking at *how people go about hybrid crafting with their personal digital media,* we have found that it can be quite challenging for people to envision how they could use their digital media in crafting practices, or how they would use Materialise in everyday life. This may be an unavoidable result of presenting participants with new ways to do things that were not possible before—in this case using their digital media as building blocks in conjunction with physical building blocks. In fact, by asking participants not only to craft—which may be challenging in itself—but also to do this in a limited time, in a group, and with a completely new platform, our workshops were quite challenging for the participants. However, Materialise nonetheless provided them with enough starting points and support to work with, and after initial exploration and getting to know the set, most participants got the hang of it and seemed to enjoy it. This strengthens our beliefs that Materialise provides a good 'starter kit' which can get people to think in the direction of hybrid crafting and explore the possibilities. Further, we witnessed the rise of practices that are similar to purely physical—more traditional—crafting practices, such as the fact that participants kept going when creations already seemed finished, the exploration and experimentation with physical and digital materials, and the fact that they only started building the final physical creation after having an idea of what to make, which strengthened our beliefs that our form of hybrid crafting through Materialise can indeed be considered a craft, albeit perhaps a starters' one.

Aside from the challenges arising from presenting a new platform, the difficulties participants had in envisioning the everyday use of such a platform may also indicate that further support should be provided in the form of examples, or concrete use contexts, in which a hybrid crafting practice may be desired. This also came forward in our findings that participants had trouble envisioning how they would fit the prototype in their everyday lives, although in the group discussions new ideas arose and were met with enthusiasm for potential use of the set.

Although it is difficult to draw objective conclusions regarding the question whether *hybrid crafting is preferred to physical or digital crafting,* we saw potential in designing for hybrid crafting for specific use scenarios. We envision that a hybrid crafting practice—be it with a building set such as Materialise or with other tools that can be designed—can be used in a reflective activity in which, apart from looking through digital media and actively engaging with these media, selecting them, making them, adjusting them, a physical making process takes place, further engaging the user and potentially increasing the engagement to the media and the creation [e.g. 3–5]. One participant, for example, imagined making something themed around his grandfather of whom he had brought some images and an audio recording. Potential contexts

and uses in which hybrid crafting can be valuable can, for example, be personal reflection and 'doing something more' with personal digital media, enhancing music playlists, embedding interactive content such as Facebook more into the physical environment of the home, personalised gifts, co-present digital media sharing and storytelling, or remote awareness systems. As such, hybrid crafting practices can be individual as well as group activities. We organised group sessions in our workshops, which may seem at first sight to contradict current craft practice, which is often an individual activity. As such, the collaborative character will have influenced what was built with the set in the workshops and how it was used, for example, there was further less room for individual reflective crafting processes and creations around themes of personal significance for one person. In our workshop, one of the designers commented that the collaborative aspect made it challenging to find a common theme within the media from different people: because you have to work with what you have, it becomes much more random and neutral and you cannot go in depth around a specific theme. However, most participants saw the collaboration as a positive aspect and they envisioned using the building set as a family activity or with friends, for example, as a new means for media sharing. These different practices highlight the importance of leaving the possibilities open for collaborative as well as individual creation, which may be an important characteristic of hybrid crafting, in this age in which making becomes more and more social [2].

Looking at the *characteristics of hybrid crafting,* as we found them in our workshops, and how we envision them to be ideally, we can conclude that most evolve around a thorough integration of physical digital in both crafting process and crafting result. First, exploration, experimentation, and iteration should be encouraged both with physical and digital materials—it should be easy to switch between building with physical and digital materials, and ideally, the ways of working with physical and digital materials should be similar. We saw that while the physical triggered plenty of exploration when participants were left without instruction, they seemed to think more before building 'final creations'. We envision physical making iterations alongside digital iterations can trigger new ideas, and new creative connections can be found when making practices become more integrated. Similarly, we saw that participants tended to start from the digital media and create their physical representations around these. This, as mentioned, was influenced in part by the set-up of the workshops, but it may reflect an important difference in crafting with physical and digital materials. For digital crafting, the starting point, or base material, will in our definition of hybrid crafting most often be digital media files, such as images or audio, rather than bits and bytes, while for physical crafting, a starting point can be any base material, such as wood, paper, or clay. Even looking at the Materialise set, physical building blocks could be used to many ends, despite having predetermined sizes and shapes, as was illustrated by our participants experimenting, while digital media files often contain concrete representations, which makes it seemingly difficult to use them to novel ends. So, apart from providing a more concrete material—giving more concrete handles to start from—digital media are also less flexible to start from than physical materials, and less open for different interpretations, and thus more difficult to fit into creations later. Although it can be challenging to find creative new angles to the content of digital media, we believe overcoming these challenges may increase the 'craftiness' of including digital materials. Both physical and digital materials can thus provide their own interesting starting points and we believe that hybrid crafting thus provides an interesting combination of crafting challenges and possibilities, an integration of concreteness and openness that can lead to new ways of thinking about crafting and novel creative expression.

We observed that participants were creative in 'bending' the physical building blocks to fit their building needs and bring in new materials where this could aid the crafting process. They did not do so with digital means, for example, look for digital content online or edit existing media. Apart from a limited time in the workshops, this was also caused by the limited skills most people have with digital crafting tools, for example, image and audio editing tools, and the limited extent to which media can be edited in the first place; by far most of the media our participants brought to the sessions were unedited. To further support the use of physical and digital means as starting points, and allowing for multiple interpretations and open-ended building opportunities, the possibilities for easy editing, manipulating and sourcing new materials should be similar for both physical and digital materials. These open-ended possibilities can not only be achieved by providing enough versatile physical parts, such as the extra magnets, but also, for example, by providing tangible means for editing digital media—such as cropping media by breaking pieces off a block or resizing media by folding or unfolding flexible blocks—or facilitating more abstract digital media searches based on theme, colour or composition.

Further, we observed a tension between the static physical and dynamic digital. Although this provided challenges in the current prototype and set-up, we believe it is exactly this combination of dynamic and static that provides such exciting possibilities for hybrid crafting, as long as this combination is carefully designed for. Physical creations can easily be displayed in the home in ways results of digital crafting cannot [63], and digital media used in these creations can draw attention to a piece or

make it possible to evolve over time, for example, as new media becomes available or as someone's interests change; increasing the likelihood, a creation will be meaningful over a longer time. However, as media change, a static physical creation may not be suitable anymore. As addressed in the results section, we envision supporting this by making the physical less static, for example, by allowing physical blocks or physical creations to evolve over time, change shape or colour or introduce movement. Another option could be to facilitate and encourage the creation of physical compositions that relate to digital media on more abstract or meta-levels—as was done only to a limited extent in the workshops—in which case physical compositions and digital media may still complement each other if the media content changes.

Finally, participants pointed out tensions between the playfulness of the building set and its explorative nature, and the possibilities for building something that lasts—which may be an aim for hybrid creations that can become cherished. Upon further reflection on these findings, our design and the observation that it was quite easy to start crafting with Materialise, we see Materialise as a *starter kit* for hybrid crafting, which focusses on introducing this new form of crafting to people and lets them explore what they would like to do with it. Similar, perhaps, to how in more traditional craft, the beginners' medium of clay may introduce the concepts of 3D sculpture to starting crafters, while more advanced crafters may move on to wood or stone sculpture. We envision the design of other hybrid crafting tools or platforms that support more advanced hybrid crafters, for example, providing more complex functionality, allowing for the development of hybrid crafting skills and also providing means to create more elaborate, lasting pieces. The playfulness of the current set is thus a characteristic of its aim to encourage exploration and discovery of what can be done with hybrid crafting for the beginner, while other hybrid craft platforms, or extensions of the set, may support the creation of more lasting structures. Interesting design opportunities are still to be addressed in how we may support the more experienced hybrid crafter, as this new form of crafting moves forward.

Summarising the points addressed above and reiterating some of the points made in Sect. 5.4, we can now formulate a list of guidelines for the *design of interactive products or tools that aim to support hybrid crafting*:

1. Envision a concrete use context or application area of the hybrid crafting practice you want to support and make sure it is clear to the user what need or desire the design may fulfil—for example, media sharing, personalised gifts or individual reflection—while the possibilities for hybrid crafting within this area should still be flexible and open-ended.
2. Think about whether the intended purpose is an individual or collaborative activity and make sure the design is suitable, or if both may be applicable, make sure there are possibilities for both collaborative as well as individual creation.
3. Facilitate for the use of physical as well as digital materials as starting points for hybrid crafting by making both physical and digital possibilities open-ended and by designing means for easy editing, manipulation and sourcing of new materials in both physical and digital realms to fit the needs of developing creations.
4. Integrate physical and digital making phases and platforms to allow for iteration, exploration and experimentation in both physical and digital and across these realms, for example, by making digital media as readily available in the form of physical building blocks as physical materials and making the interaction with physical and digital media more similar by using Tangible Interaction mechanisms.
5. Utilise the characteristics of physical—static and visible in the everyday environment—and digital—dynamic and often hidden—to reach hybrid integrations that may be displayed in everyday environments and be meaningful for a long time, by designing the physical elements to be more dynamic or be centred on abstract or meta themes.
6. Consider the proficiency of the hybrid crafters you are designing for and design mechanisms for either supporting beginners—for example, enabling explorative platforms and creations—or more advanced crafters—for example, enabling creations that can be 'made to last'. In addition, think about how your design may support the skill development of hybrid crafters as they move from beginners to experienced crafters.

7 Conclusions

In this paper, we address how we explored notions of 'hybrid crafting'—everyday creative practices of using combinations of physical and digital materials, techniques or tools, to make interactive physical-digital creations—in order to inform the design of novel products or systems that may facilitate or support these novel approaches to crafting. Our exploration focused on the design and use of 'Materialise', a physical-digital building set which was used in four hands-on creative workshops in which we aimed to gain insights into how people go about doing hybrid crafting with their personal media, whether these hybrid forms of crafting are desirable, what the characteristics of hybrid crafting are, and how we may design for these practices. We reflected on our findings and

formulated six concrete guidelines for the design of products or systems that aim to facilitate or support hybrid crafting. We propose that hybrid crafting designs need, as a *craft context,* a concrete use context or application area and an idea of social dynamics around this context. In addition, looking at the *craft process,* it needs to be possible to use both physical and digital materials as the starting point, and phases of physical and digital making need to be as closely coupled and similar as possible. Finally, addressing the *craft result*, the design should enable the exploitation of the benefits of physical and digital in the integration and display of hybrid craft, and it should fit the different needs for creations beginners or experienced crafters may have. Using these guidelines, we want to open up the design space to novel designs that support hybrid crafting practices, novel ways of crafting which provide exciting new challenges and opportunities for creative expression.

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References

1. Cardoso R (2010) Craft versus design. In: Adamson G (ed) The craft reader. Berg Publishers, Oxford, pp 321–332
2. Gauntlett D (2011) Making is connecting: the social meaning of creativity from DIY and knitting to YouTube and Web 2.0. Polity Press, Cambridge
3. Golsteijn C, van den Hoven E, Frohlich D, Sellen A (2012) Towards a more cherishable digital object. In: Proceedings of the DIS 2012, Newcastle Upon Tyne, United Kingdom. ACM, 2318054, pp 655–664. doi:10.1145/2317956.2318054
4. Odom W, Zimmerman J, Forlizzi J (2011) Teenagers and their virtual possessions: design opportunities and issues. In: Proceedings of the CHI 2011, Vancouver, BC, Canada. ACM Press, 1979161, pp 1491–1500. doi:10.1145/1978942.1979161
5. Petrelli D, Whittaker S (2010) Family memories in the home: contrasting physical and digital mementos. Pers Ubiquit Comput 14(2):153–169. doi:10.1007/s00779-009-0279-7
6. Sennett R (2008) The craftsman. Yale University Press, New Haven
7. Csikszentmihalyi M (2010) Creativity: flow and the psychology of discovery and invention. Harper, New York
8. Wiberg M, Robles E (2010) Computational compositions: aesthetics, materials, and interaction design. Int J Des 4(2):65–76
9. Kwon H, Kim H, Lee W (2013) Intangibles wear materiality via material composition. Pers Ubiquit Comput. doi:10.1007/s00779-013-0688-5
10. Wiberg M (2013) Methodology for materiality: interaction design research through a material lens. Pers Ubiquit Comput. doi:10.1007/s00779-013-0686-7
11. Petrelli D, van den Hoven E, Whittaker S (2009) Making history: intentional capture of future memories. In: Proceedings of the CHI 2009, Boston, MA, USA. ACM Press, 1518966, pp 1723–1732. doi:10.1145/1518701.1518966
12. Stevens MM, Abowd GD, Truong KN, Vollmer F (2003) Getting into the living memory box: family archives and holistic design. Pers Ubiquit Comput 7(3–4):210–216. doi:10.1007/s00779-003-0220-4
13. van den E Hoven (2004) Graspable cues for everyday recollecting. Eindhoven University of Technology, Eindhoven
14. Odom W, Pierce J, Stolterman E, Blevis E (2009) Understanding why we preserve some things and discard others in the context of interaction design. In: Proceedings of the CHI 2009, Boston, MA, USA. ACM Press, 1518862, pp 1053–1062. doi:10.1145/1518701.1518862
15. Csikszentmihalyi M, Rochberg-Halton E (1981) The meaning of things: domestic symbols and the self. Cambridge University Press, Cambridge
16. Rosner DK, Ryokai K (2009) Reflections on craft: probing the creative process of everyday knitters. In: Proceedings of the C&C'09, Berkeley, California, USA. ACM, 1640264, pp 195–204. doi:10.1145/1640233.1640264
17. Gross S, Bardzell J, Bardzell S (2013) Structures, forms, and stuff: the materiality and medium of interaction. Pers Ubiquit Comput. doi:10.1007/s00779-013-0689-4
18. Buechley L, Rosner DK, Paulos E, Williams A (2009) DIY for CHI: methods, communities, and values of reuse and customization. In: Proceedings of the CHI 2009, Boston, MA, USA, 2009. ACM, 1520750, pp 4823–4826. doi:10.1145/1520340.1520750
19. McCullough M (1996) Abstracting craft: the practiced digital hand. MIT Press, Cambridge
20. Mellis DA, Buechley L (2012) Case studies in the personal fabrication of electronic products. In: Proceedings of the DIS 2012, Newcastle Upon Tyne, United Kingdom. ACM, 2317998, pp 268–277. doi:10.1145/2317956.2317998
21. Saul G, Lau M, Mitani J, Igarashi T (2011) SketchChair: an all-in-one chair design system for end users. In: Proceedings of the TEI 2011, Funchal, Portugal. ACM, 1935717, pp 73–80. doi:10.1145/1935701.1935717
22. Kettley S (2010) Fluidity in craft and authenticity. Interactions 17(5):12–15. doi:10.1145/1836216.1836219
23. Kolko J (2011) Craftsmanship. Interactions 18(6):78–81. doi:10.1145/2029976.2029996
24. Robles E, Wiberg M (2010) Texturing the "material turn" in interaction design. In: Proceedings of the TEI 2010, Cambridge, Massachusetts, USA. ACM, 1709911, pp 137–144. doi:10.1145/1709886.1709911
25. Tanenbaum J, Tanenbaum K, Wakkary R (2012) Steampunk as design fiction. Paper presented at the proceedings of CHI 2012, Austin, Texas, USA
26. Bonanni L, Parkes A, Ishii H (2008) Future craft: how digital media is transforming product design. In: CHI 2008 Ext. Abstracts, Florence, Italy. ACM, 1358712, pp 2553–2564. doi:10.1145/1358628.1358712
27. Nimkulrat N (2012) Hands-on intellect: integrating craft practice into design research
28. Maestri L, Wakkary R (2011) Understanding repair as a creative process of everyday design. In: Proceedings of the C&C 2011, Atlanta, Georgia, USA. ACM Press, 2069633, pp 81–90. doi:10.1145/2069618.2069633
29. Rosner DK, Taylor AS (2011) Antiquarian answers: book restoration as a resource for design. In: Proceedings of the CHI 2011, Vancouver, BC, Canada. ACM, 1979332, pp 2665–2668. doi:10.1145/1978942.1979332
30. Bardzell S, Rosner DK, Bardzell J (2012) Crafting quality in design: integrity, creativity, and public sensibility. In: Proceedings of the DIS 2012, Newcastle Upon Tyne, United Kingdom. ACM, 2317959, pp 11–20. doi:10.1145/2317956.2317959

31. Lindell R (2013) Crafting interaction: The epistemology of modern programming. Pers Ubiquit Comput. doi:10.1007/s00779-013-0687-6
32. Goodman E, Rosner D (2011) From garments to gardens: negotiating material relationships online and 'by hand'. In: Proceedings of the CHI 2011, Vancouver, BC, Canada. ACM, 1979273, pp 2257–2266. doi:10.1145/1978942.1979273
33. Rosner DK (2011) Tracing provenance. Interactions 18(5):32–37. doi:10.1145/2008176.2008186
34. Ikeyima M, Rosner DK (2013) Broken probes: toward the design of worn media. Pers Ubiquit Comput. doi:10.1007/s00779-013-0690-y
35. Wallace J, Press M (2004) All this useless beauty: the case for craft practice in design for a digital age. Des J 7(2):42–53
36. Wright P, Wallace J, McCarthy J (2008) Aesthetics and experience-centered design. ACM Trans Comput Hum Interact 15(4):1–21. doi:10.1145/1460355.1460360
37. Rosner DK (2010) Mediated crafts: digital practices around creative handwork. In: Proceedings of the CHI 2010 Ext. Abstracts, Atlanta, Georgia, USA. ACM, 1753894, pp 2955–2958. doi:10.1145/1753846.1753894
38. Buechley L, Eisenberg M (2009) Fabric PCBs, electronic sequins, and socket buttons: techniques for e-textile craft. Pers Ubiquit Comput 13(2):133–150. doi:10.1007/s00779-007-0181-0
39. Perner-Wilson H, Buechley L, Satomi M (2011) Handcrafting textile interfaces from a kit-of-no-parts. In: Proceedings of the TEI 2011, Funchal, Portugal. ACM, 1935715, pp 61–68. doi:10.1145/1935701.1935715
40. Benedetti J (2012) Embroidered confessions: an interactive quilt of the secrets of strangers. In: Proceedings of the CHI 2012 Ext. Abstracts, Austin, Texas, USA. ACM, 2212363, pp 971–974. doi:10.1145/2212776.2212363
41. Rosner DK, Ryokai K (2010) Spyn: augmenting the creative and communicative potential of craft. In: Proceedings of the CHI 2010, Atlanta, Georgia, USA. ACM, 1753691, pp 2407–2416. doi:10.1145/1753326.1753691
42. Freed N, Qi J, Setapen A, Breazeal C, Buechley L, Raffle H (2011) Sticking together: handcrafting personalized communication interfaces. In: Proceedings of the IDC 2011, Ann Arbor, Michigan. ACM, 1999071, pp 238–241. doi:10.1145/1999030.1999071
43. Zhu K (2012) A framework for interactive paper-craft system. In: Proceedings of the CHI 2012 Ext. Abstracts, Austin, Texas, USA. ACM, 2212464, pp 1411–1416. doi:10.1145/2212776.2212464
44. Cheng B, Kim M, Lin H, Fung S, Bush Z, Seo JH (2012) Tessella: interactive origami light. In: Proceedings of the TEI 2012, Kingston, Ontario, Canada. ACM, 2148200, pp 317–318. doi:10.1145/2148131.2148200
45. Saul G, Xu C, Gross MD (2010) Interactive paper devices: end-user design and fabrication. In: Proceedings of the TEI 2010, Cambridge, Massachusetts, USA. ACM, 1709924, pp 205–212. doi:10.1145/1709886.1709924
46. Mellis D, Buechley L (2012) Collaboration in open-source hardware: third-party variations on the arduino duemilanove. In: Proceedings of the CSCW 2012, Seattle, Washington, USA. ACM, 2145377, pp 1175–1178. doi:10.1145/2145204.2145377
47. Mellis DA, Buechley L (2011) Scaffolding creativity with open-source hardware. In: Proceedings of the C&C'08, Atlanta, Georgia, USA. ACM, 2069702, pp 373–374. doi:10.1145/2069618.2069702
48. Williams A, Gibb A, Weekly D (2012) Research with a hacker ethos: what DIY means for tangible interaction research. Interactions 19(2):14–19. doi:10.1145/2090150.2090156
49. Wrensch T, Blauvelt G, Eisenberg M (2000) The rototack: designing a computationally-enhanced craft item. In: Proceedings of the DARE 2000, Elsinore, Denmark. ACM, 354676, pp 93–101. doi:10.1145/354666.354676
50. Wrensch T, Eisenberg M (1998) The programmable hinge: toward computationally enhanced crafts. In: Proceedings of the UIST 1998, San Francisco, California, United States. ACM, 288577, pp 89–96. doi:10.1145/288392.288577
51. Sundström P, Taylor A, Grufberg K, Wirström N, Belenguer JS, Lundén M (2011) Inspirational bits: towards a shared understanding of the digital material. In: Proceedings of the CHI 2011, Vancouver, BC, Canada. ACM, 1979170, pp 1561–1570. doi:10.1145/1978942.1979170
52. Villar N, Block F, Molyneaux D, Gellersen H Voodoo IO (2006) In: Proceedings of the SIGGRAPH 2006 emerging technologies, Boston, Massachusetts. ACM, 1179170, p 36. doi:10.1145/1179133.1179170
53. Villar N, Gilleade KM, Ramdunyellis D, Gellersen H (2007) The VoodooIO gaming kit: a real-time adaptable gaming controller. Comput Entertain 5(3):7. doi:10.1145/1316511.1316518
54. Bdeir A, Rothman P (2012) Electronics as material: littleBits. In: Proceedings of the TEI 2012, Kingston, Ontario, Canada. ACM, 2148220, pp 371–374. doi:10.1145/2148131.2148220
55. Villar N, Scott J, Hodges S (2011) Prototyping with microsoft.net gadgeteer. In: Proceedings of the TEI 2011, Funchal, Portugal. ACM, 1935790, pp 377–380. doi:10.1145/1935701.1935790
56. Huang Y, Eisenberg M (2011) Plushbot: an application for the design of programmable, interactive stuffed toys. In: Proceedings of the TEI 2011, Funchal, Portugal. ACM, 1935753, pp 257–260. doi:10.1145/1935701.1935753
57. Meyers J, LaMarche J, Eisenberg M (2010) Craftopolis: blending tangible, informal construction into virtual multiuser communities. In: Proceedings of the IDC 2010, Barcelona, Spain. ACM, 1810581, pp 242–245. doi:10.1145/1810543.1810581
58. Buechley L, Elumeze N, Eisenberg M (2006) Electronic/computational textiles and children's crafts. In: Proceedings of the IDC 2006, Tampere, Finland. ACM, 1139091, pp 49–56. doi:10.1145/1139073.1139091
59. Follmer S, Ishii H (2012) KidCAD: digitally remixing toys through tangible tools. In: Proceedings of the CHI 2012, Austin, Texas, USA. ACM, 2208403, pp 2401–2410. doi:10.1145/2208276.2208403
60. Cao X, Lindley SE, Helmes J, Sellen A (2010) Telling the whole story: anticipation, inspiration and reputation in a field deployment of TellTable. In: Proceedings of the CSCW 2010, Savannah, Georgia, USA. ACM Press, 1718967, pp 251–260. doi:10.1145/1718918.1718967
61. Reed M (2009) Prototyping digital clay as an active material. In: Proceedings of the TEI 2009, Cambridge, United Kingdom. ACM, 1517733, pp 339–342. doi:10.1145/1517664.1517733
62. Woo J-B, Kim D-J, Kim S, Jo J, Lim Y-K (2011) Interactivity sketcher: crafting and experiencing interactivity qualities. Paper presented at the proceedings of the CHI 2011 Ext. Abstracts, Vancouver, BC, Canada
63. Kirk DS, Sellen A (2010) On human remains: values and practice in the home archiving of cherished objects. ACM Trans Comput Human Interact 17(3):1–43. doi:10.1145/1806923.1806924