Replicate and Reuse: Tangible Interaction Design for Digitally-Augmented Physical Media Objects

Aakar Gupta
School of Computer Science
University of Waterloo
Waterloo, Canada
aakarg@acm.org

Bo Rui Lin*
Pinterest Inc
San Francisco, USA
blin@pinterest.com

Siyi Ji
School of Computer Science
University of Waterloo
Waterloo, Canada
sy2ji@edu.uwaterloo.ca

Arjav Patel
School of Computer Science
University of Waterloo
Waterloo, Canada
arjav.patel@edu.uwaterloo.ca

Daniel Vogel
School of Computer Science
University of Waterloo
Waterloo, Canada
dvogel@uwaterloo.ca

ABSTRACT
Technology has transformed our physical interactions into infinitely more scalable and flexible digital ones. We can peruse an infinite number of photos, news articles, and books. However, these digital experiences lack the physical experience of paging through an album, reading a newspaper, or meandering through a bookshelf. Overlaying physical objects with digital content using augmented reality is a promising avenue towards bridging this gap. In this paper, we investigate the interaction design for such digital-overlaid physical objects and their varying levels of tangibility. We first conduct a user evaluation of a physical photo album that uses tangible interactions to support physical and digital operations. We further prototype multiple objects including bookshelves and newspapers and probe users on their usage, capabilities, and interactions. We then conduct a qualitative investigation of three interaction designs with varying tangibility that use three different input modalities. Finally, we discuss the insights from our investigations and recommend design guidelines.

Author Keywords
augmented reality; tangible; design; physical objects

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

*Work done while at the University of Waterloo, Canada.

CHI '20, April 25–30, 2020, Honolulu, HI, USA.

ACM ISBN 978-1-4503-6708-0/20/04 ...$15.00.
http://dx.doi.org/10.1145/3313831.3376139

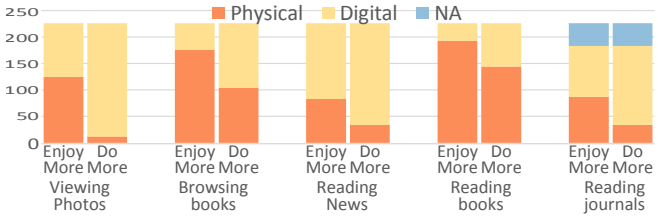

Figure 1. Survey[1] results showing a disparity in the number of people reporting they enjoy physical media browsing activities more, but use digital media activities more often.

INTRODUCTION
Technology has transformed our physical interactions into infinitely more scalable and flexible digital ones. We can peruse an infinite number of photos, news articles, and books on a single device. However, these digital experiences lack the physical experience of paging through an album, holding a newspaper, or running your fingers through a bookshelf. Multiple studies have demonstrated the value placed by users on such physical experiences. For example, people ascribe deeper engagement when reading physical books [15], a majority of scientists prefer to print online research articles [37], and people find holding a physical photo album while leafing through its pages to be a more real and intimate experience [8, 40].

To test this motivation further, we conducted an online survey[1] to understand what people enjoy more, consuming media on a digital device or its physical counterpart. We also asked them which of the two they ended up doing more often. We used a snowball sampling approach where the survey link was posted to a university student forum and members were encouraged to share the link with family and friends. The results (Figure 1) found a consistent disparity between enjoyment and usage frequency for each activity. For example, 125 people enjoy viewing physical photo albums more than digital, but only 12 actually use physical photo albums more often. In general,

[1]226 participants (89F, 135M, 2DNR, age: $\mu = 24.1$,15-69).

participant comments state they enjoyed physical experiences more, but digital consumption is more frequent owing to its scale and "up-to-date" nature. In the words of one participant, "I love the experience of seeing photos in real albums, but with the amount of photos these days, there's no way that's possible anymore."

Overlaying physical objects with digital content using augmented reality (AR) is a promising avenue towards bridging this gap. Multiple systems have proposed augmenting digital content onto books and other objects. We address the specific question of how would one design for digital content perusal when overlaying content over corresponding physical objects such that the physicality of the experience remains intact. Our focus is on digital content that has a specific physical counterpart and to design specifically for that digital content-physical object pair. For example, using one physical album to view all digital photo albums of a user, using one physical newspaper to read any news article from any website, and using one physical bookshelf to browse through multiple book collections.

Such an experience entails two primary goals - to 1) *replicate* the physical experience of using the object for a particular set of digital content, and to 2) *reuse* the object for other sets of digital content. Let's take the example of a photo album to understand the design questions posed by these two goals. *Replicate:* A user has a huge number of digital photos sorted into different digital albums. Assuming that the user is using a physical album to look at the photos of a particular digital album, it raises the following questions: What happens when the physical album runs out of pages but the digital album still contains more photos? What level of physicality should be supported by the interaction? Should it only support viewing the photos? Or should it support other physical manipulations, such as re-ordering photos in the album by removing them from one page sleeve and placing in the next one; or taking the photo out and looking at its back to see its date of printing?

Reuse: If a user is viewing photos from a particular digital album in the physical album, how do they load photos from another digital album in real-time? Do they put down the album, use a smartphone app to load the new digital album, and pick the album back again? Or do they perform an interaction to load a new album that does not involve interrupting the use and switching to a smartphone? What would such an interaction be like such that the physical experience is uninterrupted?

Consequently, the question becomes, how do we understand and design for the right level of replication of physical actions, and for seamless methods for reuse? The interaction design involves understanding how to balance between the tangibility of the physical object and the flexibility of the digital content. To this end, we first prototype several physical objects including including a photo album, a bookshelf, a newspaper, a research paper, a card-deck, and a jigsaw-puzzle, that support AR overlays using fiducial markers. We design a wholly-tangible interaction vocabulary for the physical album that supports *replicate* and *reuse*. We then conduct a qualitative study to get user feedback on the album's tangible interactions, and to probe user perspectives on the utility and desired capabilities of such physical-digital experiences. We then conduct a second qualitative study where we ask users to compare three prototypes that use three different modalities: tangible, voice, and smartphone on their usability and physicality. Our results offer nuanced perspectives on how users perceive physicality of such physical-digital objects and their interaction design.

RELATED WORK

We look at three directions of related work: 1) works that specifically investigate AR on physical media objects such as books and photo albums, 2) tangible AR, and 3) digital systems that try to replicate physical attributes.

Augmenting Information on physical media objects

There are several apps and demos that augment content onto books. Multiple works have investigated mixed reality books [17, 12, 27, 45, 9] which have content projected onto them. MagicBook [4] overlaid pages with 3D virtual scenes where users could transport themselves into the scene. Other works [17] augment information on a printed book wherein touch gestures on the book lead to annotated videos and content. Dachselt et al. [9] proposed enabling digital operations like translation by projecting the annotations on a printed book and using a digital pen. Mehmet et al. provide an in-depth review of augmented books [29]. Augmented bookshelves [39, 35] help to return a physical book to the right shelf by displaying identifying data on the shelf. Recently, Lindlbauer et al. [25] change physical object appearance such as enlarging a book by augmenting the space around.

The work in the space of augmenting information on physical media objects influenced us since it makes physical objects more "digital" with augmentations. However, prior work treats the visual and interactive presentation of content as digitally-focused augmentations on top of the physical object. Instead, we augment physical media objects with digital content so the original physical experience (visual and interactive) is preserved ("replicated") as closely possible. The changes in user expectations on media consumption due to the advent of smartphones demand new design lenses and user explorations. Replicate and reuse offers a new lens on media consumption using AR.

Tangible Augmented Reality

Tangible AR (TAR) [5] is when each augmented virtual object is mapped to a physical object and the user interacts with virtual objects by manipulating physical objects. In multiple systems [11, 6, 33], virtual objects are augmented on AR marker cards. In most of these works, virtual objects are 3D models with or without animations. Multiple works use the model-on-card system for card-matching games [11], education apps where cards correspond to planets or molecules [6], for tangible collaborative design of a cockpit [33] or of furniture [20] using physics-like actions such as inclining the card to slide down the virtual object. TAR systems using 3D physical objects such as the AR Rubik's cube [3] or the illuminating clay [32] have also been proposed. TAR systems also use other forms of input such as a hand-held tracked paddle-like prop to pick up or drop virtual objects [20, 26, 21], touch gestures on AR markers [28, 23, 36], and speech input [18].

Lee et al. [24] provide an on-depth review of TAR systems. Further, Holman et al. [16] proposed tangible paper actions including collating, folding, stapling, etc. and showed their effects on webpages projected onto paper. More recent work [14] investigates dynamic identification of physical proxies for virtual objects.

Physical attributes in Non-tangible systems

The metaphorical use of the real world for digital interactions has been discussed widely from representational to physics-based works [38, 2, 1, 42, 10]. Multiple works have explored synchronized physical-digital experiences such as note-taking [44, 31] using digital pens or Anoto paper driven scrapbooking [43]. Researchers have also explored ways of mimicking the physical interfaces digitally - a virtual shelf that reproduces a book's age and aesthetics [34], a 3D bookshelf visualizations [22], and a vertical multitouch display for virtual bookshelves. However, as Terrenghi et al. indicate [38], the simple mimicking of physical attributes digitally may not be enough for enabling a physical experience.

Works on TAR systems and the use of physical metaphors in non-tangible systems influenced our notion of reuse. Our explorations utilize these ideas with tangible interactions that are physically or metaphorically similar to the physical interactions as a way to reuse interactions while still retaining physicality.

None of the works described above explores the design space of replicating & reusing the physical experience of physical media objects for digital content. That's our goal in this paper.

REPLICATE AND REUSE INTERACTION CLASSIFICATION

We define four classes of interactions based on the operations that can potentially be supported by a physical media object that is being overlaid with digital content: *1. Browsing Interactions (B):* Interactions that are used only to view or browse the physical object with the content that's currently mapped to it. For an album, this would involve looking at the augmented photos, paging through them, and being able to move the album around in space and still see the photos. Using browsing interactions, only photos that are currently mapped to the album's pages can be viewed. *2. Physical Manipulation Interactions (P):* Interactions that enable manipulation operations that are supported by a physical object in its real-world use. For a photo album, this could be moving or swapping the physical photos within the album, taking out the photos to see the back etc.. If such operations are supported for digital content, the corresponding interactions can either be the same as the physical ones or can be completely different. For instances, photos may be swapped by actually swapping paper sheets encased in the pages or using a voice command. *2. Reusing Interactions (R):* Interactions that allow reuse by enabling loading of different digital content to be mapped onto the physical object. For the album, this includes loading more photos of the same digital album after hitting the page limit or loading another digital photo album different from the one mapped to the album. *4. Digital Manipulation Interactions (D):* Interactions that enable manipulation operations that are not feasible in a physical experience, but are performed on the digital content. For instance, digital photos can be searched, applied filters to, sorted etc, but no such manipulations exist for physical photos in an album.

Browsing (*B*) and physical manipulation (*P*) interactions fall under replication, and reusing interactions (*R*) fall under reuse. Digital manipulations (*D*) do not really fall under replicate or reuse. We therefore focus our primary attention on the first three categories but probe users on selective aspects of digital manipulation in the second study. Browsing digital content physically (eg. paging through an album) is the core interaction of the physical experience. Using that as a constant, we focus on questions surrounding reuse and physical manipulation interactions.

PROTOTYPE DESIGN: PHOTO ALBUM

Our first study is intended to provide users with a wholly-tangible interaction experience to get feedback on the ease and usefulness of such a physical interaction experience. We use a physical photo album prototype as our primary probe to investigate the above interactions in depth. The photo album prototype supports the following interactions (Parentheses show the interaction category for the interaction): 1) (*B*) browsing photos in the album, 2) (*R*) loading photos into the physical album from linked digital albums, 3) (*R*) loading more photos from the same digital album beyond the physical album's page limit, 4) (*P*) viewing the information at the back of a photo, 5) (*P*) swapping/reorganizing photos, and 6) (*P*) removing a photo. Since 4,5, and 6 are physical manipulations, we try to adhere to their physical analogues as much as possible. For the reusing interactions 2 and 3, there are no physical analogues and so we design new tangible gestures for them.

Hardware & Software

The prototype has two visual markers on every album page (Figure 2): the *page marker* that is stuck to the page and the *photo marker* that is placed over the page marker inside the transparent encasing, just like a photo. The page marker is visible only when the photo marker is taken out from its encasing. Markers are also present on the front, back covers. A database stores the photo marker-page marker association. Multiple digital albums are linked with the physical album, one of which is mapped at any moment for viewing. A logical ordering of its digital photos is mapped to the page markers and by association, to the photo markers. When the system sees a photo marker, it retrieves the associated photo and augments it onto the marker. We used the Vuforia™ AR SDK [41] with Unity for tracking markers and Microsoft HoloLens as AR glasses (Figure 2).

We use dedicated markers here for prototyping ease; however, one can implement the same system using an existing album with existing pictures as long as the pictures can be distinctly identified by an image recognition algorithm. Further, we could have used projections instead of AR glasses. However, we wanted to do the study with the current limitations in AR display technology to get user feedback on not just the interactions, but also the technical obstacles that need to be cleared before such systems can become acceptable for users.

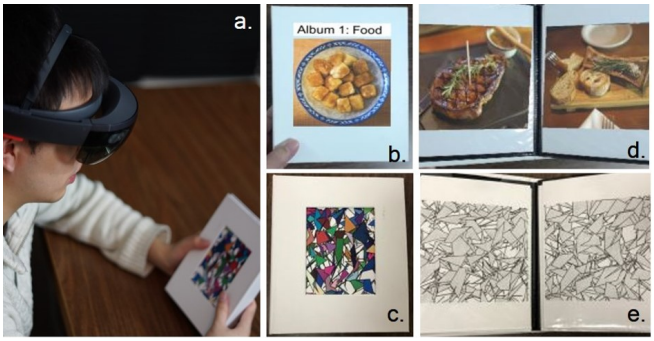

Figure 2. a)User with the physical album b) Album view via Hololens c) Actual album with marker d,e) Open album

Browsing photos (B)

The photo markers have a 1-to-1 mapping with the augmented photos both in terms of their orientation & position. Thus, the user can page through the album exactly the same way as a physical album to view the photos. Moving or tilting the album rotates the photos with it just like a physical one.

Loading other albums (R)

To view the other linked digital albums, the user turns the physical album to landscape (90 degrees) while the front cover is visible (Figure 3). This switches the physical album into album selection mode and the user sees different albums' thumbnails. The user now opens the album where every pair of pages display the name and cover photo of a linked album. To load an album for browsing, user closes the album on the desired page, turns it back to portrait which causes the front cover to display the new album's name & cover photo indicating that it has been loaded. Seeing cover-photos in this way resembles real-world searching via physical album covers.

We introduce another technique that enables quick jumping to the next linked album in the sequence. For instance, if the linked albums are sequenced chronologically and the user wants to quickly go to the next album, the user can do a quick front-back-front manipulation where they switch from the front cover (in portrait) to the back cover to the front again within 3s. This loads the next album with the new name and cover photo displayed on the front. The 3s limit prevents false triggering during routine use.

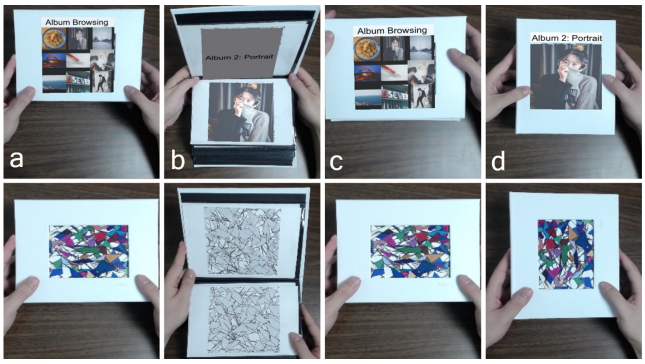

Figure 3. Tangible Album Interaction for Loading another album. a) Landscape view shows thumbnails b) Pages show cover photos c) Close a page to load its album d) Portrait view shows new album

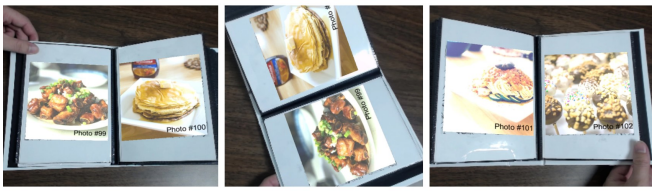

Figure 4. Tangible Album Interaction: Loading more photos from the same digital album by turning the album by 180 degrees on its last page. (left) User starts turning the album, (middle) User is in the middle of turning it, (right) the album is turned and now shows new photos

Loading more photos from same digital album (R)

For loading more photos from the same digital album, when the user is on the last page, they can turn the album upside down (180 degrees) to load the next set of photos in the new orientation (Figure 4). Thus, for a 100 page physical album, an upside turn on the 100^{th} page loads photo #101 on the last page, photo #102 on the 2^{nd} last and so on. The last page is now the first page of this set of photos. An upside turn on this set's last page (the actual first page) leads to the subsequent set. Thus the user can quickly go much farther in the album by simply jumping to the set's last page and turning upside down repeatedly. The action is easily reversible- after the upside down turn on the last page, turning it upside down again returns to the previous set. The album is reset to the first set whenever the user closes shut the physical album. Except cover, last, and first pages, the user is free to orient the album in any way on the inner pages.

Looking at the back (P)

The user can take out a photo marker, look at its back and place it back just like a physical photo (Figure 7). Markers are printed on thick sheets to provide a tactile feeling akin to real photos. Each photo marker consists of another marker at its back which displays the meta-information about the photo.

Swapping (P)

The user can take the photo markers out from the encasings and swap or reorganize their position in the album similar to a physical album (Figure 5). The 1-to-1 mapping ensures that

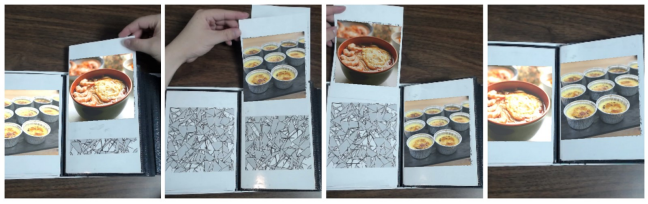

Figure 5. Tangible Album Interaction: Swapping photos. The user takes out the first marker, then takes out the second marker and places it in place of the first marker, then places the first marker in the vacated location, and sees the swapped photos. By capturing the swap, we ensure that photos in the other digital albums linked to this physical album in the same location are not swapped.

Figure 6. Tangible Album Interaction: Removing a photo. The user first removes the marker by sliding it out from the top, then reinserts it from the bottom, resulting a blank augmented photo indicating photo deletion. The reinsertion ensures that other linked digital albums are not affected.

the photos are superposed with the marker, thus resulting in an experience same as a physical album. If the markers that were taken out go outside the camera-view, they retain the photo upon being back. The system detects taking out & placing back and reorganizes mappings to ensure that the other linked albums keep their photo ordering intact.

Removing photos (P)

People occasionally remove photos permanently. However, permanent removal of a photo marker from the physical album prototype would affect its functionality for the other linked albums. Therefore, to remove a photo, the user takes the photo marker out from the top and inserts it back from the bottom (Figure 6). The system uses the photo and page marker positions to recognize this action and immediately displays a blank page. The other linked albums are not affected. The user would still be able to access the removed photo digitally. While swapping and looking at the back interactions are same as their physical counterparts, removing photos is same up until the removal, but not in the replacement.

ADDITIONAL PROTOTYPE DESIGNS

We further build several other physical media object prototypes with less tangible interactions to gather user perceptions on the larger questions of utility and contextual use of such objects.

A physical book-shelf for browsing digital books

The prototype of a single book would be very similar to the photo album. However, the physical experience of browsing a bookshelf is also very different from browsing books digitally. We prototyped a small book-shelf that could be used to browse multiple digital book collections. This is an example of a

Figure 7. Tangible Album Interaction: Viewing the back of a photo. The user simply takes out a marker and views its back.

Figure 8. A physical bookshelf being reused with different books

superobject - a collection of several physical sub-objects all of which can be overlaid. The physical books have visual markers on their front, back, and spine, as well as on each of their pages (Figure 8). The users can experience it similar to a physical book-shelf: first look at the books, take a book out, read the summary at the back, open it to read or put it back. The books are of different sizes & thicknesses so as to enable digital books to be assigned to physical books that resemble their physical versions. Here, instead of using tangible gestures, we use voice for the reusing interactions. For instance, the "Load Fantasy" command loads the Fantasy books in the user's collection. The user can then say "Next"/"Previous" to load more books of the same category. While we do not implement them, one can easily imagine conversational commands for P, D interactions such as using filters (author, ratings etc.), or rearranging the books.

A physical newspaper for reading any digital news

We build a physical newspaper prototype (Figure 9) that enables reading any digital newspaper while being able to feel the actual newsprint, page through it, fold it, and take out a page and hand it over to someone else for reading. In our prototype, each half of a page has a marker that corresponds to the image for that half. Thus the physical experience continues even when the paper is folded in half. When both markers of a page are visible, a single image for the entire page is displayed instead of combining the two half-images to preclude any misalignment. We again use voice for loading another newspaper - "Load New York Times for 5 May 2017". One can similarly create physical magazine objects that support loading of any digital magazine from any date.

A physical research paper to read digital research papers

Printing out scholarly documents is the predominant way of reading them [37]. We prototype a physical research paper object that can be used to provide a physical reading experience for any digital research paper without actually printing it (Figure 9). The object is simply a stapled collection of A4 sheets with markers that anyone can print. The reuse is supported

Figure 9. a) Physical newspaper object b) Augmented newspaper. c) Physical research paper object, d) Augmented research paper

Figure 10. (left) A physical card deck reused for different card games. (right) A physical jigsaw puzzle reused for different puzzles.

by a desktop app that allows sending any pdf document to the physical research paper. Metaphorically, this sending from the computer could be thought of as sending the document to print. Physical research papers crucially enable writing on them. We do not implement it, but it could be possible using a tracked ink-less pen [13, 46] combined with augmented inking on the document.

A physical pack of cards to load any card game

All above examples deal with browsing/reading. With a card deck, the primary activity is a multiplayer game. Card-game enthusiasts buy numerous card-games, each with its own deck. We prototype a physical deck that can be loaded with any card-game using voice. It can also enable purely virtual card-games to be played physically. Each physical card has front & back visual markers. In some games, players hold the cards in a fanned-out fashion (Figure 10). This needs marker tracking that works with high degree of occlusion and depth ambiguity which is a limitation with our implementation.

A physical jigsaw-puzzle to load any puzzle

Once one solves a jigsaw puzzle, it is effectively rendered useless. We prototype a physical puzzle (Figure 10) where the same set of pieces can be loaded with any overall picture. We use a desktop app to send different images to the physical puzzle. Card-deck and jigsaw-puzzle are examples of objects where the real-world interaction usually involves just different forms of viewing (fanned-out cards, spread-out pieces, etc.) and almost no interactions that fall under physical manipulation.

The above prototypes form a rich set of physical objects that demonstrate different ideas and will serve as useful probes for the user study.

FIRST QUALITATIVE STUDY: UTILITY AND TANGIBLE INTERACTIONS

The study focuses on the following two aspects- (a) How do people perceive the utility of physical objects with overlaid digital content that supports replication and reuse? What are their thoughts on their tangibility and their desired features?, and (b) What are the user perspectives on a physical album that supports wholly-tangible interactions of this kind?

10 participants (6 female, 4 male, age range 21-37), 3 of whom had used AR/VR glasses earlier and 3 had experience in interface design. The study took 60mins per participant. The participants were initially introduced to the concept, then given a hands-on demo with an external camera without Hololens, followed by a hand-on demo with Hololens. The participants were then asked to do the following series of tasks: finding a specific photo, finding a photo by loading more photos from the same album, loading the next album, loading an album using landscape mode, viewing the back, swapping, and removing a photo. The Hololens was then removed and participants filled out a Likert-scale questionnaire. This first-hand experience of tangible interactions completed the part designed for aspect (b) from above. Next, to get participants thinking about the larger topics in (a), all the other prototypes were demonstrated to the participants. Finally, a semi-structured interview was conducted, recorded and transcribed. During the interview, participants were also prompted to think about a scenario where they were using these objects with regular glasses with advanced AR capabilities instead of a bulky Hololens. We now describe the results, starting with (a).

User Perspectives on Utility

Most participants responded warmly to the concept of using physical objects to peruse digital content. The perspectives on utility came from two viewpoints- as an alternative to digital experiences, or as an augmentation to physical experiences. We summarize the former first.

Relaxed Use, Digital Unplugging

Multiple participants viewed it as a way of unplugging digitally (assuming the system worked with lighter, regular glasses), while still having access to the specific digital content they want. P6: *"I love this. I think it's best for when you want to sit down and unwind. And I can just look at photos from my phone without all the distractions from my phone."* Participants liked that one object is meant for only one type of content. P4: *"This gives different devices for different things - newspaper for news, album for photos. I don't have to do everything on a single device. I won't just be swiping all the time"*. Another common theme here was using digital for goal-driven use vs. physical for relaxed use. P2: *"When I'm looking for something specific, I'll prefer doing it online, but this is nice for when I just want to browse (books)."* P5: *"For news, I'm just looking to know quickly, what's happening. It's very efficient with the phone, just swipe and get it. Even if it's the same content, I don't think I'll use the physical newspaper."* In contrast, a few participants felt that the physical form factor was better for quick glances and paging through. P1: *"I like to scan the newspaper headlines in the morning, whatever catches my glimpse. Takes 2 minutes and I know everything. This can give me a feed of my subscriptions in an actual newspaper. That'll be awesome."*

Shared Use, Family

Another common theme was that this would reduce the friction in getting physical media, which some participants found more enjoyable, especially with family. P2: *"All our family holiday pics are in the phone now. I know my Mom will love if we just sit down and look at those pics in an album"*. P3: *"With the*

puzzles right now, they are all cartoons and stuff. With this I can load educational images on the puzzle and play them with my kid." Participants mentioned how such experiences can overcome issues with shared digital use. P6: *"It's weird to look at photos in my friend's phone since I don't feel comfortable swiping my finger on their phone and then their chats may pop up. It's same when I'm showing someone photos on my phone. But if we load them up here, there won't be issues like that."* Participants suggested inventive ways in which this could ease photo sharing and consumption with elder members of the family. P8: *"I sometimes get an album made for my grandparents when I visit them, because they love it. May be I just give them this album and even when I can't visit, I just send a new set of photos to it every month. And they just have to open the album to see the new photos."* Such use-cases, again, would require the AR technology to be mature enough to work with lightweight glasses.

The above two themes reflected the *alternative to digital* viewpoint. The below two reflect the *augmentation to physical* viewpoint.

Environment & Clutter

While it may be arguable if the environmental costs of using an AR device would be lower, participants saw reusability as a way to reduce paper waste and clutter. P5: *"I always print papers out. It's just huge amounts of paper and ink. With this, I'll probably only print the important papers that I need to refer to again and again. If this was a product that worked well, I would buy it right now. But obviously, it needs to support notetaking."* P3: *"I just like that there will be less clutter. Less print outs, less books, less toys. I mean, if we get a new printed album in the house, it always ends up in storage and then it's rarely seen. If there's just one album, it probably won't end up in storage."*

Overcoming physical scale constraints

Participants observed how reusing bookshelves would help retain the physical experience while overcoming the physical size, space, location constraints. P1: *"We cannot have huge libraries with all the books in every corner of the city, but these book shelves can be in smaller libraries to give the same experience."* P4: *" (I Imagine) I have such a book-shelf at my home and it's connected to the book store's shelves. So I can see what's new every week and then decide to go buy or not."*

User Perspectives on (Non) Tangibility

These experiences tread the physical-digital middle ground which elicited comments on the resulting trade-offs.

Functional vs Aesthetic Tangibility. Participants had diverging views on replicating physical aesthetics. P7, who had a design background said - *"A physical book in a book shelf tells me its thickness, number of pages, the texture of the covers are different. I think this experience is functionally physical, but not aesthetically physical."* However, another participant found the not-completely physical aspect as a plus, highlighting function over aesthetic. P10: *"I like physical books but I used Kindle because it can load any book and it still remains thin, light, good for travel. This (book), I can turn pages and have a thin book which can load thicker ones."*

Disposability

Even though one physical object functions as many, they were perceived as more disposable than physical *and* digital objects. P8: *"For me, book shelf at home is a style statement. I like having people see them. Plus, they'll be with after 50 years."* P1: *"I don't want to risk spillage on my cookbook, or on my tablet in the kitchen so I keep running to my book on the table then go back to the kitchen counter. I wouldn't mind spillage if it's this type of physical book."*

Digital Access

P7 mentioned how digital access issues may affect the physical experience - *"In a book store, I can open the book and read it, but online I can't unless I buy it. Since these are digital representations, would we have complete access? If not, I think it's more digital than physical."*

Desired Features: Subtle Digitality

Participants indicated subtle digital features that overcame present constraints in physical experiences, without disturbing the experience too much. P1: *"Browsing books in a store, I loved it. But recently I went to the store and it was so hard. I was on my phone all the time looking at ratings and reviews and comparing costs. If we have a way of displaying that information in the physical book shelf, it will be more useful."* Multiple creative ideas used the eye-worn aspect- P7: *"Let's say I'm reading Twilight in a public place. But if others are looking at my book through their glasses, I want them to see War and Peace. And I know that everybody knows that this is my curated image and it may not be real, but isn't that what Instagram is?"*. P8: *"I like late night reading, but my partner sleeps early. Can I use it to read in the dark where I feel like the light is switched on in the room or on the book?"*.

Interacting with the wholly-tangible photo album

We now look at the specific feedback participants gave on interacting with the physical photo album prototype. Figure 11 shows the participant ratings for ease of use & usefulness of the interactions. (To get ratings on the interaction and not on its current implementation, participants were told to assume that Hololens worked flawlessly). The reusing interactions were considered useful and easy to use. P5: *"Initially, yes, it seems weird to turn the album around and stuff. But once you know, then it's easy. It's obviously necessary to have some way of seeing more photos than pages and this turning action is quite nifty."* The physical manipulation interactions drew more varied perspectives. While some participants enjoyed the tangibility, other considered it cumbersome, both physically & cognitively. P9: *"If I want to take out a photo and put it back in, I need to remember to not put it back in from the bottom otherwise it will be deleted. This is not needed."* Another participant mentioned using digital-style interactions - *"The images are digital, so we should be able to touch or swipe. I kind of expected that. It is too much work to take both photos out and put them back in when I can just do some swipes and taps to swap photos."*

Participants had diverging opinions on the operations that the album should support. One participant only wanted album viewing and the rest to be controlled by a smartphone - *"Once*

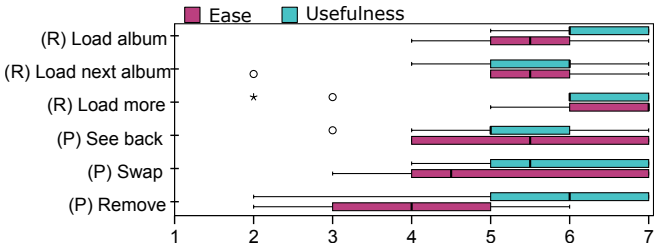

Figure 11. Physical album interactions: Usefulness & Ease

I get the album, I just want the album experience. I'll prepare a kind of a play list beforehand in my phone and then just the jumping to the next album using the front-back-front is all I need." P4: *"I understand why you have the infinite album, but I think the benefit of physical albums is their limited-ness.* In contrast, other participants wanted *D* interactions to also be included - *"It would be nice to have physical ways of doing stuff we do in the phone, like, I take a photo out and touch it with the phone and then I can share it."*

Participants also mentioned contextual issues that may be caused due to *R* interactions as they are not part of the physical album experience. P2 mentioned the midas touch issue - *"It works for me, but for my parents, I'll just switch off the orientation change part. It needs to feel completely physical. The swapping of photos feels physical so that'll be good to have."* P7 similarly suggested that tangible interactions be used with B, P, and digital be used with R, D - *"They (loading interactions) sit somewhere in the middle, not quite physical, not quite digital. I would use the physical interactions only where they seem completely physical like reorganizing photos or for looking at the back. But album selection and others can be digital using touch or in-air kind of gestures."*

While participant ratings were generally on the positive side, the interview unearthed more nuanced perspectives, establishing the need for exploring tangibility further. There were two primary takeaways from the above themes that we used for designing the second study. First, participants indicated the need to explore interactions for R, P, D that were less tangible. Consequently, we explore voice control and smartphone control in the next study. Second, even while participants liked tangible interactions, they thought that other ways of interaction may be more efficient or usable. Thus, we included the evaluation of *usability and enjoyability* in the next study. If tangibility overtly affects usability, it may not be the best choice even if the goal is to replicate the physical experience.

SECOND STUDY: TANGIBLE, VOICE, AND SMARTPHONE

The goal of this study was to understand in more depth, how tangibility, usability, and enjoyment are related and how that informs the interaction design. We compared three input modalities for the photo album which differed in their reuse, physical manipulation (R, P) interactions, while browsing interactions remained the same. The three modalities are: **Tangible**: Same as the earlier study, **Voice**: using voice or voice+gesture-on-album, **Smartphone**: using an app. For Voice, the reuse commands were "Load <Album Name>", "Load Next Album", and "Load More Photos". The physical manipulation interactions were deictic [19] - to swap two photos 1 & 2, the user said "Swap This.. With This", tapping photo 1 during the first "This"and photo 2 for the second. The other two commands were "Show the back" & "Remove" while tapping the appropriate photo. For Smartphone, the phone was placed next to the album. The app consisted of buttons and thumbnails to perform the reuse and physical manipulation interactions. Unlike the smartphone, with voice, the user does not need to switch their attention away from the album.

Apparatus

Since we were assessing usability, we modified the apparatus to address two display usability issues from the first study: 1) *FOV*: Hololens has a small field-of-view (FOV) of $30°Horizontal$, $17.5°Vertical$. We switched to Meta2 [30] that has a much larger 90° H, 50° V FOV. (2) *Opacity*: Augmented photos seen through the glasses were translucent leading to the photo-markers blending into the photos. We ran the 2^{nd} study in low-lighting which dimmed out the markers, resulting in clear, opaque photos. However, to ensure enough light for marker tracking, we used infrared lights that lit up the markers. We used Wizard of Oz for voice commands to ensure consistent recognition across native & non-native speakers.

Design & Procedure

18 participants (7F,11M, age $\mu = 26.5, 18-30$), all different from the prior study, 3 of whom had used AR glasses earlier took part. It was a within-subjects design. The 3 techniques were counterbalanced in a Latin square. The participant was first introduced to browsing the album with Meta 2, followed by a hands-on demo of the interactions of the first technique without Meta 2. They then performed a series of tasks while wearing Meta 2: finding a specific photo, finding a specific photo requiring infinite interaction, loading next album, removing a specific photo, swapping, loading an album by name, viewing the back, and loading album by name. The participant then filled the system-usability-scale (SUS) questionnaire [7], a standard usability metric. Same procedure was repeated for the 2^{nd} and 3^{rd} conditions. The photos did not repeat for a participant and were counterbalanced. After the last condition, the participant filled a questionnaire comparing the 3 techniques. While digital manipulation interactions were not part of the study, we added a "Filter" operation for Voice and Smartphone that applied an image filter to the photo. After the questionnaire, we asked the participants to use the operation and their preferences on it. Since tangible interactions that did not reflect real-world actions were not preferred in the first study, the digital manipulation operation was not implemented for Tangible. At the end, a small interview was conducted, recorded and transcribed.

Results

Table 1 shows the SUS scores. Tangible's usability was significantly lower $(F(2,34) = 7.611, p < .005, \eta^2 = .309)$ than both Voice ($p < .05$) & Smartphone ($p < .005$), which are comparable. Figure 12 shows the technique participants preferred the most for a particular interaction, as well as the technique they enjoyed most and least. Participants overwhelmingly enjoyed Voice the most. While Tangible's enjoyment &

Table 1. Second Study: System-Usability-Scores

SUS	Tangible	Voice	Smartphone
μ (95%*CI*)	58.3 (48.8, 67.8)	75.8 (65.5, 86.1)	77.9 (70.7, 85.1)

preference % echo its usability score, Smartphone is much less preferred & enjoyed than Voice, even with similar usability.

Voice: Maintains Tangibility & is Usable

Majority of the participants found voice to be the perfect middle-ground between the physical, but cumbersome Tangible condition and the quick, but attention-demanding Smartphone. P7: *"Voice was the best of both worlds, the interactions included just enough physical component but were still quick and easy to use. Physical was nice, but it reminded me of the annoying things about physical albums, instead of highlighting the nice parts."* P3: *"I don't have to dance around a bunch of moves. I can sit on my couch and just tell it to load new images without focusing on anything else. And the phone is just counterproductive here.* However, participants also raised the issue of public use. P6: *"Voice is fine in private, but in public, I'll prefer the smartphone. Although, not sure why I would use the album in public."* It needs to be noted that the enjoyment of voice as a modality is dependent on a seamless voice recognition interface.

Smartphone for prior use, not concurrent use

Aside from the focus-switching issue, participants considered Smartphone as an additional device to handle. P10: *"I don't want the album, an AR headset and a phone to view my pictures."* P1: *"If I'm holding the album, I can't hold the phone."* However, some participants liked the quickness of the phone. P8:*"I felt like I was using a remote control to change channels on my TV, very easy."* Multiple participants brought up the issue of memorability with voice. P9: *"I can't really search using voice. If I want to look for the album I want and I don't remember it's name, I can't use voice. How about using the phone for searching and then using voice while looking!"* This echoes the comment in the first study where a participant wanted to use the phone to create a playlist of sorts beforehand. Participants had similar comments on the filter interaction. P12: *"It's nice to have photo filters without the smartphone, but we can't really have all the filter options here. Maybe voice commands have these easter-eggs that we can have fun with."*

Tangible for low-frequency, low-interfering actions

Participants brought up the issue that physical manipulation interactions, while cumbersome, are naturally part of the album, but reuse interactions are not and thus they interfere with the physical experience. P15: "(Tangible) stays more true to real

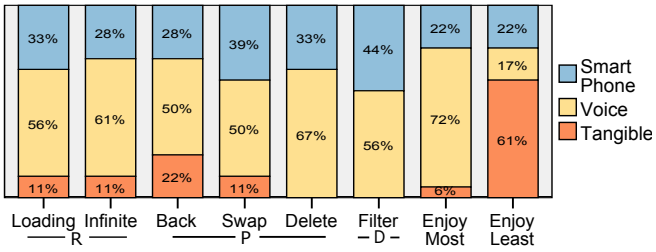

Figure 12. Participant Preferences in second study

life and I find it cool to turn the photo and see the information. I won't perform swapping or deleting too much, so it will feel nice when I do". P4: *"Changing orientation and stuff, I think I'll be afraid to handle the album freely if I know that turning it will open some other thing."* Participants had similar comments highlighting this midas touch issue. P6: *"If I'm giving the album to someone else and it rotates, then that's a problem."*

DISCUSSION

Design Guidelines for Replicate and Reuse

Based on our iterative processes and evaluations, we offer guidelines for designing for replicate and reuse: 1) Browsing Interactions should replicate the physical browsing experience. This is a core requirement for replication. 2) For Physical Manipulation Interactions, we should adhere to their physical analogues as much as possible. However, we need to consider if replicating the physical analogues compromises the object. E.g., physically swapping photos is fine, but physically removing a photo would not be fine. 3) For Reusing Interactions, there are no physical analogues and so we turn to additional tangible gestures with the object, or use other modalities voice, smartphone. There are two things one needs to consider here - a) does the new modality requires the user to switch contexts (e.g., switching to a phone vs voice), b) does the reusing interaction (or even the physical manipulation interaction) interfere with the physical experience (e.g., rotating the album or virtual buttons on the album do not require a context switch but may interfere with the experience).

Design Insights on Interaction Modalities

The photo album investigations lead us to the following insights: 1) Voice+Deictic gestures offer a nice middle-ground for reusing and physical manipulation interactions since it does not interfere with physical browsing interactions and at the same time does not force the user to switch to another device. 2) However, voice may not be suitable for digital manipulation interactions beyond simple manipulations. Thus, an application that enables users to curate their physical experience beforehand using a dedicated device such as the smartphone will be useful. 3) Tangible interactions for reuse cause interference in the physical experience. However, tangible interactions for physical manipulation, while cumbersome, are non-interfering and preferred by certain users. While these insights can apply more generally for most physical media objects, our investigation also demonstrates the way forward for designers to conduct specific case-by-case explorations. 4) Since user preferences vary, one should consider redundant support for interactions (e.g., user can choose to swap photos physically, using voice, or smartphone).

Design Insights on Real-world Use

Our purpose in this paper is to not show that such physical-digital experiences may be better than physical only or digital only experiences but to propose it as an alternative for people who may at times desire physical experiences for their digital content. As our study found, people do find these experiences useful and fun. The results from the first study indicate multiple directions for design explorations of such experiences: 1)

Designing for personal use: Users viewed the prototypes as single-purpose relaxed use objects to be used without distraction as opposed to getting digital content at once in a single device. This involves giving users the control to customize the operations and interactions they want. 2) *Designing for shared, but private use*: Users found value in imagining shared experiences with a friend or family member. This requires exploration into shared augmented views and how shared interactions on the same object may work. 3) *Designing for non-tech savvy users*: User feedback highlighted how such experiences can be of great use in helping non-tech savvy users such as older adults if they are constrained and curated properly. 4) *Designing for public use*: How would a public augmented bookshelf be designed so that multiple users can interact with it? This involves exploring the questions around multi-user interaction and how replicate and reuse would work there. While designing for these scenarios, there are multiple aspects of use that are to be taken into account - aesthetic tangibility and how much of it is desired, the disposability (and recyclability), and digital access.

Technical Challenges

Technology needs to mature for such experiences to truly be inseparable from physical ones in various aspects. For AR glasses and marker tracking, this means the following: 1) lighter-smaller glasses, 2) large FOVs, 3) marker tracking improvements including 3.1) occlusion robustness for when fingers occlude the markers, 3.2) invariance to lighting conditions, robust thin marker support (for book spines for example), 3.3) depth mapping for markers to display overlapping images correctly (as in the cards demo), and 3.4) solving hands getting overlaid with the augmentation when they are not supposed to. We experimented with non-marker tracking by taking a regular album and scanning its photos to serve as markers. The recognition robustness depended highly on the photo. However, if this works consistently, then regular physical media objects could be used for overlaying content simply by scanning them. We explored physical objects with 2D flat marker surfaces that most physical media objects have. Exploring 3D scenarios, for instance, lego bricks that can change themes just like the puzzle, may be an interesting technical challenge.

Shared Use

Different contexts require different designs. As an example of how one would approach the design in such contexts, we provide an example on how a photo album could support shared use. Assuming two users look at an album together, the experience should mirror a shared physical album. This requires the two AR glasses to communicate in real-time. One user is the designated owner whose digital collection is linked to the album. The owner gives access to the guest. The guest can browse and perform physical actions such as swapping photos. As long as the actions happen in the FOV of one of the cameras, changes are propagated to other glasses. Orientation dependent actions, if supported, happen relative to the owner's camera. For modalities such as voice, owner can give reuse interaction privileges to the guest.

CONCLUSION

We investigated the interaction design questions pertaining to using a single physical media object to provide the physical experience for all corresponding digital content. We define the design problem, and build a wholly-tangible physical album prototype, plus several other prototypes including a bookshelf, newspaper, research paper, card-deck, and jigsaw-puzzle. We conducted a study that informed us on their utility and on the use of the wholly-tangible physical album. We further conducted a second study that compared three modalities of input and analyzed the trade-offs between tangibility, usability, and enjoyment. Finally, we summarized the design insights and discussed future directions. The reinstrumentation of physical objects for digital purposes is emerging as a strong direction for augmented reality applications. We believe our work opens a dialogue in this space on how to bring back our physical experiences while retaining the digital scale and flexibility.

ACKNOWLEDGEMENTS

This work made possible by the NSERC USRA Program for undergraduate research, NSERC Discovery Grant 2018-05187, the Canada Foundation for Innovation Infrastructure Fund 33151 "Facility for Fully Interactive Physio-digital Spaces," and Ontario Early Researcher Award ER16-12-184.

REFERENCES

[1] Anand Agarawala and Ravin Balakrishnan. 2006. Keepin' It Real: Pushing the Desktop Metaphor with Physics, Piles and the Pen. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06)*. ACM, New York, NY, USA, 1283–1292. DOI: http://dx.doi.org/10.1145/1124772.1124965

[2] W Ark, Christopher Dryer, T Selker, and Shumin Zhai. 2018. Representation Matters: The Effect of 3 Dimensional Objects and Spatial Metaphor in a Graphical User Interface. (04 2018).

[3] Oriel Bergig, Eyal Soreq, Nate Hagbi, Kirill Pevzner, Nati Levi, Shoham Blau, Yulia Smelansky, and Jihad El-Sana. 2011. Out of the Cube: Augmented Rubik's Cube. *Int. J. Comput. Games Technol.* 2011 (2011), 1–7. DOI:http://dx.doi.org/10.1155/2011/570210

[4] Mark Billinghurst, Hirokazu Kato, and Ivan Poupyrev. 2001. The MagicBook: a transitional AR interface. *Comput. Graph.* 25, 5 (oct 2001), 745–753. DOI: http://dx.doi.org/10.1016/S0097-8493(01)00117-0

[5] Mark Billinghurst, Hirokazu Kato, Ivan Poupyrev, and others. 2008. Tangible augmented reality. *ACM SIGGRAPH ASIA* 7 (2008).

[6] M. Billinghurst, S. Weghorst, and T. Furness. 1998. Shared space: An augmented reality approach for computer supported collaborative work. *Virtual Reality* 3, 1 (01 Mar 1998), 25–36. DOI: http://dx.doi.org/10.1007/BF01409795

[7] John Brooke and others. 1996. SUS-A quick and dirty usability scale. *Usability evaluation in industry* 189, 194 (1996), 4–7.

[8] VP Curtis. 2011. Photographic memory: The album in the age of photography. (2011). https://scholar.google.ca/scholar?hl=en

[9] R Dachselt and S Al-Saiegh. 2011. Interacting with printed books using digital pens and smart mobile projection. *Proc. Work. Mob. ...* (2011). http://old-v1.imld.de/forschung/publikationen/data/2011/2011-CHI-ProjectiveAugmentedBooks.pdf

[10] Pierre Dragicevic. 2004. Combining Crossing-based and Paper-based Interaction Paradigms for Dragging and Dropping Between Overlapping Windows. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology (UIST '04)*. ACM, New York, NY, USA, 193–196. DOI: http://dx.doi.org/10.1145/1029632.1029667

[11] M. Fjeld and B. M. Voegtli. 2002. Augmented Chemistry: an interactive educational workbench. In *Proceedings. International Symposium on Mixed and Augmented Reality*. 259–321. DOI: http://dx.doi.org/10.1109/ISMAR.2002.1115100

[12] Raphael Grasset, Andreas Duenser, Hartmut Seichter, and Mark Billinghurst. 2007. The mixed reality book. In *CHI '07 Ext. Abstr. Hum. factors Comput. Syst. - CHI '07*. ACM Press, New York, New York, USA, 1953. DOI: http://dx.doi.org/10.1145/1240866.1240931

[13] J. Han, S. Heo, H. E. Lee, and G. Lee. 2014. The IrPen: A 6-DOF Pen for Interaction with Tablet Computers. *IEEE Computer Graphics and Applications* 34, 3 (May 2014), 22–29. DOI: http://dx.doi.org/10.1109/MCG.2014.19

[14] Anuruddha Hettiarachchi and Daniel Wigdor. 2016. Annexing Reality: Enabling Opportunistic Use of Everyday Objects As Tangible Proxies in Augmented Reality. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 1957–1967. DOI: http://dx.doi.org/10.1145/2858036.2858134

[15] Terje Hillesund. 2010. Digital reading spaces: How expert readers handle books, the Web and electronic paper. *First Monday* 15, 4 (apr 2010). DOI: http://dx.doi.org/10.5210/fm.v15i4.2762

[16] David Holman, Roel Vertegaal, Mark Altosaar, Nikolaus Troje, and Derek Johns. 2005. Paper Windows: Interaction Techniques for Digital Paper. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '05)*. ACM, New York, NY, USA, 591–599. DOI: http://dx.doi.org/10.1145/1054972.1055054

[17] Hyun-Tae Jeong, Dong-Woo Lee, Gi-Su Heo, and Cheol-Hoon Lee. 2012. Live Book: A mixed reality book using a projection system. In *2012 IEEE Int. Conf. Consum. Electron.* IEEE, 680–681. DOI: http://dx.doi.org/10.1109/ICCE.2012.6162026

[18] Sylvia Irawati, Scott Green, Mark Billinghurst, Andreas Duenser, and Heedong Ko. 2006. An Evaluation of an Augmented Reality Multimodal Interface Using Speech and Paddle Gestures. Springer, Berlin, Heidelberg, 272–283. DOI:http://dx.doi.org/10.1007/11941354_28

[19] Maria Karam and M. C. Schraefel. 2005. *A taxonomy of gestures in human computer interactions*. Technical Report.

[20] H. Kato, M. Billinghurst, I. Poupyrev, K. Imamoto, and K. Tachibana. 2000. Virtual object manipulation on a table-top AR environment. In *Proceedings IEEE and ACM International Symposium on Augmented Reality (ISAR 2000)*. 111–119. DOI: http://dx.doi.org/10.1109/ISAR.2000.880934

[21] KAWASHIMA and T. 2001. Magic Paddle : A Tangible Augmented Reality Interface for Object Manipulation. *Proc. 2nd Int. Symp. Mix. Reality, 2001* (2001). https://ci.nii.ac.jp/naid/10022426812

[22] Eike Kleiner, Roman Rädle, and Harald Reiterer. 2013. Blended shelf. In *CHI '13 Ext. Abstr. Hum. Factors Comput. Syst. - CHI EA '13*. ACM Press, New York, New York, USA, 577. DOI: http://dx.doi.org/10.1145/2468356.2468458

[23] Gun A. Lee, Mark Billinghurst, and Gerard Jounghyun Kim. 2004. Occlusion based interaction methods for tangible augmented reality environments. In *Proc. 2004 ACM SIGGRAPH Int. Conf. Virtual Real. Contin. its Appl. Ind. - VRCAI '04*. ACM Press, New York, New York, USA, 419. DOI: http://dx.doi.org/10.1145/1044588.1044680

[24] Gun A. Lee, Gerard J. Kim, and Mark Billinghurst. 1. Interaction Design for Tangible Augmented Reality Applications. In *Emerg. Technol. Augment. Real.* IGI Global, 261–282. DOI: http://dx.doi.org/10.4018/978-1-59904-066-0.ch013

[25] David Lindlbauer, Jörg Mueller, and Marc Alexa. 2017. Changing the Appearance of Real-World Objects By Modifying Their Surroundings. In *Proc. 2017 CHI Conf. Hum. Factors Comput. Syst. - CHI '17*. ACM Press, New York, New York, USA, 3954–3965. DOI: http://dx.doi.org/10.1145/3025453.3025795

[26] Julian Conrad Alan Looser. 2007. Ar magic lenses: Addressing the challenge of focus and context in augmented reality. (2007).

[27] George Margetis, Xenophon Zabulis, Panagiotis Koutlemanis, Margherita Antona, and Constantine Stephanidis. 2013. Augmented interaction with physical books in an Ambient Intelligence learning environment. *Multimed. Tools Appl.* 67, 2 (nov 2013), 473–495. DOI: http://dx.doi.org/10.1007/s11042-011-0976-x

[28] Chris McDonald and Gerhard Roth. 2003. *Replacing a mouse with hand gesture in a plane-based augmented reality system*. National Research Council of Canada.

[29] H Mehmet. 2016. The classification of augmented reality books: a literature review. In *Proceedings of INTED2016 Conference*. 4110–4118.

[30] Meta 2. 2018. Augmented Reality Glasses. (2018). https://www.metavision.com/

[31] Thomas Pietrzak, Sylvain Malacria, and Éric Lecolinet. 2012. S-Notebook: Augmenting Mobile Devices with Interactive Paper for Data Management. In *Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '12)*. ACM, New York, NY, USA, 733–736. DOI: http://dx.doi.org/10.1145/2254556.2254696

[32] Ben Piper, Carlo Ratti, and Hiroshi Ishii. 2002. Illuminating clay. In *Proc. SIGCHI Conf. Hum. factors Comput. Syst. Chang. our world, Chang. ourselves - CHI '02*. ACM Press, New York, New York, USA, 355. DOI:http://dx.doi.org/10.1145/503376.503439

[33] POUPYREV and I. 2001. Tiles : A Mixed Reality Authoring Interface. *Human-Computer Interact. INTERACT'01* (2001). https://ci.nii.ac.jp/naid/10020982585/

[34] A. Rauber and H. Bina. 1999. A metaphor graphics based representation of digital libraries on the World Wide Web: using the libViewer to make metadata visible. In *Proceedings. Tenth Int. Work. Database Expert Syst. Appl. DEXA 99*. IEEE, 286–290. DOI: http://dx.doi.org/10.1109/DEXA.1999.795181

[35] ShelvAR. 2013. ShelvAR. (2013). http://www.shelvar.com/

[36] Jinwook Shim, Yoonsik Yang, Nahyung Kang, Jonghoon Seo, and Tack-Don Han. 2016. Gesture-based interactive augmented reality content authoring system using HMD. *Virtual Reality* 20, 1 (2016), 57–69.

[37] Carol Tenopir, Donald W. King, Sheri Edwards, and Lei Wu. 2009. Electronic journals and changes in scholarly article seeking and reading patterns. *Aslib Proc.* 61, 1 (jan 2009), 5–32. DOI: http://dx.doi.org/10.1108/00012530910932267

[38] Lucia Terrenghi, David Kirk, Abigail Sellen, and Shahram Izadi. 2007. Affordances for manipulation of physical versus digital media on interactive surfaces. In *Proc. SIGCHI Conf. Hum. factors Comput. Syst. - CHI '07*. ACM Press, New York, New York, USA, 1157. DOI: http://dx.doi.org/10.1145/1240624.1240799

[39] E. J. Umlauf, H. Piringer, G. Reitmayr, and D. Schmalstieg. 2002. ARLib: the augmented library. In *The First IEEE International Workshop Agumented Reality Toolkit,*. 2 pp.–. DOI: http://dx.doi.org/10.1109/ART.2002.1106996

[40] Nancy A. Van House. 2011. Personal photography, digital technologies and the uses of the visual. *Vis. Stud.* 26, 2 (jun 2011), 125–134. DOI: http://dx.doi.org/10.1080/1472586X.2011.571888

[41] Vuforia. Vuforia | Augmented Reality. (????). https://www.vuforia.com/

[42] Pierre Wellner. 1993. Interacting with Paper on the DigitalDesk. *Commun. ACM* 36, 7 (July 1993), 87–96. DOI:http://dx.doi.org/10.1145/159544.159630

[43] David West, Aaron Quigley, and Judy Kay. 2007. MEMENTO: a digital-physical scrapbook for memory sharing. *Personal and Ubiquitous Computing* 11, 4 (01 Apr 2007), 313–328. DOI: http://dx.doi.org/10.1007/s00779-006-0090-7

[44] J. Wijnen and E.A.W.H. van den Hoven. 2011. Connected sketchbook : linking digital files to physical pages. (2011). http://repository.tue.nl/730757

[45] Chih-Sung (Andy) Wu, Susan J. Robinson, and Ali Mazalek. 2008. Turning a page on the digital annotation of physical books. In *Proc. 2nd Int. Conf. Tangible Embed. Interact. - TEI '08*. ACM Press, New York, New York, USA, 109. DOI: http://dx.doi.org/10.1145/1347390.1347414

[46] Po-Chen Wu, Robert Wang, Kenrick Kin, Christopher Twigg, Shangchen Han, Ming-Hsuan Yang, and Shao-Yi Chien. 2017. DodecaPen: Accurate 6DoF Tracking of a Passive Stylus. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology (UIST '17)*. ACM, New York, NY, USA, 365–374. DOI: http://dx.doi.org/10.1145/3126594.3126664