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A bibliometric analysis of research trends and advanced technologies in tactile graphics design

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Abstract: Tactile graphics in the human–computer interaction profession emerged in the 1970s to solve various issues visually impaired people faced and the wider social implications of such challenges. As technology continues to evolve, designers are becoming interested in tactile graphics from a human-centred design perspective, which while potentially enriching this field also risks losing valuable input from other disciplines. This study thus reviews extant literature on tactile graphics research from an interdisciplinary perspective, considering valuable input from various disciplines to identify, analyse, and discuss diverse hotspots and techniques used in tactile graphics. The process involves a bibliometric analysis of the tactile graphics literature to help researchers quickly understand the direction of research besides their application in other disciplines in order to find solutions to problems related to tactile graphics. Its findings provide insights into the new field that benefit researchers, stakeholders in the design industry and, ultimately, users of tactile graphics.

Keywords: Visually impaired, Tactile graphics, Technology, Tactile graphics design, Citespace

1. Introduction

Much information is currently presented graphically, and graphical representations of diverse information are increasingly present within today's digital age. Infographics, for instance, frequently appear in our daily lives to present anything from maps and statistical data to place layouts and public transportation graphs but also have other general purposes (Wabiński and Mościcka, 2019). Graphics can convey information instantly and simply by presenting data in a compact and organised manner. While most humans usually perceive these using their vision system, people with visual disabilities who perceive the environment through the sense of touch are unable to understand graphical representations, thereby limiting their ability to fully benefit from the world outside. As such, for the many visually impaired and blind people (numbering at least 2.2 billion people worldwide, according to the World Health Organization, with at least one billion of the former being avoidable or remaining unaddressed), tactile graphics are essential for studying, living in and understanding the world.

Tactile graphics can be created manually, but self-reports of some designers say this method is time consuming as it can take anything from one hour to several hours to prepare and complete one tactile graphic. Although this process has been slightly quickened with graphic manipulation programmes (e.g. Adobe Photoshop or Gimp), the time required to complete the graphics is still considerable (Ferro and Pawluk, 2017). Hence, relatively few tactile graphics that are accessible to touch-based readers are being created; also, unless the images get used repeatedly, such as in a class by different users over time, they are usually not accessible instantly upon request. Due to the differences in disciplines, researchers and designers need to quickly grasp how tactile graphics are generated and designed if they want to solve related problems. For example, what are the most advanced technologies currently available, what are the advantages and disadvantages of these technologies and what are the gaps in recent research. Therefore, the ability to understand different subjects in a short time is a competency that researchers need to acquire in order to better interdisciplinary research.

2. Rationale and background

Tactile graphics, consisting of raised surfaces that can be explored through touch, offer an alternative approach to visual representation, encompassing diagrams, charts, graphs, maps, images, and other non-textual spatial forms. They serve diverse purposes, including education, entertainment, navigation, and professional activities. Traditional creation processes for tactile graphics involve techniques such as thermoforming, swell paper, and embossing on thicker paper. However, recent advancements have introduced specialised printers like the Index Braille Everest-D, PIAF, ViewPlus Tiger, and IRIE Embossers, which facilitate the printing of tactile graphics from digital images.

These tactile graphics are particularly valuable for visually impaired individuals as they provide accessible information. Through one- or two-handed touch, individuals can perceive and explore the raised elements, enabling independent analysis of graphical representations. Furthermore, tactile graphics convey spatial information, enhancing comprehension and memorability of the content. To differentiate between different graphics, colours are replaced with distinctive line styles, symbols, and textures (Christin and Gerhard, 2019). It is worth noting that many of the symbols used in print are not easily recognised and interpreted by braille readers, as emphasised by Zebehazy and Wilton (2014). Therefore, when considering visually impaired readers, it becomes significantly important to move beyond using "just braille dots" and instead incorporate counting or grouping of shapes and textures, which offer more engaging and meaningful information.

3. Methods

The lives and needs of people with visual impairments are increasingly capturing to the attention of scholars and designers; however, the relatively short time that research on related issues has been developed in the design discipline and much research having focused on particular avenues has resulted in a lack of research that systematically analyses the general profile of tactile graphics and the methodologies it uses to give researchers an efficient and quick reference for an overview of academic developments. Based on this, the current study uses bibliometric analysis tools to qualitatively study the knowledge graph for research related to tactile graphics. It does so by using Scopus to derive literature and citation data then by analysing the emergent overview and current state of research on tactile graphics, possible future developments, and particular research directions in the design discipline in relation to current research in science and education.

3.1 Data collection

The data for this study was sourced from the Scopus database. Its rich literature in the field of social sciences and its compatibility with econometric analysis software provide a useful means of obtaining suitable research data. The time span of this study covers 2013 to 2023, as an increase in assistive technology for visually impairment individuals and the field is rapidly evolving (Mukhiddinov & Kim, 2021). The keyword 'tactile graphics' was used and 205 articles of literature data were obtained via this approach. Full records and cited references were exported using the Scopus export tool and imported into Citespace bibliometric analysis software for the data analysis.

3.2 Bibliometric analysis and manual interpretation

In pursuing an in-depth and accurate understanding of tactile graphics across different research areas and technologies, this study combines quantitative bibliometric analysis method with qualitative manual interpretation for a holistic synthesis of the data. The Scopus content analysis tool was used to generate yearly publications relating to tactile graphics design research, top ten countries, top ten authors, and citation reports to provide an overview of tactile-graphics research. Next, the researcher conducts a detailed analysis of the literature data to understand the design (generation) methods related to the tactile graphics field in order to compensate for any possible bias and misinterpretation of the clustering analysis caused by the econometric analysis software. Finally, summarised the current advanced tactile graphics design technologies and highlights some key milestones and developments for tactile graphics design.

In order to select the 10 articles on advanced design and production techniques for tactile graphics from a pool of 205 articles, a systematic approach is employed. The process commences with a thorough examination of the abstracts of all 205 articles to gain a broad understanding of their content and relevance. Following this initial screening, the full texts of the identified articles are retrieved and comprehensively read. During the reading phase, particular attention is given to the methodologies, techniques, and production processes outlined in the articles. The objective is to assess whether these articles offer profound insights and advancements pertaining to the design and production of tactile graphics. To evaluate the quality and relevance of each article, several factors are taken into consideration, including the rigour of the research, the validity of the methods employed, and the significance of the findings. Based on this rigorous assessment, the selection is refined, narrowing it down to the 10 articles on advanced design and production techniques for tactile graphics. It is ensured that the chosen articles encompass a diverse range of aspects or subtopics within the field, contributing to a comprehensive understanding of the subject matter.

4. Overview of research on tactile graphics

Since 2013, there has been an overall upward trend in tactile graphics research (Figure 1), with a particular surge in studies in the last two years; hence, an increasing numbers of scholars are focusing on the field of tactile graphics. As shown in the distribution of research countries (Figure 2), the main ones for tactile graphics are the USA, Germany, Japan, South Korea, and Canada. The number of articles published in the USA far exceeds that of other countries, as Figure 2 shows, which perhaps relates to the development of technologies on tactile graphics design originating in the USA. The highest number of articles was published by Takagi Noboru (Figure 3), a Japanese scholar whose main research interests are graphic description language and mobile robots. Notably, all ten osf these authors mentioned in Figure 3 are researchers in computer science engineering and human–computer interaction.

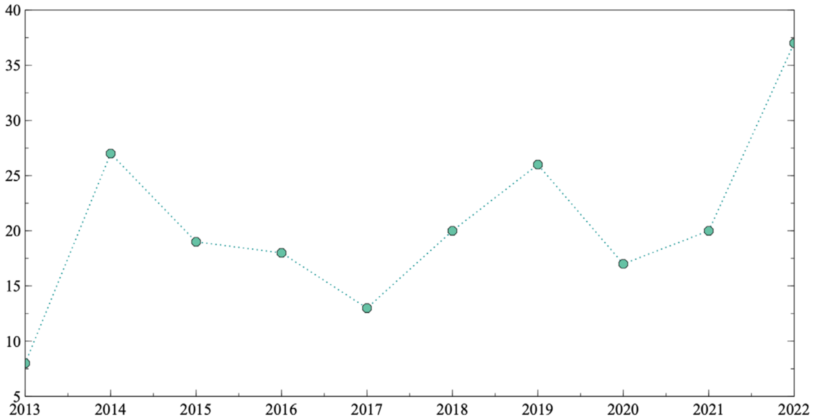


Figure 1. Yearly publications relating to tactile graphics design research from 2013 to 2023.

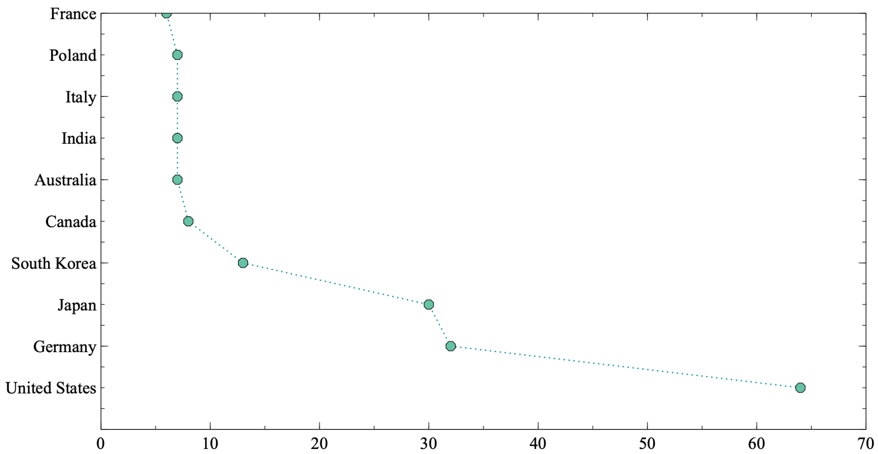


Figure 2. Top 10 countries of publication studies.

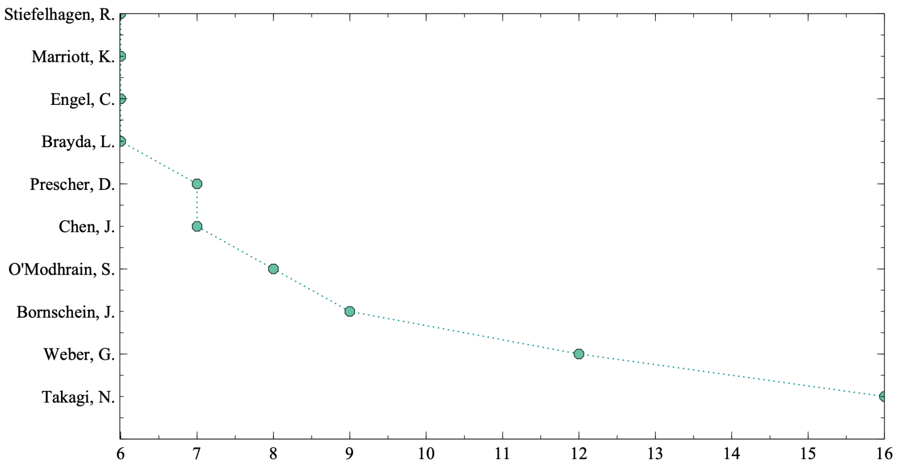


Figure 3. Top 10 authors regarding number of publication studies.

4.1 Analysis of cited research on tactile graphics

Among the selected papers, Holloway et al.'s (2018) research was the most cited (60 citations) followed by Stangl et al.'s (2014) study (48 citations) (Table 1). The main areas of research cited in the literature are accessible maps, tactile picture books, and assistive technology. There are also specific distinctions between target groups, such as entirely blind or visually impaired children. In addition, the highly cited literature categories and results are diverse, e.g. the use of controlled studies to verify that 3D printed maps do indeed offer advantages for Orientation and Mobility (O&M) training, or present insight about using a 3D printed tactile picture book as a design probe.

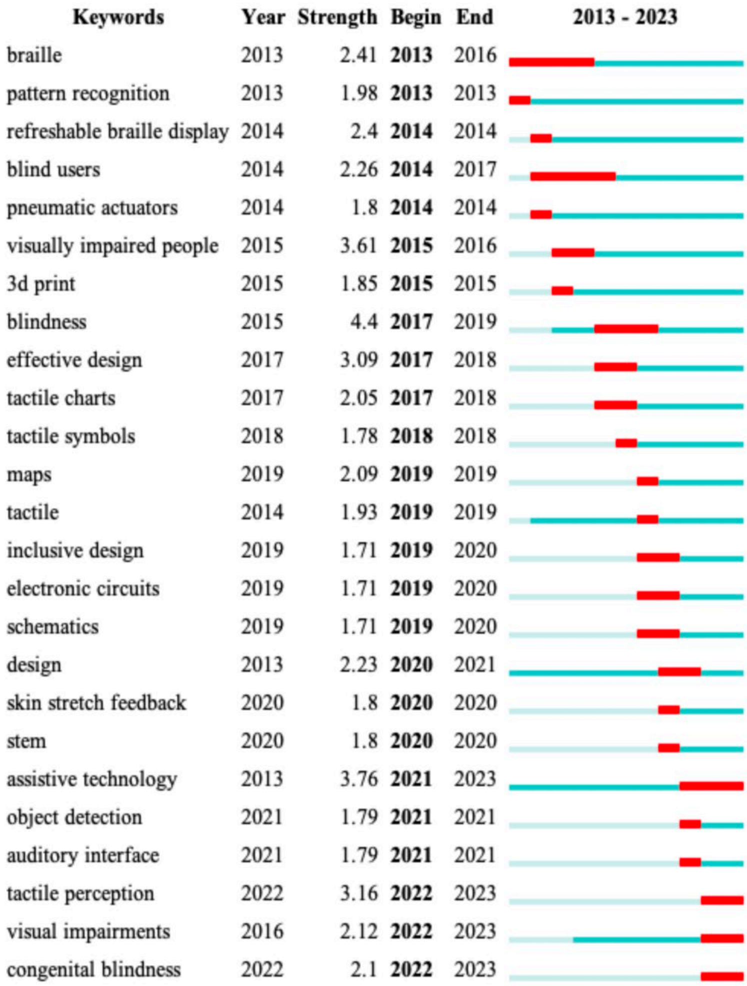
Although reading the highly cited literature provides a quick overview of tactile graphic design research, the most recently published papers may be less cited because of their recent publication date. Researchers should therefore pay attention to the date of publication in this regard lest papers published in the last two years, for example, may appear infrequently in such rankings yet still offer much.

Table 1. The highly cited articles on tactile graphics.

No	Author(s)	Title	Year	Cumulative citations	Impact factor
1	Holloway et al.	Accessible maps for the blind: Comparing 3D printed models with tactile graphics	2018	60	-
2	Stangl et al.	3D printed tactile picture books for children with visual impairments: A design probe	2014	48	-
3	Pawluk et al.	Designing haptic assistive technology for individuals who are blind or visually impaired	2015	47	3.105
4	Fusco & Morash	The tactile graphics helper: Providing audio clarification for tactile graphics using machine vision	2015	47	-
5	Shi et al.	Tickers and talker: An accessible labeling toolkit for 3D printed models	2016	46	-

4.2 Analysis of tactile graphics production methods and technologies

Generally, keywords are used as a suitable distillation of an article can indicate hot topics in tactile graphics. The keyword emergence map generated in Citespace (Figure 4) shows that the strength (>2) hot topics in tactile graphics are braille, refreshable braille display, blind users, visually impaired people, blindness, effective design, tactile charts, maps, design, assistive technology, tactile perception and visual impairments. Considering this in relation to the time zone evolution chart of tactile graphics hotspots research (Figure 5), this work demonstrates that education, technological development, and design (inclusive design) have been the top research themes in tactile graphics in recent years. It further shows that research on tactile graphics in the field of design can also be divided by graphic type into research on specific issues such as maps, charts, and symbols.



Keywords	Year	Strength	Begin	End	2013 - 2023
braille	2013	2.41	**2013**	2016	
pattern recognition	2013	1.98	**2013**	2013	
refreshable braille display	2014	2.4	**2014**	2014	
blind users	2014	2.26	**2014**	2017	
pneumatic actuators	2014	1.8	**2014**	2014	
visually impaired people	2015	3.61	**2015**	2016	
3d print	2015	1.85	**2015**	2015	
blindness	2015	4.4	**2017**	2019	
effective design	2017	3.09	**2017**	2018	
tactile charts	2017	2.05	**2017**	2018	
tactile symbols	2018	1.78	**2018**	2018	
maps	2019	2.09	**2019**	2019	
tactile	2014	1.93	**2019**	2019	
inclusive design	2019	1.71	**2019**	2020	
electronic circuits	2019	1.71	**2019**	2020	
schematics	2019	1.71	**2019**	2020	
design	2013	2.23	**2020**	2021	
skin stretch feedback	2020	1.8	**2020**	2020	
stem	2020	1.8	**2020**	2020	
assistive technology	2013	3.76	**2021**	2023	
object detection	2021	1.79	**2021**	2021	
auditory interface	2021	1.79	**2021**	2021	
tactile perception	2022	3.16	**2022**	2023	
visual impairments	2016	2.12	**2022**	2023	
congenital blindness	2022	2.1	**2022**	2023	

Figure 4. Top 25 keywords with the strength citation bursts.

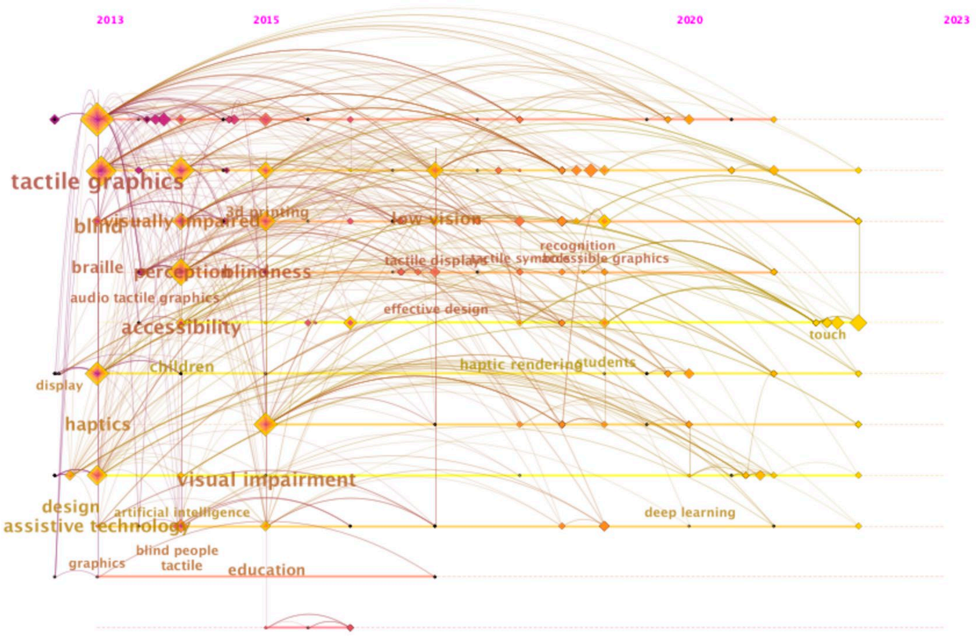


Figure 5. A 2013-2023 Time Zone Evolution of hotspots in tactile graphics research.

To further understand the current most advanced design and production technologies for tactile graphics, ten articles were selected for manual interpretation (table2). The table mentions 3D printing as a means of producing tactile graphics for visually impaired people, and various forms of such graphics result from this process. Götzelmann (2018), for example, printed tactile maps with a maximum thickness to preserve the touch functionality of the electronic device below. This 3D-printed tactile graphic allows 4–5 different elevation levels for the relief printing of lines and textures, thereby improving the map's representative capacity. In Brock et al.'s (2015) study, users could explore the map and their prototype also allowed interaction with the map through voice input. Problems with such 3D printing, however, concern the long printing time required for 3D graphics and the greater effort involved in creating the corresponding 3D digital model, the latter being a significant disadvantage for teachers.

The technological age has nevertheless brought various developments in this field besides somewhat alleviating the long-lamented time-consuming concerns about developing tactile graphics and their associated cost problems. As Lu and Zong (2017) found, the evolution of computers and related software and hardware technologies has helped researchers make great progress in stimulating elements and related technologies to develop various electronic tactile graphic displays. Such tactile graphic displays are, in fact, currently the main tool for the blind to recognise tactile graphics, with specific forms of these including Metec's DMD-12060, Sheet-Type Braille Displays, Graille, and others. Despite such advances, though, these assistive devices are currently too costly, which rather cancels out gains in this regard via computer usage as noted above.

Another key developmental factor in tactile graphics design is increasing awareness of the needs of people with disabilities. Indeed, the popularity of concepts such as inclusive design has increased significantly, as observed evident in recently published research concerning the needs of visually impaired people – including on tactile graphics. Generally speaking, such contemporary research is reflected in reviews on tactile graphics over the last decade: a significant increase in working solutions for tactile graphics production (e.g., Červenka et al., 2016; Watanabe et al., 2014), converting hand-drawn graphics (e.g., Takagi and Chen, 2014; Pandey et al., 2020), on touch-based accessible graphics (Butler et al., 2021), tactile cartography in the digital age (Cole, 2021), automatic creation of tactile graphics (Mukhiddinov and Kim, 2021), and automatic tactile maps generation (Wabiński and Mościcka, 2019), while the aesthetics of tactile graphic has also been discussed (Kent, 2019).

Table 2. Tactile graphics generation methodology.

No	Author(s), year	Title	Methodology
1	Stangl et al., 2014	3D printed tactile picture books for children with visual impairments: A design probe	Using a **3D printed** tactile picture book as a design probe.
2	Leo et al., 2016	The Effect of Programmable Tactile Displays on Spatial Learning Skills in Children and Adolescents of Different Visual Disability	Designing on programmable **tactile displays;** assessing via tests the spatial memory skills and the shapes recognition abilities of children with visual impairment.
3	Holloway et al., 2019	3D Printed Maps and Icons for Inclusion: Testing in the Wild by People who are Blind or have Low Vision	**3D printed maps** on-site at a public event to examine their suitability for the design of future 3D maps.

4	Kim et al., 2019	Multimedia vision for the visually impaired through 2D multiarray braille display.	The study describes a methodology to convert multimedia contents to braille using 2D **braille display** and the transformation of DAISY and EPUB formats into 2D braille display.
5	Engel et al., 2019	SVGPlott: an accessible tool to generate highly adaptable, accessible audio-tactile charts for and from blind and visually impaired people	The study improves the tactile bar charts, line charts, and scatterplots creation process by an **automation tool** that includes an accessible GUI.
6	Gonzalez et al., 2019	Tactiled: Towards More and Better Tactile Graphics Using Machine Learning	Employing a **machine learning model** that identifies suitable and unsuitable images for tactile graphics.
7	Abdusalomo v et al., 2020	Automatic salient object extraction based on locally adaptive thresholding to generate tactile graphics	Applying a **novel saliency cuts method** that has local adaptive thresholding to obtain four regions from a given saliency map which extracts salient objects and generates simple, important edges from natural scene images efficiently.
8	Bose et al., 2020	Utilizing Machine Learning Models for Developing a Comprehensive Accessibility System for Visually Impaired People	Applying a comprehensive accessibility **framework** that generates accessible text and tactile graphics for various graphics types in an HTML document.
9	Melfi et al., 2020	Understanding what you feel: A Mobile Audio-Tactile System for Graphics Used at Schools with Students with Visual Impairment	Introduce a mobile **audio-tactile** learning environment, which facilitates the incorporation of real educational material.
10	Lee and Cho, 2022	Automatic Object Detection Algorithm-Based Braille Image Generation System for the Recognition of Real-Life Obstacles for Visually Impaired People	The study proposes a living **assistance system**, which integrates object recognition, object extraction, outline generation, and braille conversion algorithms.

As can be summarised from the review in this study, various advanced tactile graphics design technologies are currently available. For example,

1. ***Embossers*** are tactile printers that produce raised images on paper in potential high-quality tactile graphics with a resolution of up to 1000 dpi, making them ideal for creating tactile images with fine details. An advantage of embossers concerns how they can produce multiple copies of the same tactile graphic quickly and easily. Conversely, they can be expensive and require significant training to use (Chowdhury et al., 2018).
2. ***Thermal printers*** use heat to create raised images on paper. They are fast, efficient, and can also produce high-quality tactile graphics. Notably, they are relatively affordable compared with other technologies. Despite that, they can be limiting in terms of the size and complexity of the tactile graphics produced (Hu et al., 2019).
3. ***3D printers*** can create three-dimensional objects that can be used as tactile graphics. They can produce highly detailed and complex objects, and can be used to create

customized tactile graphics for specific purposes. Nevertheless, 3D printers can be expensive and require a significant amount of expertise to operate (Stone et al., 2020).

4. ***Tactile displays*** use touch-sensitive surfaces to produce tactile graphics. They are relatively new technology and are still in the early stages of development. One advantage of tactile displays is that they can produce dynamic tactile graphics that can change in response to user input. Still, they are currently limited in terms of the size and complexity of the tactile graphics they can produce (Yang et al., 2021).

Ultimately, the advanced tactile graphic design technology available should depend on the users' specific needs. Embossers and thermal printers are ideal for producing high-quality, static tactile graphics quickly and efficiently. 3D printers are ideal for creating highly detailed, customized tactile graphics, but can be expensive and require significant expertise to use. Tactile displays are still in the early stages of development, but have the potential to produce dynamic, interactive tactile graphics in the future.

To understanding the key milestones and developments of tactile graphics design that can provide valuable insights into the evolution of technology for individuals with visual impairments. Also, it helps educate stakeholders, such as policymakers, educators, and the visual impairments, about the importance of tactile graphics and the need for continued research and development in this area.

- *Early tactile graphics*: Tactile graphics have been in use for centuries, with early examples dating back to the 16th century. These early graphics were often handmade and lacked the precision and detail of modern tactile graphics.;
- *Braille*: The development of braille in the early 19th century revolutionized tactile graphics design, providing a standardized system for representing text in tactile form. Braille also enabled the development of more sophisticated tactile graphics, such as maps and diagrams;
- *Printing technology*: The invention of printing technology in the 19th century enabled the mass production of tactile graphics, making them more accessible and affordable. The development of embossers and thermal printers in the 20th century further improved the quality and efficiency of tactile graphics production;
- *Digital technology*: The introduction of digital technology in the late 20th century transformed tactile graphics design. Computer software enabled designers to create and edit tactile graphics digitally, making the design process faster and more efficient. Digital technology also enabled the production of more complex and detailed tactile graphics
- *3D printing*: The development of 3D printing technology in the 21st century has further expanded the possibilities of tactile graphics design. 3D printing enables designers to create customized, three-dimensional tactile graphics that can be used for a wide range of purposes.

The future development of tactile graphics in the design field is likely to be shaped by advances in technology, increased collaboration across disciplines, and a growing awareness of the importance of inclusive design. As these trends continue to evolve, we can expect to see new and innovative approaches to tactile graphic design that enable greater access to information.

5. Discussion and conclusion

In manually interpreting the highly cited articles, this study has found that tactile graphics research is not only an advancement in human-computer interaction technology but also a way to help visually impaired people adapt to social life and address the barriers that they encounter in their lives - for example, helping visually impaired students to more effectively understand visual information in STEM subjects, and helping blind and visually impaired people to independently experience and understand visual artwork in art exhibitions. Although the concept of tactile graphics has received considerable attention in the context of the human–computer interaction discipline and has been the subject of much research in the development of new touch-enabled devices, the effectiveness of its use remains largely unknown because of the high cost of the equipment and the ample time involved, besides the lack of user testing because it's hard to find participants and people with visual impairment vary greatly from one individual to another.

Advanced technologies have significantly influenced the evolution of tactile graphic design for individuals with visual impairments, providing new opportunities for the creation of interactive, dynamic, and customizable tactile graphics. However, it is important to consider the limitations associated with these technologies, particularly their high cost and limited accessibility for a large portion of the visually impaired population. Consequently, research efforts should be directed towards developing affordable and widely available solutions that can be implemented in diverse settings, such as schools, libraries, and everyday environments. Furthermore, it is imperative to assess whether the increased complexity and interactivity of tactile graphics genuinely enhance comprehension and engagement for individuals with visual impairments. To this end, future research should explore collaborative design approaches that actively involve visually impaired individuals, educators, and designers in the creation and evaluation of tactile graphics. Such an inclusive approach ensures that the designs are centred around the needs and preferences of the users, while also considering cultural sensitivity. By addressing these key areas, the field of tactile graphic design can better serve its purpose in facilitating access to information and promoting meaningful engagement for visually impaired individuals.

In recent years, researchers from the design industry have gradually focused on the field of tactile graphics design, but this is still at a nascent stage of research. With the growing diversity of tactile graphic design techniques and technologies, there is a need for standardisation and guidelines to ensure consistency and compatibility across different platforms and applications. This standardisation would facilitate the widespread adoption and interoperability of tactile graphics, improving their effectiveness and usability. Also, as tactile graphic technologies continue to evolve, it is crucial to conduct long-term studies to assess their impact on education, employment, and social inclusion for visually impaired individuals. Research should explore the long-term benefits, challenges, and potential unintended consequences of relying on tactile graphics as a primary mode of accessing visual information.

While the article provides valuable insights into the importance of tactile graphics for visually impaired individuals and highlights the challenges associated with their development, it has certain limitations that should be acknowledged. Although the article suggests investigating the interdisciplinary perspective to address unresolved issues, it does not delve into the specific design principles, methodologies, or frameworks that can be applied. Therefore, future research should provide a more detailed exploration of the design perspective and its potential contributions would enhance the practical implications of the study. By addressing these scope considerations, future research can contribute to the sustainable development of tactile graphic design, ensuring that it meets the diverse needs of visually impaired individuals and empowers them in various aspects of their lives.

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