BYO*: Utilizing 3D Printed Tangible Tools for Interaction on Interactive Surfaces

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ABSTRACT

Sharing and manipulating information are essential for collaborative work in meeting scenarios. Nowadays, people tend to bring their own devices as a result of increasing mobility possibilities. However, transferring data from one device to another can be cumbersome and tedious if restrictions like different platforms, form factors or environmental limitations apply.

In this paper, we present two concepts to enrich interaction on and between devices through 3D printed customized tangibles: 1) Bring your own information, and 2) bring your own tools. For this, we enable interactivity for low-cost and passive tangible 3D printed objects by adding conductive material and make use of touch-enabled surfaces. Our system allows users to easily share digital contents across various devices and to manipulate them with individually designed tools without additional hardware required.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

3D printing; digital fabrication; rapid prototyping; capacitive sensing; input sensing; data sharing; data manipulation; data visualization.

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INTRODUCTION

In recent years, corporate environments have been confronted with a shift in the way we use technology at workplaces. The proliferation of mobile and highly-capable computing devices (e.g., smartphones, tablets) together with the introduction of the *Bring Your Own Device (BYOD)* paradigm changed the way how workers cooperate [1]: Information is brought, manipulated and taken away after the collaboration as digital artifacts [24]. To that end, multiple devices with varying form factors, from personal smartphones to wall-sized shared (multi-)touch displays (e.g., Microsoft Surface Hub) are employed. Moreover, a broad range collaboration habits, ranging from private to shared interaction, needs to be covered.

While practical and useful, such multi-device and multi-user collaboration scenarios still suffer from limited interaction possibilities: To share information from a (small) personal device, participants have to pass around the device or transfer the content to a bigger display through screen mirroring. Projected information is often only accessible read-only on the shared screen and thus, direct interaction with the data is only possible for the projecting participant at their private device. Further, sharing data takes over the complete screen; displaying content from multiple participants at the same time is not supported. To overcome the restrictions such approaches, users have to transfer the data to the common screen device, a process that can be slow, tedious and error-prone. Furthermore, interaction on such (multi-) touch devices is often criticized as lacking haptic experience and interaction richness [4].

To alleviate the aforementioned problems, we propose to use custom 3D printed interactive tangible objects that embody user-defined information or functionality. They allow for direct interaction through physical manipulation (c.f. [16, 5, 12]). 3D printing of such tangibles can be low-cost because no additional hardware needs to embedded because capacitive touch sensing technology is used to sense interactions.

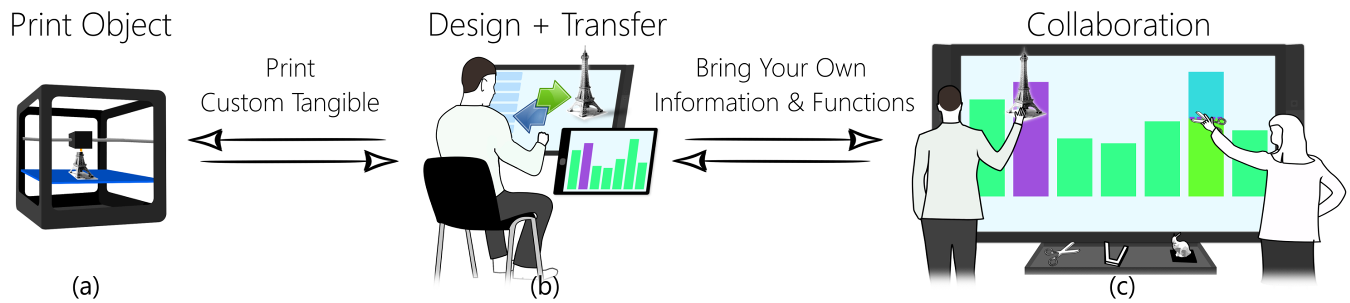

Figure 1. Concept of BYO*: (a) A custom designed tangible is printed, (b) the user adds a functionality or transfers information to the custom tangible, and (c) the user brings the tangible with the linked function (BYOT) or information (BYOI) to a collaborative workspace. Additional 3D printed tools can be already available and other users can bring their own printed tangibles with them.

Therefore, we propose to extend the *BYOD* paradigm by two new concepts:

- Bring Your Own Information (BYOI)
- Bring Your Own Tool (BYOT)

BYOI allows users to easily store and transfer digital contents from device to device by touching the displaying device with a custom tangible token. BYOT allows embedding custom functionality into 3D printed tangible objects. Those objects are supposed to be used for fast and natural interactions on various capacitive touchscreens, resulting in more precise and faster input.

In summary, we contribute BYO*: A set of concepts and interaction techniques for haptic and tangible interactions in a multi-device and multi-user cooperation scenario through custom 3D printed tangibles. We practically validate our approach by a set of example applications that illustrate both concepts.

RELATED WORK

This papers concerns several areas including tangibles on interactive surfaces and fabrication of interactive 3D objects. We discuss related work in these areas in the following.

Tangibles On Interactive Surfaces

Early prior work investigates how to detect tangible objects on an optical touchscreen [2, 25]. More recently, commonplace capacitive sensing technology is employed to detect tangibles. Many approaches are based on capacitance tags, proposed by Rekimoto [16]. Presence and location of tangible objects are detected by conductive material within the tangible object or additional electronics [27, 23, 22]. Moreover, various interactions, such as the combination of multiple objects [5], or touch input on the object itself [5, 20] can be detected through capacitive sensing. By using magnetic hall grids, objects can be identified [13] or located above a screen [14].

However, so far all approaches are restricted to handcrafted objects which require manual assembly of additional hardware. This limits the set of possible form factors of tangible objects. Also, it adds to the cost and complexity of manufacturing.

Fabricating Interactive 3D Objects

One common approach to create interactive tangible objects is to add or embed electronic components and circuits to them. This is performed by embedding cameras [18], or accelerometers [6] or by attaching acoustic [15], or capacitive [17] sensors. By requiring assembly of additional components, those approaches are time-consuming and often require expert knowledge in electrical wiring. Further, current research investigates how to directly fabricate customized interactive elements within a 3D object. Objects may be extended by means of conductive plastic [11, 20, 21] or spray [7]. Moreover, 3D printed pipes are used to redirect in- or output channels in 3D printed objects [26, 3, 19, 10].

BRING YOUR OWN *: CONCEPT AND PROTOTYPE

To overcome the presented restriction in collaborative meeting scenarios, we expand the ”Bring Your Own Device” paradigm into new domains: *Bring Your Own Information (BYOI)* and *Bring Your Own Tool (BYOT)* (c.f. figure 1).

BYOI: Enhancing interaction between devices

Sharing digital contents between multiple devices can be cumbersome, especially if the sharing has to be fast and with low setup costs across different systems/vendors. This issue increases even more, if one or more systems are unpersonalized (e.g., no private mail or cloud account available) or the data can not be stored persistently. To overcome those issues, we present a fast and cost-effective sharing solution based on customized 3D printed conductive tangibles.

We enable the use of customizable tangibles with conductive patterns to allow users to select digital contents on a multi-touch screen and virtually store it on the 3D printed tangible. The actual data gets uploaded to a remotely located cloud storage, linked with the unique token id. To retrieve the contents on other devices, the token has to be placed again on a touch-enabled screen. This also works, if the same token id is encoded into another object.

BYOT: Enhancing direct interaction with data

Manipulating digital data on large screens can be cumbersome due to complex menus or conflicts between multiple persons that are standing in the way of each other. In addition, the

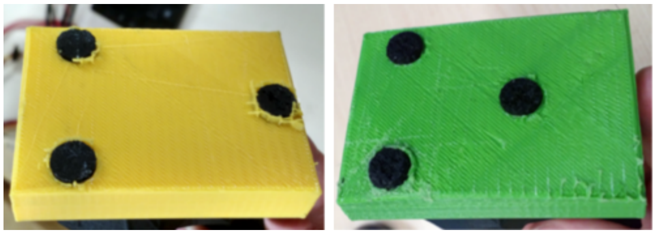

Figure 2. Two similar 3D printed objects with different token ids. The black parts are printed with conductive material, while the yellow and green parts are made of normal plastic.

actual functionality behind the touch interaction may be not visible beforehand.

We, therefore, enable direct data manipulation on touch-enabled surfaces with customized 3D printed conductive tools. This allows users to enrich direct interaction with digital contents by attaching a functionality (e.g., moving objects, customized data filters, copy/paste) to an individually shaped 3D printed tangible (e.g., rake, clock, scissors).

FABRICATION AND DETECTION OF TANGIBLES

To realize the BYO* concepts, we present a rapid design and fabrication process that generates customized tangible objects that can be used on capacitive touch screens. We further elaborate on the pattern detection that is used to identify individual tokens.

Fabrication of Customized Tangible Objects

Currently, tangible objects are often simply shaped or require additional manual assembly effort (both to get custom shapes and embed sensors) [23, 22, 9, 27]. Yet, the tangible's shape is an important factor in designing tangible user interfaces and highly varies for different application scenarios [8], requiring such tangibles tools to be highly individualized.

Therefore, we opt out to fabricate tangible tools through multi-material 3D printing, as this technology can

1. rapidly manufacture highly individualized shapes at low-cost,
2. handle conductive and rigid materials at once, and
3. directly embeds powerless and passive conductors, that enable sensing via a commodity capacitive touchscreen.

We decided to implement the tangible tools using commonly available multi-material 3D printers. This makes the approach accessible to a wide audience.

To that end, we utilize a BCN3D Sigma 3D printer (ca. $2500), ordinary PLA (ca. $30 per kg), and a commercially available conductive PLA by Proto-pasta (ca. $96 per kg), which has an average resistivity of 30 - 115 Ω * cm. We identified an optimal extrusion temperature of 220 deg C (nozzle diameter 0.4 mm) with the cooling fan turned on.

In essence, fabrication follows the standard 3D printing process: After designing or downloading a 3D model, a unique conductive pattern is inserted into the model. For our prototypes, we manually designed the pattern geometry using Blender and OpenSCAD. In future implementations, this could be easily automatized by generating pattern geometries that fit a given 3D model and also by providing high-level modification possibilities for designers (c.f. [19, 20]). We have started to automatize this process by creating reusable scripts in OpenSCAD which allow generating patterns depending on adjustable parameters (e.g. size and thickness of conductors).

Detection and Identification of Tangibles on Capacitive Touch Screens

For detection and identification of 3D printed tangibles, we use custom conductive patterns on the bottom of each object. The conductive parts are recognized as individual touch points on a touch-enabled surface. Each has to be about the size of a fingertip and have at least half a centimeter space in between to guarantee a reliable detection of two distinct points.

After recognizing multiple touch points, our system measures the relative distance between each of them and create a unique token id. The tracking is rotation invariant, not depending on the actual point size (as long as it is recognized as touch point) and robust to identify the same array of touch points on different screens. Figure 2 shows two 3D printed tangibles with two different arrays of touch points to create two distinct token ids.

EXAMPLE APPLICATIONS

In this section, we present two demonstration applications which implement our introduced concepts.

Information Transfer Token (BYOI)

As an example for sharing and transferring information across mobile phones, notebooks, and a large wall-mounted device, we implemented a simple application to transfer digital images. Therefore, we 3D printed multiple tangibles (tokens) which are partly conductive. Each of them has different touch patterns at the bottom (c.f. figure 2) to uniquely identify them across all devices. Figure 3 shows a sharing scenario where a user selects two images on the smartphone and uses the custom token to virtually store them onto it. The images then get uploaded in the background to a cloud storage and can be retrieved by using the same token on a (different) device.

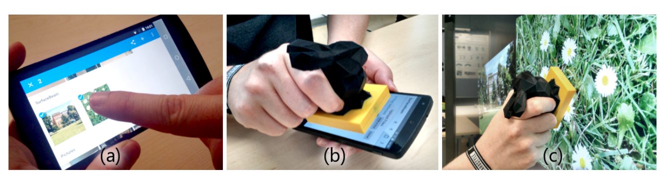

Figure 3. A user (a) selects multiple pictures from a smartphone, (b) puts the custom 3D printed token onto the screen, and (c) transfers the pictures to the large screen.

Custom 3D Printed Set of Tools (BYOT)

To demonstrate different functionalities, we printed customized tangible tools with various effects on digital contents (c.f. figure 4). Each tool has a function bound to its form and

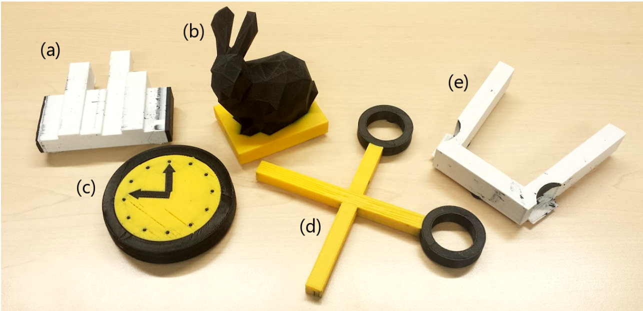

Figure 4. Example set of 3D printed tangibles for data manipulation: (a) diagram, (b) transfer token, (c) clock, (d) scissors, and (e) jar shape. The black parts are printed with conductive material, while the white and yellow parts are made of regular plastic.

created touch pattern which allows users to use them as physical input for touchscreens. For example, we implemented an interactive data visualization application where each value is represented as a virtual data point on the screen. A user can use a jar-shaped tool to filter and collect only data points that apply to a customizable filter. Other data points will virtually "fall through" the jar and are not collected. Another scenario would be the selection of multiple data points with the scissors tool and display them as a bar chart by using the diagram shaped tangible.

LIMITATIONS

We implemented our system for three different platforms: 1) Android, 2) UWP and 3) web-based system. However, our application relies on the touch detection of the underlying operating system and how it delegates touch events. Therefore, using capacitive material to simulate regular touch points can result in difficult and unexpected behaviors for different devices. Capacitive touch controllers and touchscreens expect a touch input to have a reasonable size to be identified as a human finger touch event. The minimum size mostly depends on the used touch matrix resolution and device size. Hence, the minimum size can be larger on huge wall-mounted displays, but more fine-granular on mobile phones. This issue can be resolved by using the raw capacitive data of touch controllers. Unfortunately, those are typically not accessible and hidden behind an abstraction layer.

In addition, if touch points are too close to each other, most touchscreens interpret them as a single blob (larger, undefined touch shape) or do not recognize them at all. Thus, no useful touch event is provided. For example, the Microsoft Surface-Hub drops touch input if the recognized size is larger than 30x30 mm. Moreover, very sensitive touchscreens may also detect capacitive parts which are not directly visible or are not placed directly on top of the screen, but are hovering slightly above. This can yield in another unexpected behavior if the capacitive wiring to connect the touch points inside the object is too close to the touch-enabled surface. To overcome this issue, we print the connecting parts inside an object with at least 2-3 mm space between the surface and printed wire.

CONCLUSION

In this paper, we introduced BYO*: A set of concepts and interaction techniques for haptic and tangible interactions in a multi-device and multi-user collaboration scenario. We presented two example applications that allow users to 1) enrich the interaction between devices to transfer digital contents between touch-enabled platforms without additional hardware, and 2) enrich direct data manipulation with customized 3D printed tools.

As a future work, we plan to create more objects with different functionalities and evaluate those in a user study. Further, we want to investigate private input which adds a privacy layer on top of our concepts. This can be used to include user privileges to each object or enable multiple functionalities attached to the same object, but for different users.

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REFERENCES

1. Aurélien Ammeloot, David Benyon, and Oli Mival. 2015. Design principles for collaborative device ecologies. In *Proceedings of the 2015 British HCI Conference on - British HCI '15*. ACM Press, New York, New York, USA, 255–256. DOI: http://dx.doi.org/10.1145/2783446.2783598
2. Patrick Baudisch, Torsten Becker, and Frederik Rudeck. 2010. Lumino : Tangible Blocks for Tabletop Computers Based on Glass Fiber Bundles. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)* (2010), 1165–1174. DOI: http://dx.doi.org/10.1145/1753326.1753500
3. Eric Brockmeyer, Ivan Poupyrev, and Scott Hudson. 2013. PAPILLON: Designing Curved Display Surfaces with Printed Optics. In *Proceedings of the 26th annual ACM symposium on User interface software and technology - UIST '13*. ACM Press, New York, New York, USA, 457–462. DOI: http://dx.doi.org/10.1145/2501988.2502027
4. William Buxton, Ralph Hill, and Peter Rowley. 1985. Issues and Techniques in Touch-sensitive Tablet Input. In *Proceedings of the 12th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '85)*. ACM, New York, NY, USA, 215–224. DOI: http://dx.doi.org/10.1145/325334.325239
5. Liwei Chan, Stefanie Müller, Anne Roudaut, and Patrick Baudisch. 2012. CapStones and ZebraWidgets: sensing stacks of building blocks, dials and sliders on capacitive touch screens. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*. ACM Press, New York, New York, USA, 2189–2192. DOI: http://dx.doi.org/10.1145/2207676.2208371

6. Jonathan Hook, Thomas Nappey, Steve Hodges, Peter Wright, and Patrick Olivier. 2014. Making 3D Printed Objects Interactive Using Wireless Accelerometers. In *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14*. ACM Press, New York, New York, USA, 1435–1440. DOI: http://dx.doi.org/10.1145/2559206.2581137
7. Yoshio Ishiguro and Ivan Poupyrev. 2014. 3D Printed Interactive Speakers. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*. ACM Press, New York, New York, USA, 1733–1742. DOI: http://dx.doi.org/10.1145/2556288.2557046
8. Hiroshi Ishii and Brygg Ullmer. 1997. Tangible Bits: Towards Seamless Interfaces Between People, Bits and Atoms. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '97)*. ACM, New York, NY, USA, 234–241. DOI: http://dx.doi.org/10.1145/258549.258715
9. S Kratz, T Westermann, M Rohs, and G Essl. 2011. CapWidgets: tangile widgets versus multi-touch controls on mobile devices. *Proceedings of CHI 2011* (2011), 1351–1356. DOI: http://dx.doi.org/10.1145/1979742.1979773
10. Gierad Laput, Eric Brockmeyer, Scott E. Hudson, and Chris Harrison. 2015. Acoustruments: Passive, Acoustically-Driven Interactive Controls for Hand Held Devices. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15* (2015). DOI: http://dx.doi.org/10.1145/2702123.2702416
11. Simon J Leigh, Robert J Bradley, Christopher P Purssell, Duncan R Billson, and David a Hutchins. 2012. A Simple, Low-Cost Conductive Composite Material for 3D Printing of Electronic Sensors. In *PloS one*, Vol. 7. e49365. DOI: http://dx.doi.org/10.1371/journal.pone.0049365
12. Jakob Leitner and Michael Haller. 2011. Geckos: Combining Magnets and Pressure Images to Enable New Tangible-object Design and Interaction. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*. ACM Press, New York, New York, USA, 2985. DOI: http://dx.doi.org/10.1145/1978942.1979385
13. Rong-Hao Liang, Han-Chih Kuo, Liwei Chan, De-Nian Yang, and Bing-Yu Chen. 2014. GaussStones : Shielded Magnetic Tangibles for Multi-Token Interactions on Portable Displays. In *Proceedings of the 27th annual ACM symposium on User interface software and technology - UIST '14*. ACM Press, New York, New York, USA, 365–372. DOI: http://dx.doi.org/10.1145/2642918.2647384
14. Rung-Huei Rong-Hao RH Liang, KY Kai-Yin Cheng, Liwei Chan, Rong-hao Liang Kai-yin Cheng, Liwei Chan, Rung-Huei Rong-Hao RH Liang, KY Kai-Yin Cheng, Liwei Chan, Chuan-Xhyuan Peng, Mike Y. Chen, Rung-Huei Rong-Hao RH Liang, De-Nian Yang, and Bing-Yu Chen. 2013. GaussBits: Magnetic Tangible Bits for Portable and Occlusion-Free Near-Surface Interactions. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13* (2013), 1391–1400. DOI: http://dx.doi.org/10.1145/2470654.2466185
15. Makoto Ono, Buntarou Shizuki, and Jiro Tanaka. 2013. Touch & Activate : Adding Interactivity to Existing Objects using Active Acoustic Sensing. In *Proceedings of the 26th annual ACM symposium on User interface software and technology - UIST '13*. ACM Press, New York, New York, USA, 31–40. DOI: http://dx.doi.org/10.1145/2501988.2501989
16. Jun Rekimoto. 2002. SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems Changing our world, changing ourselves - CHI '02*. ACM Press, New York, New York, USA, 113. DOI: http://dx.doi.org/10.1145/503376.503397
17. Munehiko Sato, Ivan Poupyrev, and Chris Harrison. 2012. Touché: Enhancing Touch Interaction on Humans, Screens, Liquids, and Everyday Objects. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*. ACM Press, New York, New York, USA, 483. DOI: http://dx.doi.org/10.1145/2207676.2207743
18. Valkyrie Savage, Colin Chang, and Björn Hartmann. 2013. Sauron: Embedded Single-camera Sensing of Printed Physical User Interfaces. In *Proceedings of the 26th annual ACM symposium on User interface software and technology - UIST '13*. ACM Press, New York, New York, USA, 447–456. DOI: http://dx.doi.org/10.1145/2501988.2501992
19. Valkyrie Savage, Ryan Schmidt, Tovi Grossman, George Fitzmaurice, and Björn Hartmann. 2014. A Series of Tubes: Adding Interactivity to 3D Prints Using Internal Pipes. In *Proceedings of the 27th annual ACM symposium on User interface software and technology - UIST '14*. ACM Press, New York, New York, USA, 3–12. DOI:http://dx.doi.org/10.1145/2642918.2647374
20. Martin Schmitz, Mohammadreza Khalilbeigi, Matthias Balwierz, Roman Lissermann, Max Mühlhäuser, and Jürgen Steimle. 2015. Capricate: A Fabrication Pipeline to Design and 3D Print Capacitive Touch Sensors for Interactive Objects. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology - UIST '15*. ACM Press, New York, New York, USA, 253–258. DOI: http://dx.doi.org/10.1145/2807442.2807503
21. Martin Schmitz, Andreas Leister, Niloofar Dezfuli, Jan Riemann, Florian Müller, and Max Mühlhäuser. 2016. Liquido: Embedding Liquids into 3D Printed Objects to Sense Tilting and Motion. In *Proceedings of the 2016*

CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '16. ACM Press, New York, New York, USA, 2688–2696. DOI: http://dx.doi.org/10.1145/2851581.2892275

22. Simon Voelker, Christian Cherek, Jan Thar, Thorsten Karrer, Christian Thoresen, Kjell Ivar Øvergrd, and Jan Borchers. 2015. PERCs: Persistently Trackable Tangibles on Capacitive Multi-Touch Displays. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology - UIST '15*. ACM Press, New York, New York, USA, 351–356. DOI: http://dx.doi.org/10.1145/2807442.2807466
23. Simon Voelker, Kosuke Nakajima, Christian Thoresen, Yuichi Itoh, Kjell Ivar Øvergrd, and Jan Borchers. 2013. PUCs: Detecting transparent, passive untouched capacitive widgets on unmodified multi-touch displays. In *Proceedings of the 2013 ACM international conference on Interactive tabletops and surfaces - ITS '13*. ACM Press, New York, New York, USA, 101–104. DOI: http://dx.doi.org/10.1145/2512349.2512791
24. Daniel Wigdor, Hao Jiang, Clifton Forlines, Michelle Borkin, and Chia Shen. 2009. WeSpace. In *Proceedings of the 27th international conference on Human factors in computing systems - CHI 09*. ACM Press, New York, New York, USA, 1237. DOI: http://dx.doi.org/10.1145/1518701.1518886
25. Cary Williams, Xing Dong Yang, Grant Partridge, Joshua Millar-Usiskin, Arkady Major, and Pourang Irani. 2011. TZee: Exploiting the Lighting Properties of Multi-touch Tabletops for Tangible 3D Interactions. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*. ACM Press, New York, New York, USA, 1363. DOI: http://dx.doi.org/10.1145/1978942.1979143
26. Karl Willis, Eric Brockmeyer, Scott Hudson, and Ivan Poupyrev. 2012. Printed Optics: 3D Printing of Embedded Optical Elements for Interactive Devices. In *Proceedings of the 25th annual ACM symposium on User interface software and technology - UIST '12*. ACM Press, New York, New York, USA, 589–598. DOI: http://dx.doi.org/10.1145/2380116.2380190
27. Neng-Hao Yu, Li-Wei Chan, Seng-yong Yong Lau, Sung-Sheng Tsai, I-Chun Hsiao, Dian-je Tsai, Lung-pan Cheng, Fang-i Hsiao, Mike Y Chen, Polly Huang, Yi-ping Hung, Li-Wei Chan, Seng-yong Yong Lau, Sung-Sheng Tsai, I-Chun Hsiao, Dian-je Tsai, Fang-i Hsiao, Lung-pan Cheng, and Mike Y Chen. 2011. TUIC: Enabling Tangible Interaction on Capacitive Multi-touch Display. *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11* (2011), 2995–3014. DOI: http://dx.doi.org/10.1145/1978942.1979386