A Systematic Literature Review of Paper Prototyping

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User-centered design is an imperative method in testing the feasibility of software before committing to a permanent model. Research teams are utilizing paper designs as a medium for tangible interactions to determine how to visually organize a potential system. Paper prototyping permits the flexibility to select, rearrange, and discard various levels of information to be displayed to the participants. Valuable understandings can be garnished through the use of realistic scenarios to assist designers in designating the appropriate approach to compliment their framework. This paper presents an analysis of pertinent literature that investigates the utilization of paper prototyping within the developmental stage of a user study. Furthermore, this work discusses common themes, concepts, and challenges that have been observed during previous fundamental paper prototyping studies. Lastly, this work highlights state-of-the-art prototyping styles, evaluation methods, and offers insights on ways to address current challenges relevant to the field.

CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

Additional Key Words and Phrases: paper prototyping, systematic, review, analysis

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1 INTRODUCTION

Paper prototyping is a common low-fidelity technique for building user interfaces and performing usability testing before the software implementation phase. This approach is mostly applied by designers, developers, and researchers as a reliable, simple, and low-cost way of determining possible problems with the user interface or the user experience. The process involves many possible users representing the target audience and an interactive activity where they either build or evaluate an interface. These activities can be individual or team efforts, and the users are given materials (e.g. paper, cardboard, scissors, etc.) with which to operate. Early research on paper prototyping discusses the usefulness of the technique since it can help increase quality while reducing the development iterations [M. Rettig. Prototyping for tiny fingers. Commun. ACM, 37(4):21–27, 1994.]. The use of paper prototyping has evolved since then, with technology improvements and research advances there are a myriad of contexts that leverage this approach.

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Early research in the field discusses the usefulness of low-fidelity prototypes for specific purposes. Even though high-fidelity prototypes are still useful in their own regard due to their interactivity and design close to the final product (Low vs. high-fidelity prototyping debate, Jim Rudd, Ken Stern, and Scott Isensee. 1996. Low vs. high-fidelity prototyping debate. interactions 3, 1 (Jan. 1996), 76–85. DOI:https://doi.org/10.1145/223500.223514), low-fidelity approaches allow for proof-of-concepts where it is feasible to understand possible functionality issues or layout considerations in order to improve the experience. Paper prototyping is prominent in professional settings, being a cost-effective way for companies and small businesses to test their products [4, 53]. Moreover, the technique is applied in many contexts such as education [44, 50], software design and development {Walsh2010, Ollila2008, software testing [15, 24], healthcare [10], and more. Also, paper prototyping is being explored as a companion technique to modern technologies such as Virtual and Augmented Reality (VR/AR) [33].

This research area has been thoroughly explored throughout the years. However, there is a lack of in-depth analysis on current studies involving paper prototyping. This review aims to explore existing literature studying paper prototyping and its applications. This work will be based on four main research questions. RQ1: What are the objectives and contexts in which studies apply paper prototyping? This first question will allow researchers to understand where paper prototyping is being applied. The objective is to find the contexts in which the technique has been implemented, analyze why it is an important methodology for that specific use case, and present statistics along with in-depth discussions of the findings. RQ2: What are the materials implemented in paper prototyping activities? Paper prototyping has multiple important components, from the target audiences to the design objectives. However, the literature seeks to understand which materials are the most effective to connect the user to the experience. Paper is not the only type of material, multiple studies show the use of crayons, pencils, pens, cardboard, and more; in an attempt to find more creative outcomes and effective tools. Therefore, this review will present the most prominent materials, how they are applied, and discussions on their usefulness for each activity. RQ3: What are the challenges presented by paper prototyping applications? Finally, it is important to acknowledge current problems or challenges that arise during the creation of such prototypes or during their utilization. This literature review will compile the current challenges presented by existing studies, the reasons why they are considered challenges, and discussions on possible solutions given by the community.

2 METHODOLOGY

This section discusses the process undertaken to search, include, exclude, and analyze the papers for the review. We detail the steps taken during the exploration of articles including keywords, terms, filters, sorting preferences, tags, and more (See Figure 1). Moreover, a criterion is presented as the referenced resource throughout the research process to include or exclude papers. Finally, an overview of the analysis methods are described in the section.

2.1 Search

In this section, the search process is presented. The following contains information on primary resources and configurations used during the overall procedure. For example, resources refer to the specific online databases in which the queries were submitted, while the configuration alludes to the keywords and filters applied to the search.

This SLR contains papers from a total of databases, these include ACM Digital Library (DL), IEEE Xplore (?) … These selected articles were not refined to be from any specific journal or conference, however, the final selection did include papers from both types of venues. After initial results, prominent conferences were identified: Conference on Human Factors in Computing Systems (CHI),

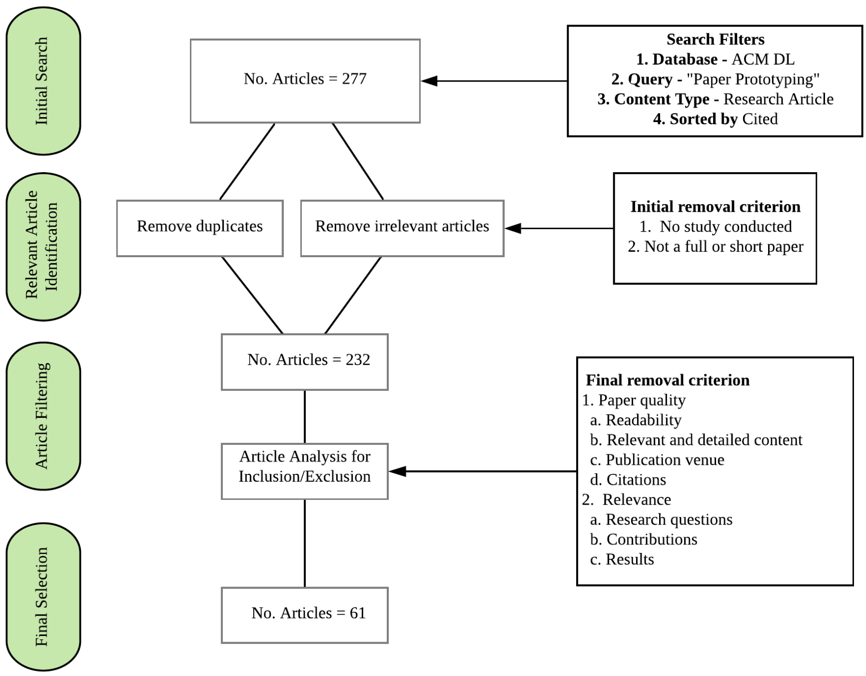

Fig. 1. Methodology for the inclusion and exclusion of articles in the literature review.

Interaction Design and Children (IDC), Designing Interactive Systems (DIS), Computer Science Education (SIGCSE), and Innovation and Technology in Computer Science Education (ITCSE). From the same cluster of articles, very common journals were also identified: Transactions on Computer-Human Interaction (TOCHI), Journal of Usability Studies, Journal of Computing Sciences in Colleges, Personal and Ubiquitous Computing, and Transactions on Computing Education (TOCE).

Another important component of the search process were the keywords. These were compiled during the research, as papers were identified the keywords provided by the authors were considered for expanding the queries. With the main topic being paper prototyping, that term was utilized in every search query along with complimentary words or phrases. For example, the goal of this research topic is to educate through the use of paper prototyping, therefore an important term to consider is education. We also leveraged the use of similar words or related topics, e.g. education or learning or instruction or pedagogy. One of the main search queries used in this review was paper prototyping + education which yielded an initial count of 196 papers. This represents the raw results of the query search, without future amendments in configurations or filtration through the inclusion/exclusion criteria.

Finally, a necessary set of configurations was implemented during the search procedure. This includes the use of filters, tags, sorts, and more. For example, in ACM the search was narrowed through the filter labeled as content type which indicates if a publication is a full paper or a panel paper. In this specific review, we are not including panel papers (details on this can be found in the selection criteria section). Another example is the use of year ranges since our interest is in recent research, there is no need to include papers from before a certain year.

2.2 Selection Criteria

This section presents a set of criteria used during the literature review to include or exclude papers in the final count. Such a set of rules is important to maintain a rich group of papers relevant to the topic and easily detecting outliers that could affect the results. The selection criteria are presented and explained in detail below.

Papers to be included in this work must be full or short papers presented in a conference as part of their proceedings or published in a journal. Articles labeled as tutorials, panel papers, workshops, posters, or abstract will not count towards the final count. Another inclusion criterion is the publication date since the review is on recent research. It is important to keep in mind that this SLR will include papers from 2006 to 2020 (time of this review). These previous criteria are specified as the more technical ones, from the perspective of search configurations where they do not require analysis or deep understanding of the articles. However, the following criteria target a more in-depth approach to including or excluding these papers, since they require researchers to find important aspects through a thorough analysis.

The papers need to comply with good quality. There are various ways to identify this criteria, and in this review we used the following: writing, content, venue, and acceptance. The quality of a paper can be seen directly through the writing style, grammar, syntax, and overall structure of the work. These papers must be well-presented, easy to read, and understandable. Moreover, the content they present is another indicator of quality, since there could be papers with promising ideas but not great execution or delivery. The venue in which the article is published influences the acceptance a paper might get from the community, therefore it is significant to explore both characteristics. Reviewed articles shall be relevant to the current reviewed topic. This feature can be detected through the thorough analysis of a paper's core idea, research questions, and results. Most times, the title of a paper can be deceiving since there are many terms used in similar areas. Therefore, a very important aspect of this review is to carefully read the papers, identify their goals, research objectives, and analyze the results. This way, the overall work can be correctly classified as relevant or non-relevant to the current topic.

Papers that did not follow the inclusion criteria mentioned above were automatically excluded from the final selection. These articles were not completely unused, since, unless they were irrelevant to the topic, they are related to the overall goal of this review and did serve a purpose as background information. Therefore, they were implemented as part of the related work section and as general knowledge for the rest of the review.

3 ANALYSIS

3.1 Research Trends

This section explores the publication statistics for articles in the paper prototyping research community. Out of the 277 articles found in the database, a total of sixty one (61) were selected as the final group to review. Based on the final selection, publications range from 2006 to 2019, with a trend on paper prototyping research. Figure 2 Experiments in the field seem to have started in 2006, even though there are publications from before that year that focus on theoretical research. From the initial year to 2008, there was a publication increase, bringing the total of publications to eight papers (13%) in three years. The year 2009 showed a small setback with only three publications, but research interest in the field was climbing as 2010 became the best year (tied with 2012) in terms of research articles for paper prototyping with eight papers in one year. The most publications in the field are presented between 2010 to 2014 with a total of twenty eight articles (46%). In 2015, there was a decrease in publications, but from 2016 to 2019 the article count stays consistent.

Conference or Journal Name	Article(s)	Count
Conference on Human Factors in Computing Systems (CHI)	[5, 12, 18, 26, 27, 33, 34, 36, 38, 39, 46, 51, 60]	13
Interaction Design and Children (IDC)	[24, 31, 32, 37, 55]	5
Engineering Interactive Computing Systems (EICS)	[4, 11, 25, 43]	4
Computer-Human Interaction of Australia (OZCHI)	[16, 19, 23, 61]	4
Tangible and Embedded Interaction (TEI)	[30, 54]	2
International Conference on PErvasive Technologies Related to Assistive Environments (PETRA)	[15, 45]	2
Others	[1–3, 6–10, 13, 14, 17, 20–22, 28, 29, 35, 40–42, 44, 47–50, 52, 53, 56–59]	31 (1 each)

Table 1. Reviewed articles published in conferences.

Another analysis performed to understand the publication data in the area includes articles per venue. The literature review focuses on publications in the ACM DL, however there are many possible venues where the topic could fit. Therefore, Table 1 is created to identify the different communities that include paper prototyping. Studies in paper prototyping are mostly published in the Conference on Human Factors in Computing Systems (CHI) with a total of thirteen articles (21%). The second venue with most publications in the field is Interaction Design and Children (IDC) with five articles (8%). The third venue with most publications is a tie between Engineering Interactive Computing Systems (EICS) and Computer-Human Interaction of Australia (OZCHI) with four articles each (7%). The fourth venue with most publications is another tie between Tangible and Embedded Interaction (TEI) and PErvasive Technologies Related to Assistive Environments (PETRA) with two articles each (3%). The rest of the venues are all tied with one article each (2%), including Ubiquitous Computing (UbiComp), Computer Science Education (SIGCSE), Human Computer Interaction with Mobile Devices and Services (MobileHCI), Computer-Human Interaction in Play (CHI PLAY), Intelligent User Interfaces (IUI), Journal of Usability Studies, and more.

This section focuses on the understanding of the publications in the area of paper prototyping. Studies started in the year 2006, with an increase in the subsequent three years. In 2010, the field got its biggest number of contributions with eight publications (13%) that year alone. After that increment in research interests, the article count remains consistent until the year 2019. The Human-Computer Interaction (HCI) community seems to be the most engaged in studies involving paper prototyping, with CHI identified as the venue with most publications in this area. Nonetheless, the remaining venues involve mainly HCI-focused researchers.

3.2 RQ1: What are the objectives and contexts in which studies apply paper prototyping?

This first question will allow researchers to understand where paper prototyping is being applied. The objective is to find the contexts in which the technique has been implemented, analyze why it is an important methodology for that specific use case, and present statistics along with in-depth discussions of the findings. This literature review explores the contexts in which each article applied paper prototyping to understand the possible needs and current trends. The research area is interdisciplinary, being versatile in different applications and fields. This is presented by

Objective Category	Article(s)	Count	Percentage
Simplicity (Redesign)	[1–6, 8, 11, 16, 17, 19, 22, 23, 25, 26, 28–31, 43, 45, 48, 49, 53, 56, 58, 61]	27	44.26%
Prototype Testing	[3, 6, 9, 14, 15, 20, 21, 27, 30–32, 34, 35, 39, 40, 43, 45–47, 51–53, 55–57, 59]	26	42.62%
Building Prototypes	[5, 6, 9–11, 17–21, 30, 38, 41, 46, 48, 49, 51–54, 57, 59–61]	24	39.34%
Engagement/Interaction	[2, 4, 7, 10, 12, 13, 22, 24, 29, 32, 36–38, 44, 50, 54, 55, 57, 60]	19	31.15%
Learning Tools	[2, 3, 6, 8–10, 12, 17, 23, 25, 28, 30–32, 35, 41, 44, 49, 58]	19	31.15%
Influence	[2, 9, 15, 17, 19, 24, 28, 35, 36, 41, 44–46, 48–50, 56]	17	27.87%
App Design/Development	[4, 11, 22, 26, 27, 29, 32, 33, 36, 39, 42, 48, 50, 59, 60]	14	22.95%
Enhance Experience	[4, 7, 10, 12, 18, 20, 26, 29, 33, 42–44, 48]	13	21.31%
Compare	[1, 13, 20, 22, 27, 29, 34, 40, 47, 49, 55, 58]	12	19.67%
Low-Fidelity	[11, 13, 20, 24, 26, 27, 33, 42, 43, 54]	10	16.39%
Game Design and Development	[8, 15, 37, 41, 47, 55, 57]	7	11.48%
Automatic Extraction	[5, 22, 26, 39, 54, 57]	6	9.84%
Easy to Use	[4, 5, 18, 33]	4	6.56%
Participatory Design	[10, 32, 37, 60]	4	6.56%

Table 2. Objectives from reviewed articles.

the analyzed data, with seven (7) main context categories selected during the analysis since they comprise a 95% of the publications. These are Health, Communication, User Interface/Experience (UI/UX) Design, Augmented/Virtual Reality (AR/VR), Research, Workforce, and Education. However, the review identified a total of ten different context categories across the sixty articles, leaving three remaining categories with one publication each: Environment, Authoring Stories, and Security. This section will discuss trends for research contexts, publication statistics, and applications of each category. Statistics are rounded up and the categories include overlapping articles, therefore there are multiple articles included in different categories.

The analysis results show that paper prototyping is mostly implemented in the UI/UX Design research area (see Table 3), with the overwhelming majority of articles leveraging the technique to create better interfaces and experiences during their use. This review identified thirty five papers (57%) applying paper prototyping in their studies. The second most prominent category is research, referring to the study of paper prototyping for an understanding of application techniques, evaluation methods, and more. This category presents nineteen articles (31%) exploring the uses of paper prototypes. Moreover, the educational context is the third most consistent with thirteen articles (21%). Not surprisingly, paper prototyping is being included in learning environments, being a great introduction to multiple activities due to its straightforward, convenient, and effective process. The communication category presents a total of six articles (10%), with paper prototyping serving as a tool for improving social interactions during the creation of the prototypes or in the

Context Category	Article(s)	Count
UI/UX Design	[3, 4, 8–11, 13, 15, 18–20, 22, 25–29, 31, 33, 34, 37–40, 43, 45–47, 49, 50, 52, 54, 55, 60, 61]	35
Research	[1, 2, 5, 7, 11, 12, 16, 20, 24, 25, 34, 37, 42, 44, 49, 51, 52, 58, 59]	19
Education	[2, 12, 14, 17, 23, 30–32, 36, 41, 44, 50, 58]	13
Communication	[7, 10, 19, 40, 56, 60]	6
AR/VR	[6, 30, 33, 45, 46]	5
Workforce	[4, 45, 53]	3
Health	[3, 10, 21]	3

Table 3. Articles published and their context categories.

final products. Then, AR/VR which contains five articles (8%), exploring the use of this prototyping technique to improve interactivity with either a virtual environment, or between the virtual and real world. Finally, workforce and health are tied with three articles each (5% respectively), having articles study the usefulness of paper prototyping in the industry and healthcare environments.

Figure 2 provides an overview of publications per year from each context. This review's final selection ranges in publications from 2006 to 2019. Starting in 2006, *UI/UX Design* is studied consistently with the category being the only article from that year, having its maximum number of articles in 2010 with seven (7), and being present every year except for 2015. Then, in 2007 the research community started exploring more in-depth aspects of the paper prototyping methodologies, and the first publication for the *research* category appeared. This also remained consistent, with articles published every year except in 2006, 2009, 2015, and 2019. The maximum number of research papers for this category is four (4) in 2012. *Educational* contexts began implementing paper prototyping techniques in 2008, with ten (10) out of the thirteen (13) total articles being published in the span of five (5) years, from 2008 to 2012. The rest of the context categories are present in various years, with no prominent quantities, however they are consistently explored throghout the literature.

3.2.1 UI/UX Design. Paper prototyping proves usefulness in the design of digital interfaces. The literature shows many articles implementing systems that leverage the creation of hand-drawn (or crafted) prototypes to automatically generate user interfaces. Based on the analysis, this represents the most prominent application of the technique, providing effective translations from physical-based creations to the digital environment. In [39], the authors create a tool called FrameWire, that receives paper prototype recorded frames from tests as input and semi-automatically produces an interactive digital version. The application uses computer vision techniques to extract features from the interface (e.g. fields, buttons, layouts, etc.), along with user click detection, and screen frame similarities. The authors take the extracted features and create a hierarchical cluster of the frames to understand similarities between the frames. Moreover, [27] presents the creation of a tool that, similarly, receives hand-drawn sketches of a user interface to generate interactive components as HTML pages. However, this article does not use advanced analysis techniques (e.g. computer vision) and the input is static instead of continous frames from testing recordings. Furthermore, in [33] the authors create a toolkit leveraging AR technologies to translate the real-life low-fidelity prototypes into interactive digital interfaces. All of the aforementioned articles show a trend in the research community to apply paper prototyping to the automated generation of interactive

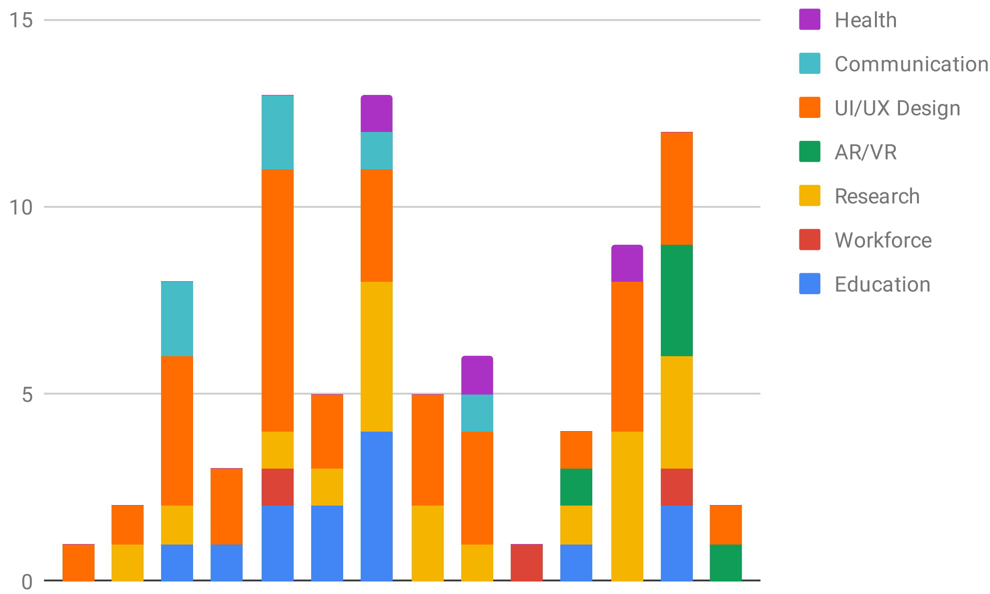

Fig. 2. Contexts categories published per year.

UIs. Currently, there are many high-fidelity prototyping tools, but they require time and expertise to allow for efficient design processes. Therefore, low-fidelity approaches are being explored as a solution, providing users with the ability to quickly sketch their ideas and automatically (or semi-automatically) generate interactive interfaces. This improves the process efficiency, and increases the accessibility for novice programmers and designers.

3.2.2 Research. Multiple other articles present the implementation or analysis of paper prototyping in research contexts. This category refers to the critical analysis from articles exploring the uses, possibilities, and approaches to paper prototyping in the research community. For example, [24] presents the study of paper circuitry in paper prototypes as a method to improve engagement of children during play-testing sessions. The article investigates the possible influences of interactivity in low-fidelity prototypes during testing sessions for children, since it could become difficult to maintain their attention for long periods of time with static objects. The authors explore the addition of buttons and lights for the prototype components, providing interactivity and feedback during the tests. However, in [51], the authors create a tangible user interface using paper and wood as their materials for the elderly to evaluate their experience with the product. In this case, the paper prototypes were used to further explore the experience of elderly users with the interface, providing an understanding of the feasibility, usefulness, and simplicity of tangible components for the studied audience. Bousseau et al. [5] leverage paper prototyping activities to study novice designers and their ability to perform collaborative tasks and finalize a concept through the application of hands-on materials. This study discusses design concepts and collaborative processes between participants, but utilizes the paper prototyping approaches to achieve the understanding of interactions between users. In summary, paper prototyping techniques are included in many research contexts to provide deep analysis on different audiences, interactivity, interface evaluations, user performance, and more. The research community is consistently investigating how to improve paper prototyping approaches while exploring the effectiveness of implementing the techniques in current studies.

3.2.3 Education. Another prominent context category is education, where articles study the use of paper prototypes for learning or teaching purposes. The implementation of such technique is exclusively associated to its use during educational activities. Robinson and Pérez-Quiñones [50] explore ways to change the perception of computer science for middle school girls. In this case, the authors do not focus on teaching any specific topics on any subject, however they utilize the paper prototyping techniques as a bridge between the tangible physical world and the computing field. Such an approach is common between many of the reviewed articles. However, in [23] the authors explore Research-through-Design (RtD), an idea that proposes the generation of knowledge through design. The work focuses on contributing principles for RtD-based teaching, where they use design activities to teach students, leading to them generating knowledge through the interaction process. Some activities leverage paper prototyping techniques for students to sketch design ideas and conduct testing. In this study, the authors do not build a bridge using paper prototyping as in the first example, but they do create activities that take advantage of the technique for student learning gains. Another example is [17], an article that studies Visual Thinking (VT) approaches applied to Computational Thinking (CT) design phases for students (K-12) to improve their communication, brainstorming processes, and overall design outcomes. To facilitate students' design activities, the authors explored the literature and decided that paper prototyping would be suitable to easily introduce the concepts to each group (elementary, middle, and high school). In [30] the authors study the use of both AR visualizations with low-fidelity prototypes to help students learn. This allows the learner to manage physical objects, receive feedback, and later conduct their personalized experiemnts using simulations. These examples show the usefulness of paper prototyping implementations in different activities since it allows for physical manipulation and efficient creations with common, perceptible materials that will translate into interactive digital systems.

3.2.4 Other Contexts. Apart from the three most prominent context categories, others were identified in the literature. *Communication* is the fourth most prominent, presenting the use of paper prototyping activities as a method to improve collaborative sessions and communication with target audiences. This was briefly seen in the Education context, where some implementations want to help students communicate more effectively. However, other articles focus more on the use of the prototyping technique to allow for clear communication between parties. In the case of [10], the authors study the use of prototyping approaches to help non-verbal children develop their language skills. On the other hand, articles like [60] focus on the collaboration aspect of the activities, with the design of a game between students using paper prototyping techniques. Another context is *AR/VR*, showing the uses of virtual environments to compliment the tangible objects in different activities. [6] bridges the gap between 2D Design and 3D Design by applying paper prototyping and translating the creations into three-dimensional, virtual interfaces. In [45] the authors allow for the use of photo prototyping (a paper prototyping technique) to transfer the ideas into the AR-context for easier, clearer visualizations. Finally, other contexts involve *workforce* and *health*, with studies focusing on the use of paper prototyping approaches in each category's needs. In *workforce*, an example can still be [45] since the application is specifically designed and evaluated with workers from the automotive industry. As for *health* applications, [21] discusses the design of dynamic wearable AR displays focused on wellness.

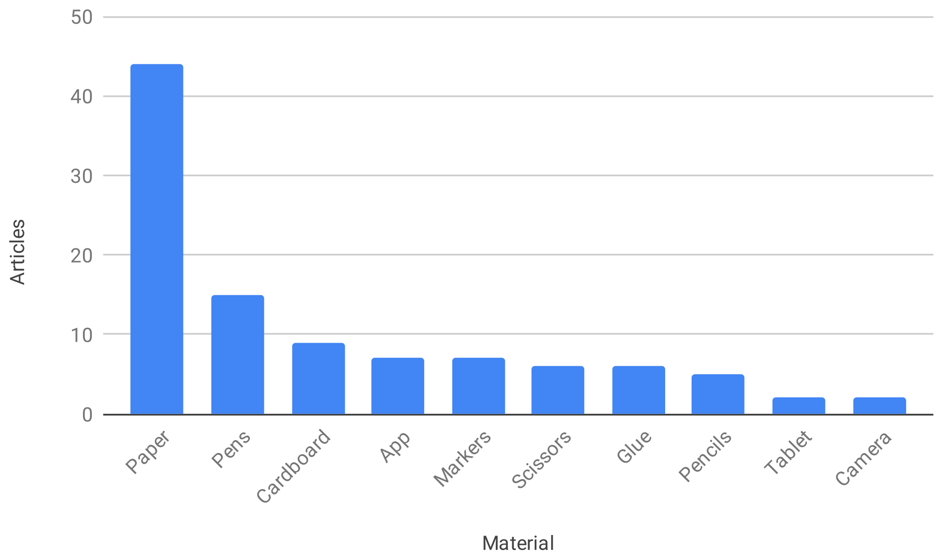

Fig. 3. Materials used in articles from the literature review.

3.3 RQ2: What are the materials implemented in paper prototyping activities?

Roughly 38% of the articles used pencils and/or pens. Pencils and pens are writing utensils that are used to write, draw, or note down information. Nebeling and Madier et al. [46] used pencils and pens to draw for the backgrounds for the AR/VR environment. The purpose of this study is to create an AR/VR application using a camera and the proper drawing utensils. There are templates that are created so that users can easily sketch backgrounds for the application. The 360proto is an app that uses the camera to take pictures of the sketches so it can be transformed into the AR/VR perspective. Paper is the most common material used in paper prototyping. Over half of the articles used paper. Paper is a material that is used to write or copy information on. Kang et al.[30] uses AR visualizations to stimulate complex systems using paper. In the article, a bike with no gears is used as an example of a complex system. The participants use paper, pen, and pencils to make paper gears and cut them out using scissors. The paper gears are placed on the background with the bike using AR canvas and a top down document camera. The bike is now simulated using Rainbow, an AR-based desk.

According to our search criteria, there were only five articles (8%) that used cameras in their case studies. A camera is an optimal instrument used to record images. It is the most common equipment used to take photos to recall certain moments. Li et al. [39] uses a camera to video record interactions that take place from the traditional paper prototyping methods. The recordings are then used for the tool FrameWire to help enhance and make paper prototyping practices less challenging. Results from paper prototyping are usually manually recorded but FrameWire is a tool that cuts down the time to look at results from paper prototyping, like being able to quickly find a specific recording or get numerical data. Another approach to using cameras in these studies is to include webcams so computers can view paper prototyping models [33]. ARcadia is a tool on the web that brings paper prototyping to life with augmented reality (AR) using tangible objects. Using

Material Category	Article(s)	Count	Percentage
Paper	[1, 3, 5, 7–13, 16–27, 29–32, 34, 36–39, 41, 42, 45–52, 54, 56, 58, 61]	44	72.13%
Pens	[3, 5, 16, 17, 25, 31, 33, 34, 45–47, 49, 51, 56, 58]	15	24.59%
Cardboard	[5, 10, 20, 23, 33, 37, 46, 51, 52]	9	14.75%
Markers	[5, 8, 29, 30, 33, 36, 50]	7	11.48%
App	[4, 11, 13, 22, 27, 44, 50]	7	11.48%
Scissors	[13, 30, 33, 37, 46, 48, 51]	7	11.48%
Pencils	[5, 22, 32, 46, 50, 52]	6	9.48%
Glue	[5, 13, 33, 36, 42, 45]	6	9.48%
Camera	[30, 33, 39, 45, 46]	5	8.20%

Table 4. Most frequently published materials and their respective articles.

sufficient programming practices will allow you to interact with paper prototyping models by the webcam recognizing movement and acting according to the programmer's code.

Only two articles used cardstocks and one used LED lights. Hershman et al. [24] used paper prototypes to get feedback from children. Paper, cardstock and LED light were used as the primary materials for the experiment. Paper was mainly used to make the record and playback button on the cardstock. Cardstocks are also called pasteboards and are thickers and more durable than writing paper. LED (light-emitting diodes) are semiconductor light sources that discharge light when current flows. LED lights were placed inside or on the back of the paper so that the buttons lit up when they were pressed. The researchers wanted to get results from the children to see why they selected a specific button (because it lit up, physical properties).

Scissors are essential in paper prototyping. They assist with the shapes and sizes of the materials. When designing an interface, designers can cut the paper in squares or circles for the user's preference. Even in participatory design, participants have the option to cut the paper to whatever size they will reasonable for the design. In one user study, the participants were asked to create costumes for doll-sized mannequins. After sketching their costumes on paper, the participants cut out each design to attach them to the mannequin [5].

Glue is a temporary bond for materials. Glue makes it easy to take apart paper interfaces during designing. There are many different varieties of glue making it versatile. [36] takes advantage of this versatility. In their study, they used personal clothing glue to attach buttons to their clothing, white liquid glue to outline electric connections between pins, fabric glue to secure fabric designs in place, and hot glue to avoid the dangers of sewing needles.

Applications (apps) are computer software and/or programs that can be downloaded onto mobile devices. From the papers of the search, apps are primarily used to interpret the low fidelity prototyping. In [22], a poster was designed to show users how to interact with their mobile devices. The poster has the same UI symbols as the application. Paper versions of action symbols were selected by users by which ones would be more appealing when seen on a mobile device.

Sometimes paper is not the strongest material to use. Cardboard is then used for sturdiness purposes. Paper contributes to the appearance aspect of prototyping, but cardboard exemplifies the physical properties of a prototype. Cardboard allows users to see the actual or scaled depths and volumes of created objects. A prototype for a DJ turntable was made out of cardboard. To see the toggle switches, the disc rotating, and the volume control moving up and down would be hard to imagine on a one-dimensional piece of paper [33].

Activity Task Category	Article(s)	Count	Percentage
Complete Tasks on Prototype	[3, 4, 13, 14, 18, 19, 21, 22, 25, 26, 29, 30, 36, 38–43, 45, 46, 49, 50, 52, 53, 56, 57, 59, 61]	29	47.54%
Focus Groups	[1, 2, 6, 8, 11, 12, 16, 18, 21, 30, 32, 34, 36, 42, 44, 47, 49, 50, 55, 60]	18	29.51%
Create andor Design Prototye	[5, 6, 8, 10, 23, 27, 31, 33, 34, 37, 42, 43, 46, 47, 50, 51, 59, 60]	17	27.87%
Field Study	[7, 12, 15, 16, 35, 44, 48, 54]	7	11.48%
Discussion	[1, 2, 8, 30, 50, 61]	6	9.84%
Demonstration	[27, 30, 35, 37, 43]	5	8.20%
Interactive Storytelling	[19, 24, 31, 57]	4	6.56%
Game Play	[15, 47, 55]	3	4.92%
Survey	[28, 35, 49]	3	4.92%
Course	[23]	1	1.64%
Test User Prototype	[37]	1	1.64%
Mind Mapping	[17]	1	1.64%
Execution Tree	[17]	1	1.64%
Storyboard	[17]	1	1.64%

Table 5. Most frequently conducted activity tasks and their respective articles.

Challenge Category	Article(s)	Count	Percentage
Experience	[1, 2, 6, 10, 12, 14, 15, 17, 19, 23, 25, 30, 34–36, 46, 47, 49, 59]	19	31.15%
Not Stated	[4, 7, 33, 40, 41, 45, 48, 50–56, 58]	15	24.59%
Limited State	[1, 3, 8–10, 15, 16, 18, 20, 25, 28, 31, 34, 37, 44]	15	24.59%
User Misinterpretation	[6, 10, 15, 22–24, 28, 30–32, 34, 36, 37, 46, 60]	15	24.59%
Knowledge	[1, 3, 6, 10, 15, 17, 25, 30, 46, 49, 56, 61]	12	19.67%
Prototype Error	[11, 24, 26, 27, 29, 43, 47, 60]	8	13.11%
Limited Supplies	[6, 9, 18, 20, 34, 43, 46, 47]	8	13.11%
Motivation	[17, 19, 24, 30, 31, 35, 59]	7	11.48%
Accurate Evaluation	[2, 11, 18, 38, 42, 44]	6	9.84%
User Age Range	[10, 15, 17, 24, 30, 37]	6	9.84%
Limited Detection	[15, 20, 38, 46]	4	6.56%
System Error	[9, 13, 27]	3	4.92%
Time	[12, 14, 16]	3	4.92%
System Modification	[21, 31, 57]	3	4.92%
Lack of Participants	[2, 10]	2	3.28%

Table 6. Most frequently encountered challenges and their respective articles.

3.4 RQ3: What are challenges in paper prototyping applications?

3.4.1 Experience. [14] had many challenges throughout the process of completing their work. The team wanted to use an agile software development methodology called Scrum that gave smooth and planned actions to complete their task. Lack of experience played a major role in affecting the results of the project. The team's lack of familiarity with Scrum and the logistics with it made things a lot more difficult. Scrum had three major roles: Project Owner, Team, and ScrumMaster. Due to lack of experience, they did not have a fully committed Product owner which is key in delivering information. Which led to the product owner's responsibility being split up between the team and ScrumMaster. The team had sprints and deadlines and they had a difficult time determining the time in which something should be completed. If the team was more experienced and prepared then things would have gone a lot smoother.

3.4.2 Knowledge. [35] main objective was to inform people about their body weight and how the things they used daily affects the environment. A scale was made so participants could step in it to see their body and carbon weight. Some of the challenges that the researchers had was the lack of knowledge that the participants had. A lot of the participants did not know what carbon weight was and how it's electricity consumption affected the environment, which made it difficult to get some results. According to some surveys the participants thought that "environmental concerns have been overblown". This mindset can also make things challenging.

3.4.3 User Age and Knowledge. [30] wanted to create an AR system that allows young children to design and experiment with complex systems using low fidelity. The children are to create a system and be assisted by the digital stimulation. Some challenges that came along with this was the age of the children. The children were in grades K-5, therefore they all would not have the knowledge to use some things because they are still developing. Children had a hard time at the beginning because they could not understand what they were supposed to do. They also had a hard time with the softwares functionalities and complained about things like the sensitivity. These complications led the children to change aspects of the prototypes that were created, which made it difficult for the experiments.

4 CONCLUSION

This paper dived into the approaches of the paper prototyping. Answering three main questions. What are the objectives and contexts in which studies apply paper prototyping? What are the materials implemented in paper prototyping activities? What are the challenges presented by paper prototyping applications? Paper prototyping is an excellent way of using a cheap, simple, and reliable way to give an interactive activity. Paper prototyping consist of many different materials and components for user interaction. It is an excellent tool for testing and feasibility of software in early stages and is used as a great way to give and receive feedback from analysis

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