UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE INFORMÁTICA
PROGRAMA DE PÓS-GRADUAÇÃO EM COMPUTAÇÃO

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An Evaluation of Immersive Infographics for News Reporting: Quantifying the Effect of Mobile AR Concrete Scales Infographics on Volume Understanding

Thesis presented in partial fulfillment of the requirements for the degree of Master of Computer Science

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Porto Alegre
August 2024

CIP — CATALOGING-IN-PUBLICATION

Giambastiani, Mariane

An Evaluation of Immersive Infographics for News Reporting: Quantifying the Effect of Mobile AR Concrete Scales Infographics on Volume Understanding / Mariane Giambastiani – Porto Alegre: PPGC da UFRGS, 2024.

82 f.: il.

Thesis (Master) – Universidade Federal do Rio Grande do Sul. Programa de Pós-Graduação em Computação, Porto Alegre, BR–RS, 2024. Advisor: Luciana Porcher Nedel.

1. Augmented Reality. 2. Immersive Infographics. 3. Infographics. I. Nedel, Luciana Porcher. II. Título.

ACKNOWLEDGMENTS

Gostaria de expressar meus agradecimentos a todos que contribuíram para a realização desta dissertação de mestrado. Primeiramente, agradeço à minha orientadora Luciana Porcher Nedel, cuja orientação, dedicação e insights foram fundamentais para o desenvolvimento deste trabalho. Agradeço também aos meus coorientadores Jorge Wagner e Carla Maria Dal Sasso Freitas por dedicarem seu tempo neste trabalho e por suas valiosas contribuições e sugestões. Minha gratidão se estende aos colegas de laboratório que, de diversas maneiras, apoiaram e encorajaram-me durante a realização deste trabalho. Não posso deixar de mencionar a minha família, e principalmente ao meu marido Renan de Queiroz Maffei, cujo apoio esteve sempre presente e foram cruciais para superar os desafios e obstáculos encontrados ao longo deste percurso.

ABSTRACT

Augmented Reality (AR) allows us to represent information in the user's own environment and, therefore, convey a visceral feeling of its true physical scale. Journalists increasingly leverage this opportunity through immersive infographics, an extension of conventional concrete scales infographics reliant on familiar references to convey volumes, heights, weights, and sizes. Our goal is to measure the contribution of immersive concrete scales infographics to the user's understanding of the information scale. We focus on infographics powered by tablet-based mobile AR, given its current much more widespread use for news consumption compared to headset-based AR. We designed and implemented a study apparatus containing three alternative representation methods (textual analogies, image infographic, and AR infographic) for three different pieces of news with different characteristics and scales. In a controlled user study, we asked 26 participants to represent the expected volume of the information in the real world with the help of an AR mobile application. We also compared their subjective feelings when interacting with the different representations. While both image and AR infographics led to significantly better comprehension than textual analogies alone across different kinds of news, AR infographics led, on average, to a 31.8% smaller volume estimation error than static ones. Our findings indicate that mobile AR concrete scales infographics can contribute to news reporting by increasing readers' abilities to comprehend volume information.

Keywords: Augmented Reality. Immersive Infographics. Infographics.

RESUMO

A Realidade Aumentada (AR) nos permite mostrar informações no próprio ambiente do usuário e, portanto, transmitir uma sensação visceral quando usamos escalas concretas. Os jornalistas aproveitam cada vez mais esta oportunidade através de infográficos imersivos, uma extensão dos infográficos convencionais que dependem de referências familiares para transmitir as noções de volumes, alturas, pesos e tamanhos. Nosso objetivo é medir a contribuição dos infográficos imersivos em escalas concretas na compreensão do usuário sobre a escala informada nas notícias. Nós nos concentramos em infográficos em AR para dispositivos móveis, dado seu uso atual muito mais difundido para consumo de notícias em comparação com óculos de AR. Projetamos e implementamos um aparato de estudo contendo três métodos alternativos de representação (texto, infográfico em imagens e infográfico em AR) para três notícias distintas com diferentes características e escalas. Em um estudo controlado com usuários, pedimos a 26 participantes que representassem o volume esperado das notícias no mundo real com a ajuda de um aplicativo móvel de AR. Também comparamos seus sentimentos subjetivos ao interagirem com as diferentes representações. Embora os infográficos tanto como imagem como em AR tenham tido resultados significativos quando comparamos com apenas analogias textuais, em diferentes tipos de notícias, os infográficos em AR em média tiveram um erro de estimativa de volume 31,8% menor do que os infográficos como imagens. Nossas descobertas indicam que infográficos em escala concreta em AR para aplicações em dispositivos móveis podem contribuir, aumentando as habilidades dos leitores para compreender informações de volume em notícias jornalísticas.

Palavras-chave: Realidade Aumentada. Infográficos Imersivos. Infográficos.

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LIST OF ABBREVIATIONS AND ACRONYMS

AR	Augmented Reality
VR	Virtual Reality
HMD	Head-mounted Display
MRTK	Mixed Reality Toolkit
NYT	The New York Times

CONTENTS

1 INTRODUCTION

When reading the news, either on paper or through a news app or website, we often find infographics, i.e., visualizations enriched with illustrations and annotations to present information (Burns et al., 2022). *Immersive infographics* leverage augmented (AR) or virtual (VR) realities to increase information understanding, using narratives to offer an alternative perspective, comprising, in our view, one of the most exciting applications of *Immersive Analytics* (Marriott et al., 2018). In particular, through infographics based on the concept of *concrete scales* (Chevalier, Vuillemot and Gali, 2013), we can provide users with the sense of *data visceralization* (Lee et al., 2021), conveying volumes or dimensions that can often be difficult to estimate through abstract numbers alone.

Visceralization is something that typically refers to instinctive reactions and emotional feelings. For example, when we watch an action movie where the actor is climbing a colossal mountain, and we feel fear, or when we watch a TV advertisement asking for help from poor children, we feel sad. This kind of feeling that evokes a solid and fast response is a visceral experience. Although visceral things are widely used in entertainment media, they can also engage viewers in data visualization. The concept of *data visceralization* introduced by (Lee et al., 2021), which is a mix of data visualization with visceral experience, is not only a way to show data in huge dimensions or volumes but is also a method to show information that could cause visceral feelings in the viewers.

Using infographics to engage readers also tries to evoke a visceral experience in the viewers. Infographics are widely used to inform messages that need to be understandable, easy, and fast. Thus, the infographics must be intuitive and straightforward; sometimes, the message must be visceral to invoke a fast response from the readers. However, the visceral perspective can be harmed when we use infographics to present, for example, the amount of waste produced in one year using an image. Therefore, if the same infographics were shown now as an immersive infographic using AR, this alternative visualization method can increase the visceral experience when we are trying to inform the volume of abstract quantities.

Not surprisingly, media companies have been investing in this kind of application as a way of improving their readers' experiences, as exemplified, most prominently, by The New York Times (NYT) (Clark et al., 2022). The NYT started exploring AR reporting in 2018 (Roberts, 2018) and has since published at least 31 examples of "AR storytelling" (Development, 2022), including many that could be classified as *immersive infographics*. Most of them have been produced in partnership with Instagram and work through the popular Instagram application as an "AR filter" (He, 2020). They complement news articles where conventional and animated infographics are also presented, offering the opportunity for a different perspective. The news company has also stated the intention of targeting mixed reality headsets in the future (Clark et al., 2022).

Some of the AR infographics presented by the NYT offer a visceral understanding, for example, of the meaning of a given amount of rain measured in inches (Adurogbola et al., 2022) or of the performance of Olympic athletes (Bartzokas et al., 2021a). Some leverage a first-person egocentric perspective, for example, to illustrate how virus particles flow in the air inside a classroom under different ventilation conditions (Bartzokas et al., 2021b). Other examples also demonstrate how immersive 3D infographics, even in AR, can help explain very small or very large phenomena, such as how face masks intercept virus particles (in a much enlarged 3D representation) (Bartzokas et al., 2020) or how wildfires can cause storms (in a miniature 3D representation) (Popovich et al., 2021).

The opportunities created by immersive visualizations for information understanding and storytelling have also been discussed in recent data visualization literature (Isenberg et al., 2018), particularly from the perspective of *data visceralization*, i.e., data experiences that evoke visceral feelings to facilitate the understanding of physical measurements and quantities (Lee et al., 2021). Immersive infographics can take advantage of such feelings, for example, to educate users about the environmental impact of their consumption habits (Assor et al., 2024; Assor et al., 2023). Nonetheless, to the best of our knowledge, there is still limited research surveying the quantitative and qualitative benefits provided by such representations.

In the course of this work, after a review of foundational concepts and pertinent literature (as delineated in Chapter 2), we developed a controlled user study designed to gauge the impact of immersive infographics on the comprehension of volumetric data (elucidated in Chapter 3). In this study, our primary focus is directed toward the examination of concrete-scale immersive infographics, which we have operationalized through a mobile Augmented Reality (AR) tablet application, simulating a 3D news visualization approach currently used in news applications.

Our central hypothesis is that concrete scales immersive infographics are poised to significantly enhance individuals' comprehension of vast numerical quantities, surpassing the efficacy of textual analogies or static infographics in image format, all while maintaining the user within the confines of a singular device without necessitating transition to alternative platforms, such as a see-through Head-Mounted Display (HMD).

To investigate this hypothesis, in our comparative study, we asked 26 participants to indicate the volume they imagined when reading news about large volumes of trash, money, and water through an AR volume specification tool. The outcomes of this comparative investigation are presented in Chapter 4, while a comprehensive discussion and interpretation of our findings are provided in Chapter 5. Given the affirmation of our central hypothesis, we are compelled to assert that mobile AR concrete scales infographics hold substantial promise in augmenting readers' comprehension of the informational content disseminated through news media (as expounded upon in Chapter 6).

In summation, our research endeavors not only to empirically scrutinize the efficacy of immersive infographics within the realm of volumetric comprehension but also to underscore their potential utility as a transformative tool within the landscape of contemporary journalism, fostering enhanced engagement and comprehension between news consumers.

2 BACKGROUND AND RELATED WORK

Our work builds upon the existing literature on the use of conventional *concrete scales* infographics (section 2.1) and on the incipient topic of immersive infographics (section 2.2). In our study, we evaluate one of the possible types of immersive concrete scales infographics (section 2.3). Additionally, our work is closely related to the concept of *Immersive Journalism* (section 2.4).

2.1 Conventional Concrete Scales Infographics

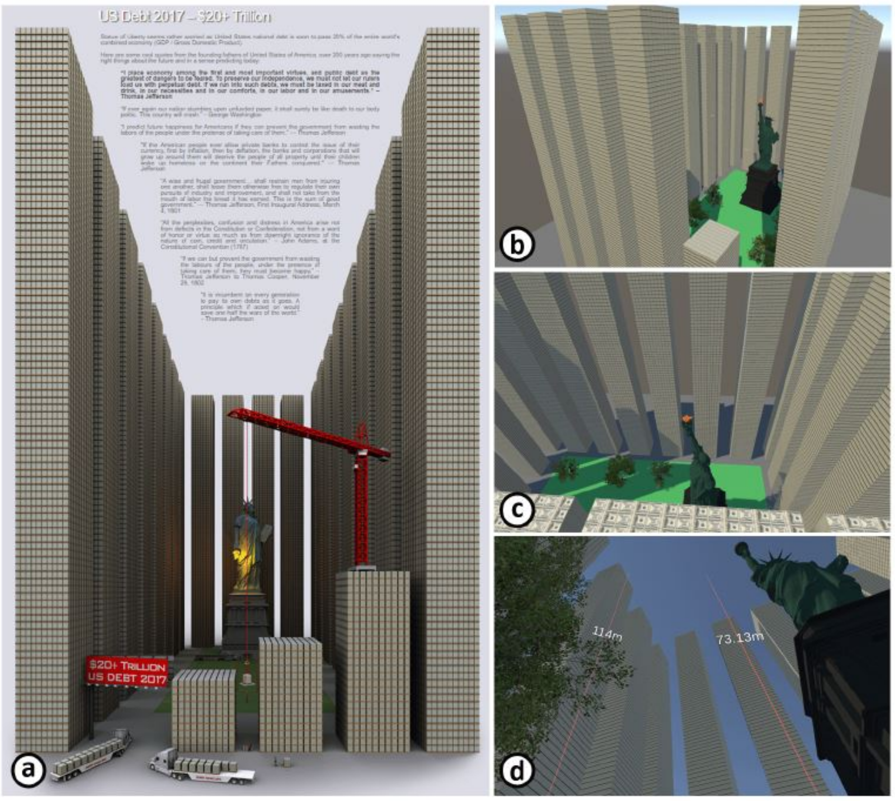
News stories often resort to analogies, either in textual or graphical format, as a resource to more efficiently convey complex numeric information, putting it in perspective to help readers understand and remember data they could have trouble picturing in its original format (Hullman et al., 2018; Riederer, Hofman and Goldstein, 2018). Using the concept of *concrete scales*, i.e., visually re-expressing the information in terms of magnitudes and units that are easier to grasp, as defined by (Chevalier, Vuillemot and Gali, 2013), is particularly helpful in informing quantities and dimensions. For instance, in Figure 2.1 (b) shows the caloric quantity of drinks and foods using sugar cubes instead of numerical values. Concrete scales can help readers understand, for example, how enormous quantities of money compare to the ones they are used to in their personal lives. Chevalier et al. exemplified this with a visualization of illustrative stacks of banknotes comparing their sizes to landmark New York City buildings, as shown in Figure 2.1 (a). A similar example was later revisited by Lee et al. in the context of VR (Lee et al., 2021). The Figure 2.2, shows the concrete representation of the US Debt in $100 Bills.

Another common application of conventional concrete scales infographics is raising awareness of waste production. As an example, Brazil reportedly produces 1.52 million tons of waste weekly. Even though this information is clear, it corresponds to an unfathomable amount for most people. To explain how immense this amount of garbage is, the writers at Brazilian magazine *Piauí* offered as a context that this quantity would be the equivalent to six and a half cruise ships, as shown the Figure 2.3, structures widely known for their massive sizes (Gorziza, Ceará and Buono, 2021). Moreover, to support this comparison, they used infographics to stimulate the readers to think about the real size of this amount of waste.

Figure 2.1 – Prototypes of infographics using concrete scales (a) Show how big is the 115 trillion dollar debt by progressively stacking 100 dollar bills next to familiar objects like an average-sized human body, sports fields, or iconic New York City buildings (b) Sugar stacks compare caloric counts contained in various foods and drinks using sugar cubes and (c) How much water is on Earth? shows the volume of oceans and rivers as a sphere whose size can be compared to Earth's. Adapted from: (Chevalier, Vuillemot and Gali, 2013)

Source: Chevalier, Vuillemot and Gali (2013)

Figure 2.2 – 3D prototype of US Debt Visualized in $100 Bills. (a) Reference scene that Lee et al. (2021) used to build the prototype (© Oto Godfrey, Demonocracy.info, used with permission). (b) Overview of the scene with the Statue of Liberty in the center. (c) Looking down from the top of a stack. (d) Looking up from ground level and at labels of stack (114m) and Statue height (73.13m). Adapted from: Lee et al. (2021)

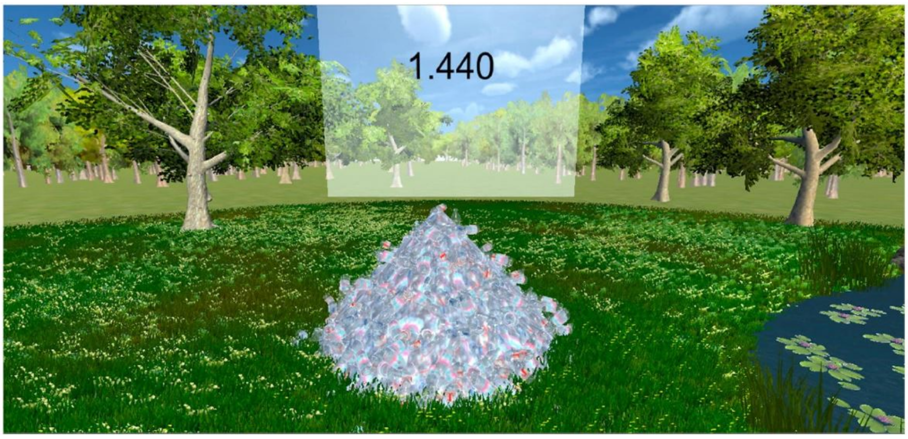


Source: Lee et al. (2021)

Figure 2.3 – In just one week, Brazilians throw away the equivalent of almost seven cruise ships. In total, 1.52 million tons of solid waste were discarded weekly in 2019. Translated from Portuguese. Adapted from: Gorziza, Ceará and Buono (2021)

Source: Gorziza, Ceará and Buono (2021)

Figure 2.4 – Concrete scale and numerical representation of the consumption of single used bottle plastic by ten persons in one year. Adapted from (Chirico et al., 2021).



Source: Chirico et al. (2021)

Figure 2.5 – The current iteration of Carbon Scales for each manufacturing process. (*left*) The finished Carbon Bits were represented by wooden blocks. (*center*) The data physicalization was set in a local library as part of a public installation. (*right*) Adapted from: (Lindrup, Menon and Biørn-Hansen, 2023).

Source: Lindrup, Menon and Biørn-Hansen (2023)

(Chirico et al., 2021) conducted a study showing statistical data on plastic consumption using VR. They compared three types of visualization: textual or numerical, concrete in the form of infographics, and mixed. The Figure 2.4 shows the concrete and textual representation of the total plastic consumption by ten persons in only one year. In their study, they evaluated emotions, the sense of presence, and attitudes toward the use of plastic. Results indicated that the concrete and mixed formats were more effective than the numerical format, with similar results.

Concrete scales representations can also be employed in a physical format. (Lindrup, Menon and Biørn-Hansen, 2023), for example, used data physicalizations to depict the amount of carbon emitted in the food manufacturing process, as shown Figure 2.5. They chose three types of food, asparagus, cheese, and hamburger, and displayed, in the form of wooden blocks, the amounts of carbon emitted in each part of their manufacturing as wooden blocks.

2.2 The Case for Immersive Infographics

Most of us are probably used to seeing infographics in printed format or even in online news (Provvidenza et al., 2019; Lu et al., 2020). With the widespread adoption of mobile devices equipped with AR capabilities and the growing use of mobile applications for news consumption—according to Pew Research, 86% of Americans get news on digital devices (Shearer, 2021)—, we are now also able to visualize infographics in 3D space, what we refer to as *immersive infographics*.

Recent works have already mentioned the use of infographics in immersive settings. (Isenberg et al., 2018), for example, discussed the challenges and opportunities for immersive visual data stories. One of the possibilities they pointed out to improve knowledge about data was the use of infographics for immersive storytelling. According to (Longhi and Cordeiro, 2018), immersive infographics can also be called *hyperinfographics* given their ability to convey more information than simpler non-immersive infographics.

The use of infographics in AR has recently increased in visualization research. (Yantong, Bing and Xiaofeng, 2020), for instance, used AR to visualize the Beijing 2022 Winter Olympics infographics. (Dehghani et al., 2020) presented an AR-based infographics app for enhancing knowledge in biology classes. (Chen et al., 2020; Chen, 2020) proposed a set of tools to help non-expert users create self-authoring storytelling using infographics in AR. In Figure 2.6 are examples of infographics users create using the Chen et al. mobile authoring tool (MARVisT).

Moreover, as introduced by Lee et al. (2021), visceral experiences in immersive environments can help users better understand quantities and scales. Lee et al. argue that *data visceralization* offers us the possibility of “being there” and taking our conclusion about how immense famous monuments are, for example. In the same perspective, the literature has discussed VR applications for a deeper understanding of data regarding various social and environmental problems. Scurati and Ferrise (2020), for example, highlighted the potential of VR to provide motivational and informative experiences.

We believe the concepts of *concrete scales* and *data visceralization* are directly applicable to immersive infographics, leveraging the user’s physical environment as a reference of scale. Prior work has already successfully employed mobile AR as a tool to improve volume understanding in the context of food portion estimation

Figure 2.6 – Examples developed using MARVisT by Chen et al. (2020) (a) An isotype chart combines the reality versus the virtual glyphs. The four mobile phones in the second row visualize their price using the size channel. (b) Michael Knuepfel's keyboard frequency bar chart was recreated and enhanced using MARVisT. Both the color and height channels are used for double encoding. (c) Moodley brand identity's physical infographics recreated by MARVisT using color and height to encode various data attributes. (d) A smiling face created by a user. The face consists of how much fruits the user eat in a week. (e) A calendar visualization where the design displays the sleep duration per night in the March 2018 using the color to represent time. (f) A 3D bar chart that depicts the designer's favorite seat in the library. Color represents the day of the week. Adapted from: Chen et al. (2020)

Source: Chen et al. (2020)

Figure 2.7 – A user looks at how much waste his restaurant produces weekly. The waste is represented by virtual trash bags, which are displayed directly in the restaurant environment using augmented reality. Adapted from: Assor et al. (2024)

Source: Assor et al. (2024)

(Stütz et al., 2014; Rollo et al., 2017).

An early example of immersive AR infographics was recently demonstrated by (Assor et al., 2023; Assor et al., 2024), with the goal of providing users with ecological feedback. They argued that using AR to present waste data has the potential to help people understand the amount of waste they produce. They illustrated this idea through AR prototypes representing a series of examples, such as a week's worth of waste produced by a restaurant, represented by garbage bags, as shows Figure 2.7; the amount of water used in a toilet, represented by one-liter bottles, in Figure 2.8 (*left*); the amount of waste generated to manufacture smartphones, as shows Figure 2.8 (*center*); and the number of plastic cups accumulated over time, in Figure 2.8 (*right*). While their work is closely related to ours, our study extends beyond waste visualizations. More importantly, our main goal is to evaluate the effect of such representations in terms of users' understanding of volumes compared to other approaches.

2.3 Types of Immersive Concrete Scales Infographics

While a systematic survey is beyond the scope of the present work, a brief review of current uses of immersive concrete scales infographics in the literature (section 2.2) and in the news media (chapter 1) suggests two dimensions of particular relevance in their design space: **the adoption of AR or VR** and **the adoption of distorted or real scales**.

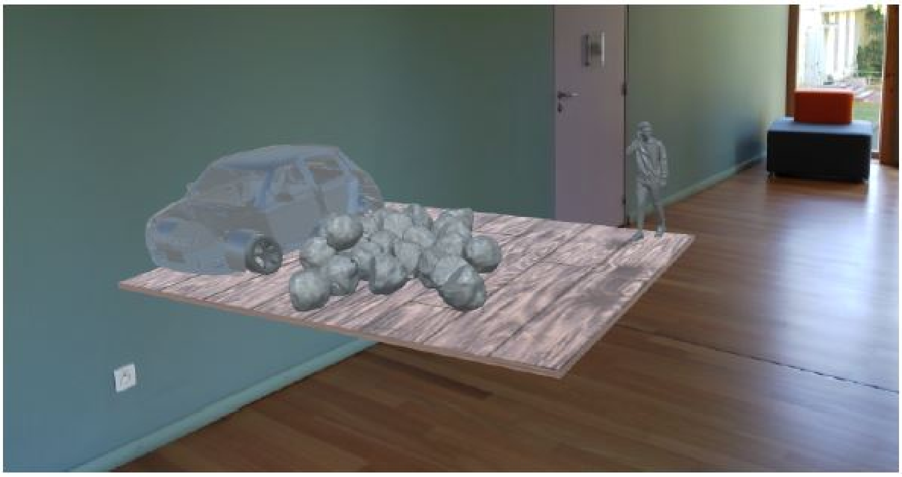
Figure 2.8 – Illustrative examples of AR waste prototyped by Assor et al. (2023). Liters of water represented using water bottles next to the toilets (average flush amount of water). (*left*) Approximate amount of material displaced and emitted to manufacture eight smartphones. (*center*) Quantity of single-use plastic cups accumulated for a given period of time. (*right*)

Source: Assor et al. (2023)

Concrete scales infographics in VR have the key advantage of being unconstrained by the reader's physical space. In this approach, it is possible to demonstrate, for example, the scale of buildings, even if the user is located in an indoor environment. Virtual objects can be added as context for the information, and the user is entirely focused on the information presented. On the other hand, AR infographics have the advantage of leveraging the reader's familiar environment and real objects as a reference for the information. They may also be considered more convenient by readers, not requiring isolation from the physical environment. An additional advantage, particularly within the short-term future, is that AR infographics can be simulated through camera applications for mobile devices such as smartphones and tablets, currently much more widely available than headsets and already associated with news reading by a large number of people (Rosenstiel and Mitchell, 2012; Shearer and Mitchell, 2021).

While the opportunity to display the information on its real scale is the biggest motivation for an immersive perspective, in some cases, the amount of data will inevitably be too large to represent in most environments. While, in this case, the information could perhaps be visualized in AR by asking the user to move outdoors or to a window, another option would be to present a miniaturized concrete scales infographic. In this scenario, a miniature view could also include 3D virtual objects at the same scale for size reference, similar to a conventional concrete scales infographic. Such an example was demonstrated by (Assor et al., 2023) by rendering a virtual avatar and a virtual car next to a large number of trash bags, all in miniature sizes, as shown Figure 2.9. The same scale distortion approach could be used to visualize microscopic particles such as viruses, as discussed above. The

Figure 2.9 – Miniature view of an AR waste, with a car and standing man as reference points. Adapted from: Assor et al. (2023)



Source: Assor et al. (2023)

contribution of miniature or enlarged AR concrete scales models, in comparison to conventional infographics and real-scale ones, remains to be evaluated and is beyond the scope of this work.

Another example of immersive AR concrete scales infographics was recently demonstrated also by Assor et al. (Assor et al., 2024), with the goal of presenting waste accumulation. They argued that using AR to show waste data has the potential to help people understand the amount of waste they produce. They illustrated this idea through AR prototypes representing a series of examples, such as a week's worth of waste produced by a restaurant, represented by garbage bags; the amount of water used in a toilet, represented by one-liter bottles; the amount of waste generated to manufacture smartphones; and the amount of plastic cups accumulated over time. Assor et al. developed the waste visualization scenario in three formats: text, 3D image on a screen, and AR, similar to our study. They evaluated users' emotional feelings over the formats through the PANAS questionnaire, while we used the Smile or Scowl questionnaire. While our work is closely related to theirs, our study extends beyond waste visualizations because our main goal is to evaluate the effect of such representations in terms of users' understanding of volumes in different visualization formats.

2.4 News Infographics and Immersive Visualization for Journalism

Infographics have been largely used in news media. As an example, consider the fact that Brazil reportedly produces 1.52 million tons of waste weekly. Even though this information is clear, it corresponds to an unfathomable amount for most people. To explain how immense this amount of garbage is, the writers at Brazilian magazine *Piauí* offered as a context that this quantity would be the equivalent to six and a half cruise ships, structures widely known for their massive sizes (Gorziza, Ceará and Buono, 2021). To support the comparison, they used infographics to stimulate the readers to think about the real size of such an amount of waste. We used this infographic as inspiration to create one of our scenarios (3).

Looking for new ways to gain greater understanding from readers, journalists are exploring other information formats. Immersive infographics are part of a broader trend of using AR for storytelling, what is sometimes referred to as *immersive journalism*. Immersive views can offer spectators a first-person experience of news or events (Peña et al., 2010), helping them "feel" and "live" the information and thus induce empathy with the story being told. In addition to AR views, VR is also often used, for example, to display panoramic videos and images. With increasing support for mobile AR and the popularization of new headsets, the use of *immersive journalism* approaches is likely to grow.

Providing the viewer with a first-person experience can be an excellent way to use the sense of presence to sharpen people's feelings, as shown by (Peña et al., 2010). According to (Longhi, 2017), narratives in VR, 360-degree videos, or even sliding interfaces could be considered immersive journalism.

In recent years, journalists have explored, in particular, the immersive potential of 360-degree images and videos. In 2015, for example, The New York Times published *The Displaced* (Solomon and Ismail, 2015), an immersive documentary on the life of three children displaced from their homes because of war. After one of the biggest environmental tragedies in Brazil, the filmmaker Jungle produced *River of Mud* (Jungle, 2016), a 360 documentary about the collapse of a mining dam. In another perspective, The Guardian published a VR simulation called *6x9: a virtual experience of solitary confinement* (Guardian, 2016), demonstrating to the viewers how it is to live in a solitary cell. Besides documentaries, VR can also serve as a playful way to visualize data charts, such as experiencing the fluctuations in a Nasdaq stock chart through a roller coaster metaphor, as proposed by The Wall Street Journal (Kenny and Becker, 2015).

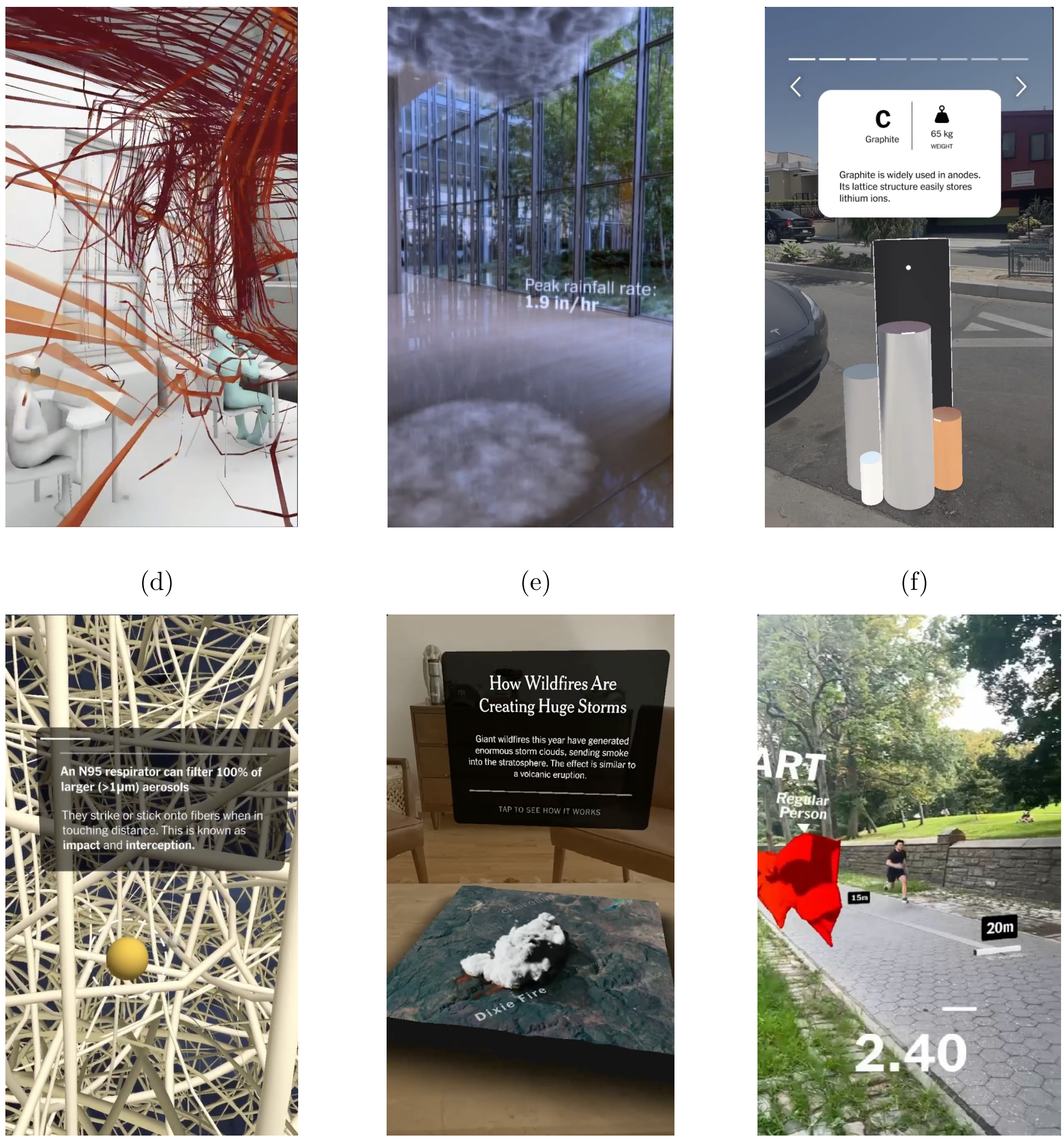
The news media is increasingly integrating AR in its reporting, as exemplified, most prominently, by The New York Times (Clark et al., 2022). The NYT has published at least 31 examples of "AR storytelling" in recent years (Development, 2022), including many that could be classified as immersive infographics. Most of them have been produced in partnership with Instagram and work through the popular Instagram application as an "AR filter" (He, 2020). They complement news articles where conventional and animated infographics are also presented, offering the opportunity for a different perspective.

Some of these examples are strongly connected to the concept of *data visceralization* (Lee et al., 2021). They offer a visceral understanding, for example, of the meaning of a given amount of rain measured in inches (Figure 2.10b) or of the performance of Olympic athletes (Figure 2.10f), either to show the proportion of materials that compose a battery in an electric car (Figure 2.10c). Some of their immersive infographics provide a first-person egocentric perspective, for example, to illustrate how virus particles flow in the air inside a classroom under different ventilation conditions. (Figure 2.10a).

Other examples illustrate how immersive infographics, even in AR, can help explain very small or very large phenomena, such as how face masks intercept virus particles in a much enlarged 3D representation (Figure 2.10d), or how wildfires can cause storms, in a miniature 3D representation. (Figure 2.10e).

Figure 2.10 – Recent examples produced by The New York Times in partnership with Instagram illustrate the design space of immersive mobile AR infographics. They include immersing users into an egocentric room-scale perspective to understand the flow of virus particles in the air (a), conveying a *data visceralization* of the meaning of a given amount of rain (b), or illustrating proportions of materials in electric car batteries (c). In another approach, AR infographics can also engage readers in understanding very small or very large phenomena, such as how masks capture virus particles (d), how wildfires cause storms (e), and show the race performance of a gold medalist (f).

(a) (b) (c)



Source: The New York Times (©2022) (Development, 2022).

3 EXPERIMENT DESIGN

While immersive concrete scales infographics can take multiple possible approaches, as discussed above, in this work, we are particularly interested in investigating their effects when users explore concrete scales metaphors in 1:1:1 scale through mobile devices in AR, allowing the use of the user's physical environment as a scale reference. To this end, we designed a set of three different study stimuli (section 3.1) based on different pieces of news corresponding to quantities of different units of measurement. We also designed a user study (section 3.2) in which we asked 26 participants to experience, through a mobile application (section 3.3), the volumes they estimated after interacting with each stimulus in each of three possible representations (textual, image, and AR).

3.1 Study Stimuli

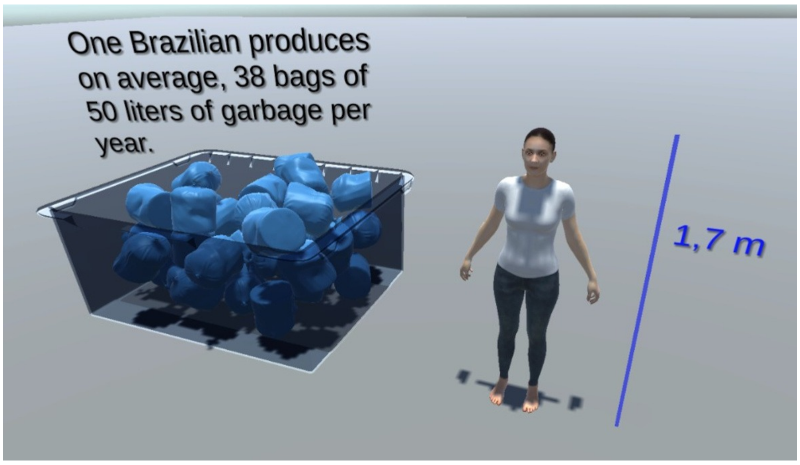
To create a set of immersive infographics, we collected and adapted three examples of news articles presenting different units of quantities: kilograms of trash, liters of water, and amounts of money. We chose these three examples because the units involved are difficult to estimate in text alone without any visual aid. For each adapted piece of news, we generated textual summaries using analogies to familiar objects (shown in the boxes at the beginning of each section below) and developed an infographic prototype using the Unity3D game engine (Figure 3.1 and Figure 3.2). It is noteworthy that while the examples are presented here translated into English, in the study, they were shown in Brazilian Portuguese, the participants' native language.

3.1.1 Waste production per capita (***Trash***)

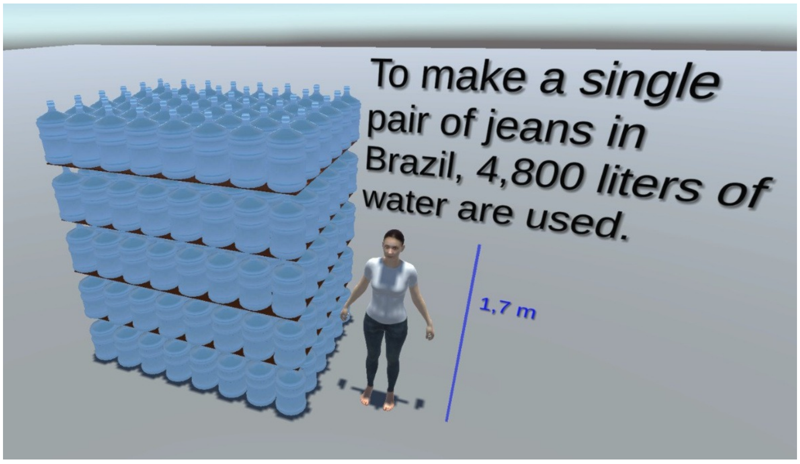
In 2019, 79.06 million tons of urban solid waste were generated in Brazil. Each Brazilian produced an average of 379.2 kg of garbage per year. This weight is equivalent to approximately 38 bags of 50 liters of garbage. Can you imagine how much space it would take to store 38 50-liter bags of garbage? Adapted from (Gorziza, Ceará and Buono, 2021).

Figure 3.1 – The static infographics we generated for our three selected pieces of news. The static infographics employ familiar objects (50-liter trash bags, 20-liter water gallons, and R$100 banknotes) to convey the information size. Additionally, following common practices in journalistic infographics, they include a 1.7m human representation to further contextualize the information size.

(a) Trash



(b) *Water*



(c) *Money*

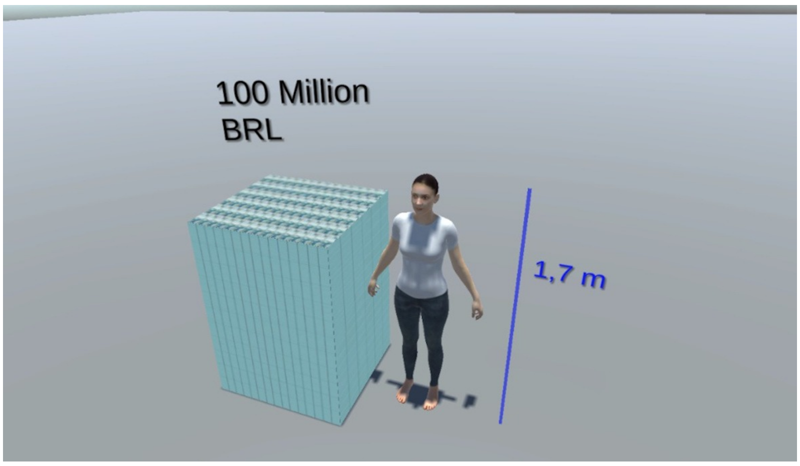


Figure 3.2 – The immersive concrete scales infographics we generated employ the same familiar objects used for the static infographics (Figure 3.1). However, they are rendered in 1:1:1 scale in the user's real environment for exploration through our tablet-based mobile AR application. Note: while text contrast appears low in the screen captures, the participants considered it easily readable in our experiment.

(a) Trash

(b) *Water*

(c) *Money*

In Brazil, we often find news telling us a quantity in kilograms when, in fact, the objective is to inform a volume. In this situation, a reader might try to imagine how much space that amount of garbage takes up. However, thinking about the volume of something with just mass information is physically wrong since volume depends on the density of a material. Thus, if we use infographics to represent the volume, the reader can better understand the amount of garbage shown in the news reports. The garbage bags in Brazil are measured in liters, so we decided to use a bag of 50 liters because it is largely used at homes, and the 50-liter bag can store an average of 10 kilograms of trash. We know that this chosen metaphor may not make sense for other countries. However, it can be easily adapted following the same logic but using different parameters of measures.

Using this metaphor, we decided to adapt this news by adding the information that 379.2 kg is approximately 38 bags of 50 liters of garbage. In this way, we inform the same amount from a different perspective to give the readers physical references to improve their comprehension. Therefore, using this news as a reference, we created a 3D model to show this quantity of garbage to the readers (Figure 3.1a). Garbage bags were piled in a simplified manner inside a rectangular container so participants would find it easy to understand and specify their volume in the study.

3.1.2 Use of water in manufacturing (*Water*)

Making a pair of jeans in Brazil consumes more water than a person in a month. According to the United Nations, a person uses about 3,000 liters of water per month, while manufacturing a single pair of jeans in Brazil uses about 4,800 liters, equivalent to approximately 240 gallons of 20 liters. Can you imagine how much space 240 gallons of 20 liters of water would occupy? Adapted from (Ceará and Buono, 2021).

Although liters are a unit of volume, if the reader does not know how much space a thousand liters takes up, they will hardly understand how much water is needed to make a pair of jeans and how much water a person needs in a month. Reflecting on this problem, we decided to rewrite this news by adding the information that 5,200 liters correspond to 260 familiar gallons of 20 liters. For this scenario, we decided to use water pumps of 20 liters because in Brazil these types of gallons are very popular and would be easily recognized by users. Also, like in the garbage scenario, this metaphor of 20-liter gallons can easily be replaced by other types of water storage objects such as PET bottles. We also adapted the original information, changing the number of liters from 5,200 to 4,800 so that we could construct a prototype with a regular prism format, which we considered fairer in order to assess users in the experiment (Figure 3.1b) in a way similar to the regular container used in the *Trash* scenario.

As a consequence of the selected metaphors, in both *Trash* and *Water* scenarios, the infographics' total volumes are larger than the minimum possible volume occupied by the amount of water or trash mentioned in the news. This is due to the empty spaces around the objects' irregular shapes when stacked in a natural way. Our intention was to measure the understanding of the estimated volume of these concrete scales metaphors, and even in the textual analogies, participants were asked to imagine a stack of these kinds of objects in their estimations.

3.1.3 Amount of money in a lottery prize (*Money*)

> *A prize of R$ 100 million from Mega-Sena can yield a monthly salary of R$ 896 thousand for the winner. If you invest the prize money in a simple fixed-income investment, a certificate of deposit that pays 100% of the CDI index, with the current interest rate at 12.65%, the prize will yield R$ 10.7 million in the first year. Can you imagine how much space 100 million reais in R$100 banknotes would occupy?* Adapted from (Cristóvão, 2022).

It is common to find news articles referring to vast amounts of money, as illustrated by this one on Brazil's most famous lottery prize. It is intuitive to think about things one can buy with that money. Another common way of representing large amounts of money is to describe how much space it would take up if we stacked familiar banknotes. For this scenario we decided to use money in R$100 banknotes because this metaphor is a classic example already discussed in prior concrete scales infographics work (Chevalier, Vuillemot and Gali, 2013; Lee et al., 2021), a consequence of the fact that large quantities of money can be considered hard to conceive. We adapted this excerpt to ask participants about the space that 100 million BRL in R$100 banknotes would occupy (Figure 3.1c). The value of 100 million was also selected so that the resulting representation would fit our selected test environment. During development, we experimented with different examples, and concluded that a larger amount, such as 1 billion, would be too large for users to view on a tablet, compromising the immersion of the visualization.

3.2 User Study Design

We designed a within-subjects study to test our set of infographics (i.e., Trash, Water, and Money). With them, we intended to measure to what extent a mobile AR visualization can help people understand volume quantities better than conventional approaches.

Therefore, for each infographic, we provided three different manners of reading and visualizing the information: (i) a simple text describing the news with analogies to familiar objects, (ii) an image showing a 3D infographic about the news containing a human-sized reference, and (iii) an immersive concrete scale infographic in mobile AR showing the same infographic of the image but in the user's environment and supporting immersive exploration.

Since our goal is to evaluate each visualization approach under its expected usage mode in a real news reading scenario, in the immersive condition, users are not constrained to the same viewing angle predefined by the static image infographic. Instead, they are allowed to walk around to get a better understanding of the space occupied by each 3D model, as they hypothetically could also do in their homes. However, we decided that the participants should all take the tests in the same place, a common environment often used by participants at the university so that everyone would have the same physical objects as spatial reference.

3.2.1 Hypotheses

Recent works on the use of infographics in immersive settings have mainly assessed emotions (Chirico et al., 2021; Assor et al., 2023; Assor et al., 2024). However, the main idea of using concrete scales infographics is to convey the exact or best possible estimated value of the data being shown to spectators through some metaphor they know well (Chevalier, Vuillemot and Gali, 2013; Lee et al., 2021).

In this work, our aim is to assess how much infographic visualization in mobile AR helps readers understand quantities. We opted to conduct our study to estimate only volumes for evaluating three visualization formats (Text, Image, AR) in three scenarios based on news pieces (Trash, Water, Money) to maintain the experiment within a limited time duration. Since what matters is to use a metaphor based on common knowledge, volume estimation seemed to be a natural choice for representing the quantities mentioned in the news. Furthermore, we also measured participants' feelings using a specific metric for infographics.

We defined three hypotheses for our study:

- H1 Interacting with a mobile AR infographic will lead to a smaller volume estimation error than an Image only.
- H2 Viewing an Image infographic will, in turn, lead to a smaller volume estimation error than textual analogies only.
- H3 Interacting with a mobile AR infographic will lead to a higher degree of *concerned*, *sadder*, and *awestruck* reported feelings compared to both Text and Image.

H1 expresses the main objective of this study and corresponds to our speculation that immersive concrete scales infographics should improve the understanding of volume information by allowing the use of the physical environment as a reference. **H2** reinforces the expressivity power of infographics in general, positing that both immersive and non-immersive ones will contribute to the user's understanding. In addition to the quantitative measures, we will also verify the participants' opinions through **H3**, and we believe they will feel more impacted by the immersive concrete scales infographics than by the other two conditions.

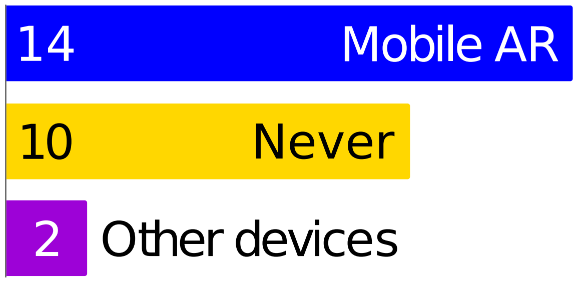
3.2.2 Procedure

We recruited 26 graduate and undergraduate volunteers from our University (17 male, 8 female, and 1 gender not informed, mean age 25.15, SD 6.5). Before starting our user study, we asked them two questions, as shown Figure 3.3. Ten participants reported never having used AR before, while 14 had already used mobile AR, and 2 had already used it through other devices such as headsets. Moreover, 22 participants reported being used to reading the news on their smartphones.

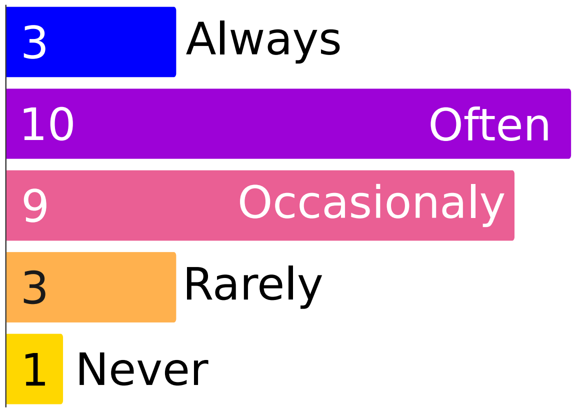
The three pieces of news were presented to participants in counterbalanced order using the Latin square, and so were the visualization formats except for Text,

Figure 3.3 – Questions asked to the participants before starting our user study.

(a) Question 1: Do you already have used AR before?



(b) Question 2: How often do you read news in your smartphone?



which the participants always viewed first. Our reasoning was that viewing any infographic (either Image or AR) before the textual version would inherently compromise the user's original assessment, and results would not be accurate for text modality. Moreover, using this approach, we could measure the surprise effect of text modality versus the other modalities. In total, we had six possible order combinations groups as shown in Table 3.1. Also, all the participants did the tasks in the same controlled space that had some desks, chairs, trash cans, and poufs.

After viewing the news in each format (Text, Image, and AR), we asked the

Table 3.1 – We separated the participants into six groups, each doing the tasks differently to balance our user study.

Groups	Training			Trash			Water			Money		
A	Txt	Img	AR	Txt	Img	AR	Txt	AR	Img	Txt	Img	AR
B	Txt	Img	AR	Txt	AR	Img	Txt	Img	AR	Txt	AR	Img
	Training			Water			Money			Trash		
C	Txt	Img	AR	Txt	Img	AR	Txt	AR	Img	Txt	Img	AR
D	Txt	Img	AR	Txt	AR	Img	Txt	Img	AR	Txt	AR	Img
	Training			Money			Trash			Water		
E	Txt	Img	AR	Txt	Img	AR	Txt	AR	Img	Txt	Img	AR
F	Txt	Img	AR	Txt	AR	Img	Txt	Img	AR	Txt	AR	Img

participants to interactively adjust a rectangular prism in mobile AR to represent the volume reported in the news (subsection 3.3.1). With the estimated volume provided by the users, we expect to measure how well each visualization modality helps participants understand the actual volumes described in the news.

The training was executed in the same order for all groups as shown Table 3.1, and the tasks were performed in the same order of the Figure 3.4. However, for the Text format, we asked the participants to imagine a chair and then draw a prism with the size of the chair that they had imagined, as in Figure 3.4-1. We showed them an image of a chair next to the person with the height indicated, as in the static infographics of the Figure 3.1. Then, they had to draw a prism to replicate the same volume indicated in the image, as in Figure 3.4-2. For the last training step, we showed a chair in mobile AR and then asked them to draw a prism that replicates the size of the 3D chair, as in Figure 3.4-3.

In addition, we asked participants how they felt when visualizing and reading each news piece in the three visualization modalities to gather their feelings and evaluate whether they changed depending on the visualizations. For this, we used the *Smile or Scowl?* infographic taxonomy developed by Lan et al. (Lan et al., 2021), who categorized feelings into twelve moods (six smiles and six scowls) as a result of two subsequent user studies where participants reacted to a set of 976 infographics on different topics.

3.3 Mobile App

We developed an Android mobile application to support reading and visualizing the news. On the application's initial screen, there were 12 buttons, each representing a specific task for the user, in Figure 3.5. The first column of buttons corresponds to the test tasks performed before the start of the experiment, as detailed in Table 3.1. Clicking on the text tasks buttons directed users to a new screen containing the full text of the news. On each text screen, there was a cube-shaped button that redirected participants to the volume specification tool screen, as shown Figure 3.6. The volume specification tool is discussed more detailed in subsection 3.3.1.

For the image viewing tasks, users were directed to another screen containing an infographic associated with each news article, with an additional button leading

Figure 3.4 – The participants of group A perform the tasks with the Trash scenario after the Training in the following order: (1) The user is presented with the Text format, then draws the prism in AR to estimate the volume reported in the text. (2) The user is presented with the static infographic as an Image and then draws the prism in AR to estimate the volume reported in the static infographic. (3) The user is presented with the immersive infographic in mobile AR, they could walk around the infographic and then draws the prism to estimate the volume reported in the AR infographic.

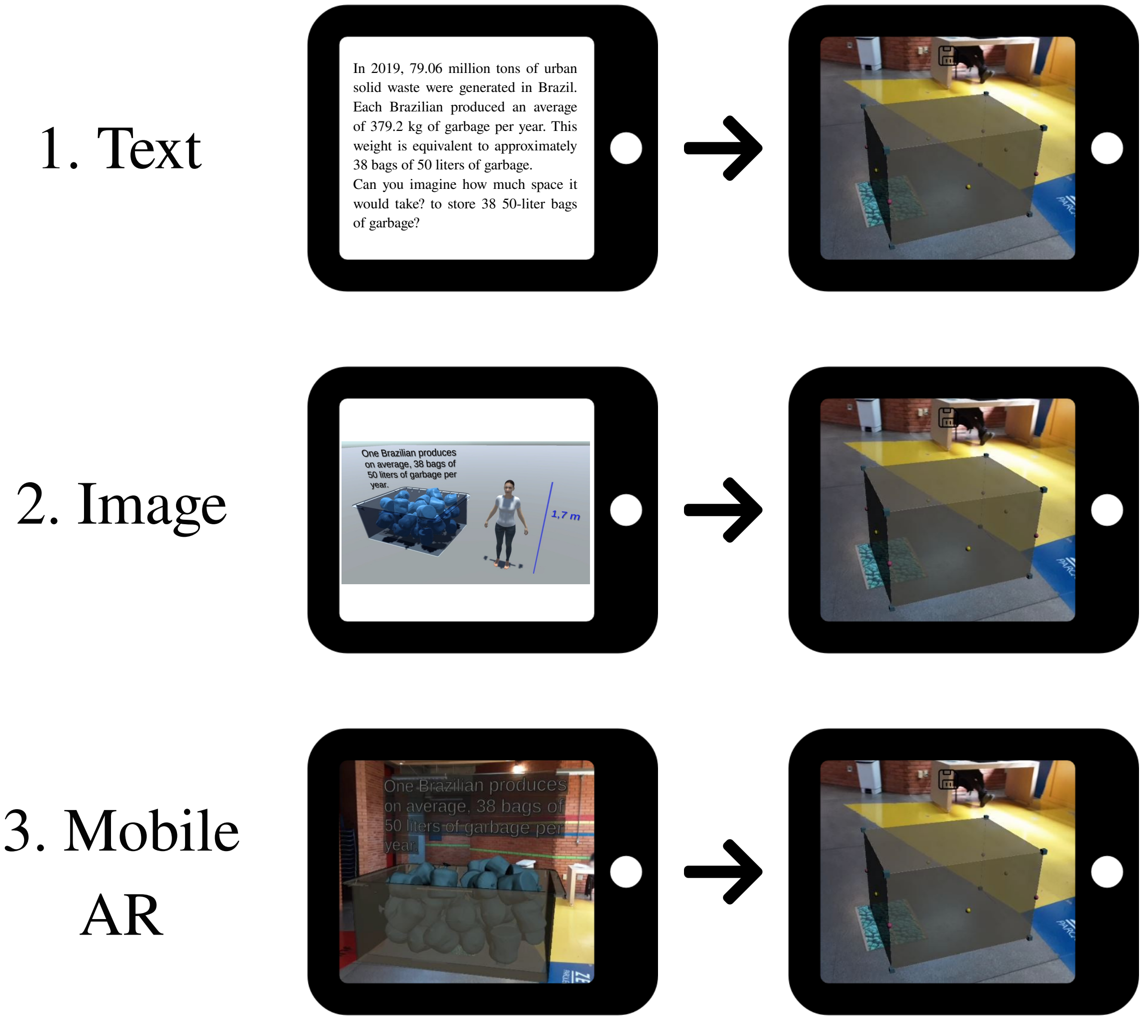


Figure 3.5 – Screenshot of the mobile app home menu. Note that the texts of the app was in Portuguese because the participants were Brazilian native speaker.

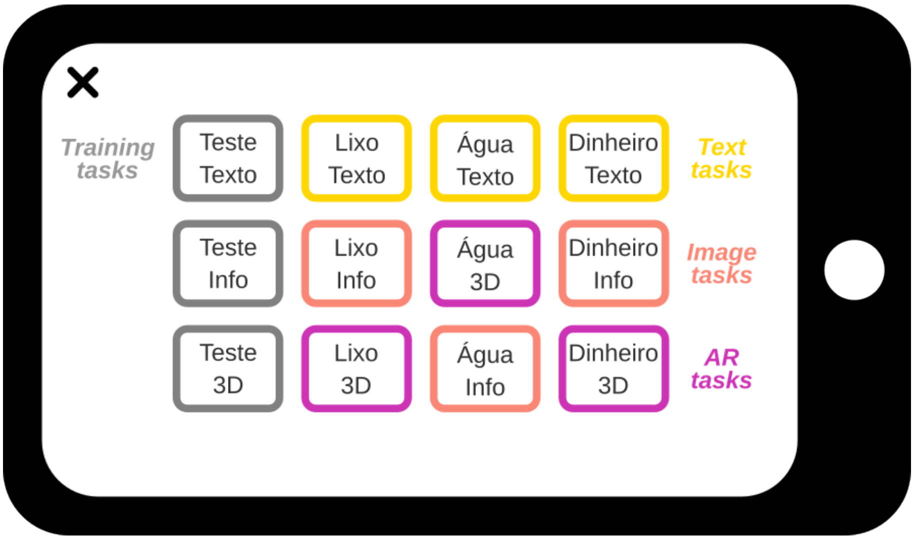
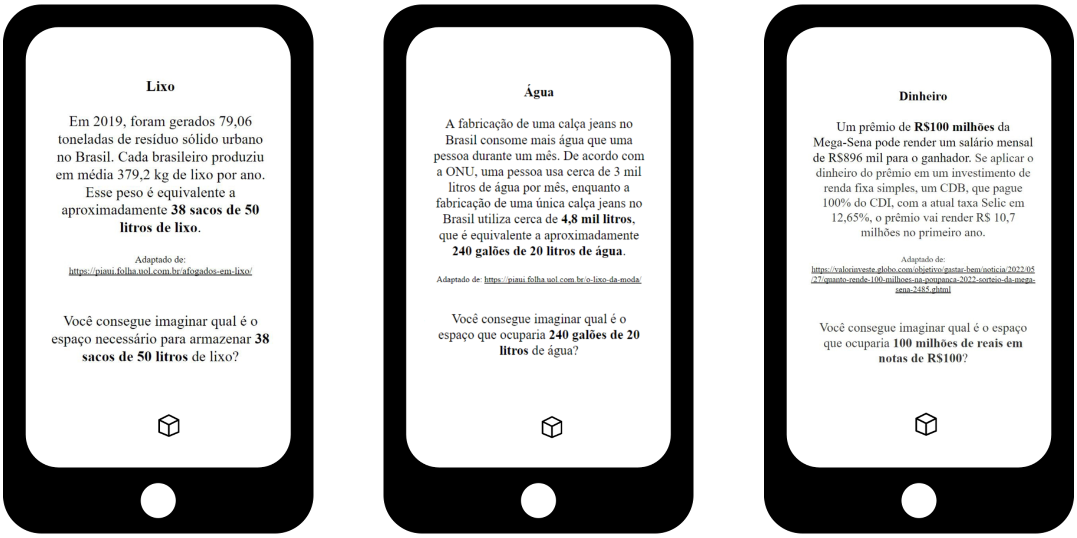


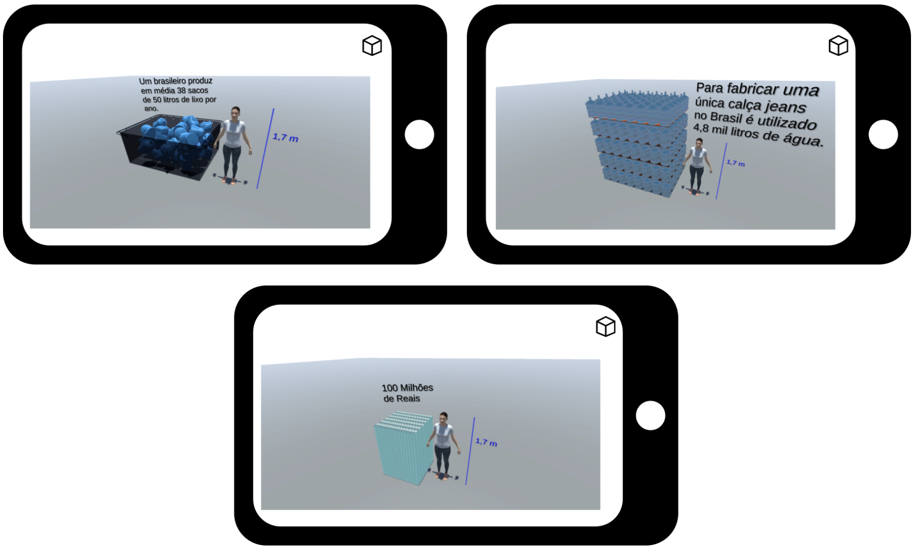
Figure 3.6 – Screenshots of the Text tasks. Note that the texts of the app was in Portuguese because the participants were Brazilian native speaker.

(a) Trash (b) Water (c) Money



them to the volume specification tool, as detailed in Figure 3.7. In the AR news viewing tasks, participants were redirected to a screen that allowed using the camera. On these screens, participants needed to point the camera at markers on the floor, and the 3D infographics were then overlaid in AR, as illustrated in the images Figure 3.2. These screens also included a button in the top right corner to access the volume tool.

Figure 3.7 – Screenshot of the Image tasks. Note that the texts of the app was in Portuguese because the participants were Brazilian native speaker.



3.3.1 Volume Specification Tool

As introduced in Sect. 3.2.2, after reading and viewing the news in each of the three modalities, Text, Image, and AR (the order of the last two being always counterbalanced), we asked participants to draw, using a mobile AR tool, a rectangular prism to represent the volume discussed on the news. We used the MRTK interaction toolkit (Microsoft, 2022) for Unity3D to implement this tool, enabling efficient prism manipulation through widgets. Figure 3.8 shows an example of a rectangular volume prism. Users may change the size of the prism by dragging its corners (blue cube widgets). With the pink sphere widgets in the vertical edges, participants can rotate it around the y-axis. Finally, with the yellow sphere widgets in the middle of each prism face, it is possible to move the prism along the floor plane. With these three features, participants can adjust the size of their prism, rotate and translate it to bring it closer to real objects in the environment, and use them as a spatial reference to provide reasonable volume estimations. The system automatically records the final selected volume.

3.4 Design Choices

In developing our experiment, we made several critical design choices to ensure an optimal user experience and practical functionality. This section outlines

Figure 3.8 – Our AR volume specification tool allowed users to translate, rotate, and scale a semitransparent rectangular prism to indicate their estimations for the volume informed in the news. Real-world objects available in the environment could serve as size references.

the rationale behind these decisions, which include the selection of mobile platforms, strategies for user study design, the use of markers in augmented reality, and the choice of development tools.

3.4.1 Why a mobile app?

Smartphones and tablets are widely used and are already part of people's daily lives. Phones and tablets are easily portable and are typically less expensive, avoiding the need for further investments in specialized equipment. Familiar touch-screens and intuitive interfaces make Mobile AR straightforward for users to interact with. It is easier for developers to create and distribute AR applications through established app stores and platforms. It is generally more comfortable as it does not require additional wearable equipment, which can be more user-friendly for casual use.

We used a Samsung Galaxy Tab S6 Lite to run the application. This tablet is an excellent choice for AR applications thanks to its 10.4-inch display, which offers a spacious, immersive screen for effective interaction. It strikes an outstanding balance between performance and affordability, making it a cost-effective solution that delivers sufficient power for a wide range of AR tasks. Its lightweight and portable design enhances usability, while the user-friendly Android interface ensures easy operation. Positioned in the mid-range price bracket, the Galaxy Tab S6 Lite is well-suited to the general population, offering a practical and accessible option for everyday users.

3.4.2 User Study Counterbalancing

We deliberately decided not to fully counterbalance our conditions because we considered that evaluating textual analogies after seeing them visually could benefit the result of the text volume estimation. Therefore, we decided to always run the text before the other two modalities (image and augmented reality) to prevent visual learning from improving the result of the text volume estimation.

3.4.3 AR with Markers

We used a marker to position the infographics in the camera field of view with the correct scale, as we needed to ensure that the virtual objects had an accurate concrete scale and not an approximated one. For that, we used the Vuforia software development kit. In this work, we could not use localization methods based on structure from motion using a monocular camera as these methods do not guarantee a correct scale (Szeliski, 2022).

3.4.4 Unity 3D

Unity 3D is a good choice for building AR mobile apps due to its cross-platform capabilities, allowing developers to create applications for both iOS and Android from a single codebase. It offers robust support for major AR frameworks like ARKit and ARCore, enabling the development of advanced AR features such as object tracking and spatial mapping. Unity's extensive Asset Store provides a wealth of pre-built assets and tools, accelerating growth and reducing time spent on asset creation.

Additionally, Unity's robust development environment includes a visual editor, real-time 3D rendering, and flexible scripting with C#, all of which facilitate the creation of high-quality, interactive AR experiences. Its large community and comprehensive support resources further enhance the development process, making Unity a practical and efficient choice for creating engaging and optimized AR mobile applications.

4 RESULTS AND FINDINGS

In this section, we report the results of our comparative user study regarding volume understanding, infographic-induced feelings, and users' perceptions. For increased readability, we structured this section around our most relevant findings. For the statistical comparisons, as our samples were not parametric, we used the Friedman test with the Wilcoxon-Nemenyi-McDonald-Thompson post-hoc test (Hollander, Wolfe and Chicken, 1999). The significance is indicated as follows: ($*$) for $p < 0.05$, ($**$) $p < 0.01$ and ($***$) $p < 0.001$.

4.1 AR infographics consistently led to smaller volume estimation errors across the different news (H1 ✓)

Figure 4.1 shows the percentage of volume estimation error for each one of the news examples and visualization modalities, as well as an aggregation of all study trials across examples. Meanwhile, Figure 4.2 shows the distribution of the absolute volume estimates for each news item with their respective real volume values indicated by a pink line.

We were particularly interested in observing how AR would compare to Image, i.e., to what extent AR infographics would be more helpful for volume understanding than conventional infographics.

Grouping all tasks together, as shown in Figure 4.1–bottom-right, the percentage of error is significantly different across all formats. Users were more accurate in estimating volumes for news presented using Image than Text ($**$); the same holds for AR when compared to Text ($***$) and Image ($**$). While Image resulted in an average error of 55.12%, AR led to an average estimation error of 37.57%, i.e., a reduction of 31.8%. These findings confirm H1, indicating that AR outperforms Text and Image for volume understanding.

We also analyzed the three different news scenarios individually. In the *Trash* scenario (Figure 4.1 –top-right), our study was also able to identify a significant improvement in estimation accuracy when using AR in comparison to Image ($**$). In this scenario, Image led to an average volume estimation error of 65.93%, while AR resulted in 44.43%, a reduction of 32.6%. In the *Water* and *Money* scenarios, we could not say AR was better than Image, as we could not find statistical signif-

Figure 4.1 – Results of the error (percentage) in volume estimation for each piece of news. Considering the combination of all scenarios, AR led to a significantly smaller estimation error compared to both other modalities, and the same was also observed in the Trash scenario specifically. Both types of infographics led to significantly smaller estimation errors compared to textual analogies alone.

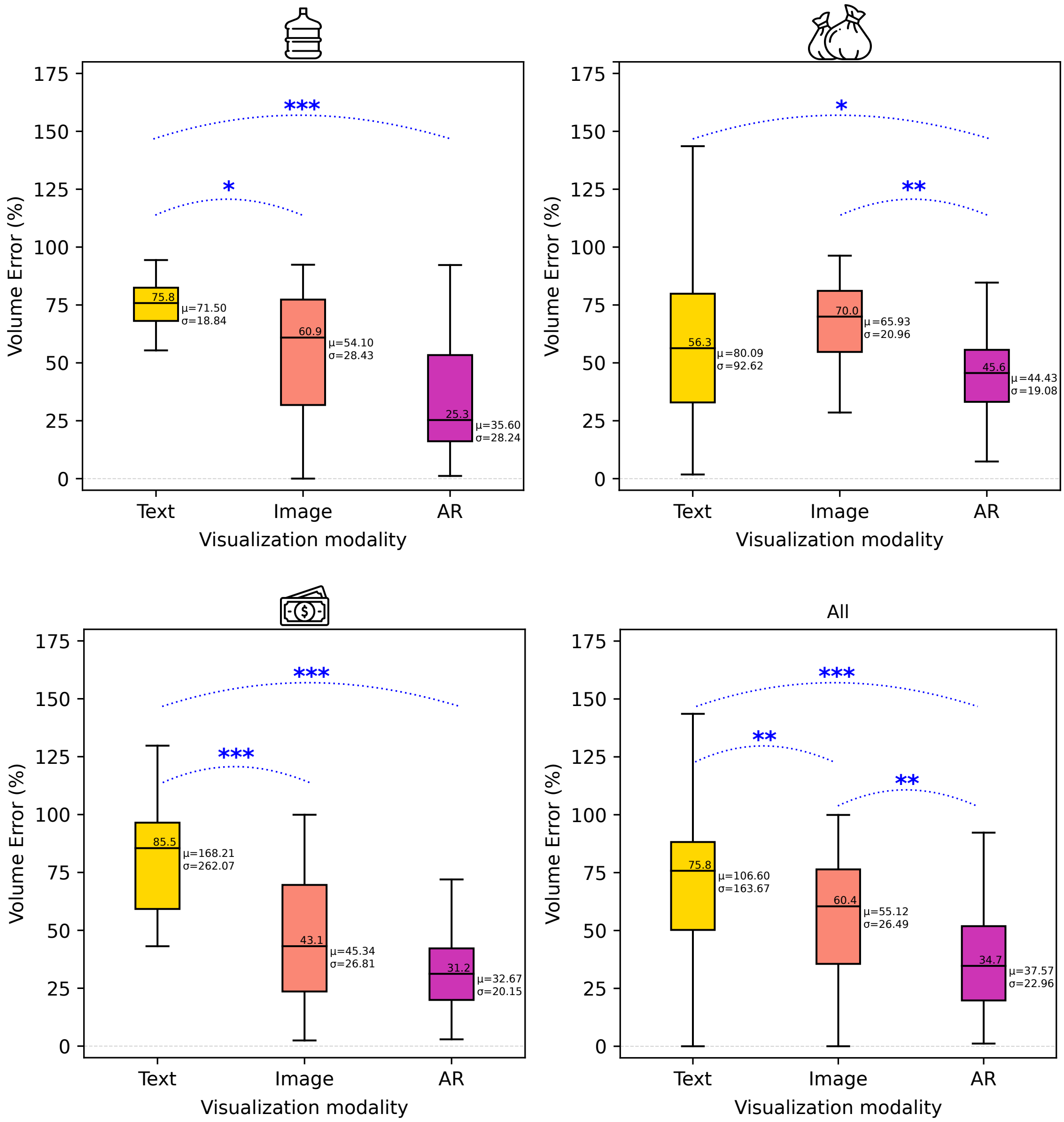
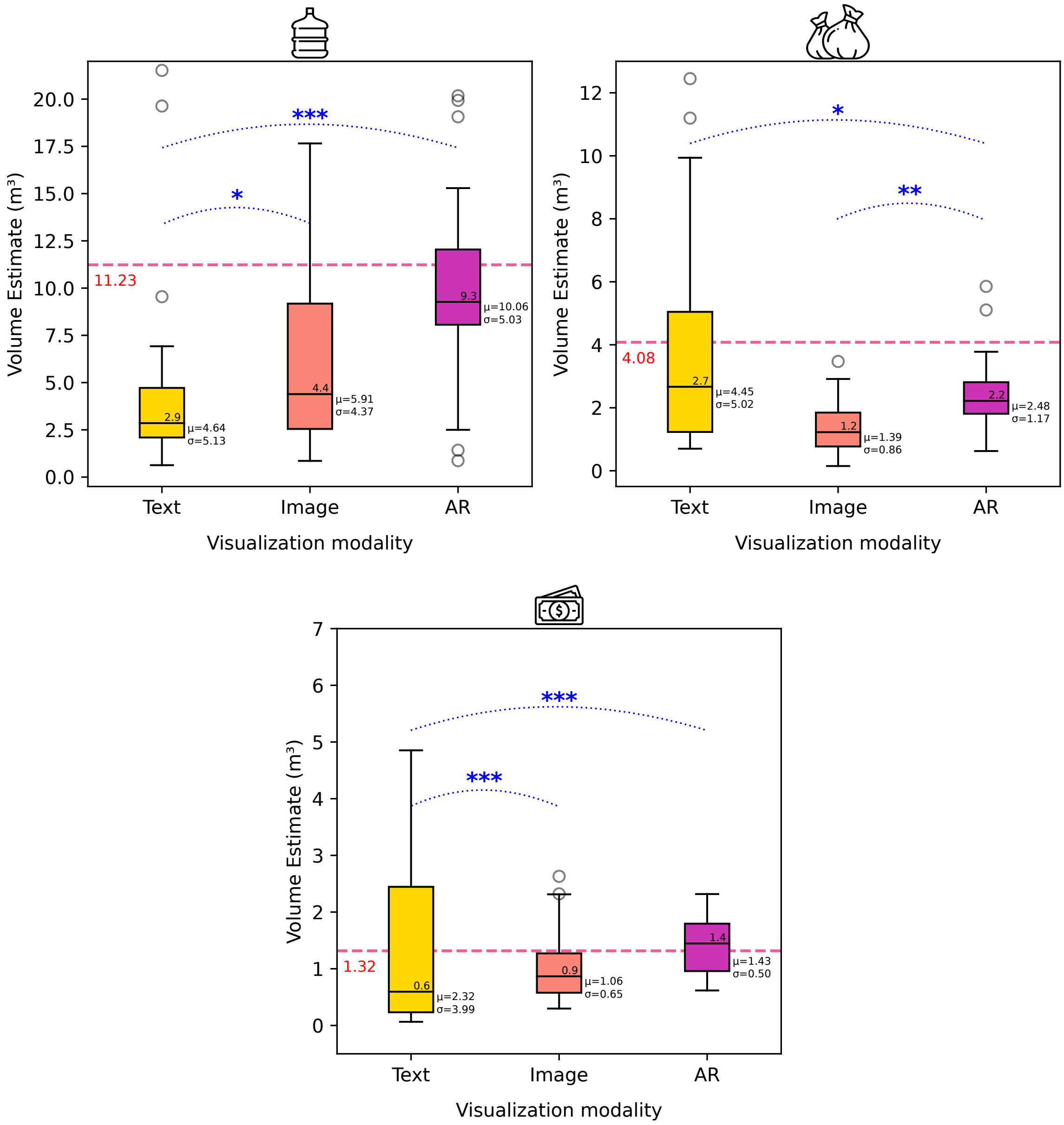


Figure 4.2 – Results of volume estimation in m^3 for each news piece: *Water*–left, *Trash*–center, and *Money*–right, presented from the largest to the smallest. The pink lines indicate the correct volume of each 3D infographic representation. Note that each plot is on a different y-scale.



icance between them. However, the volume estimation of the *Money* AR was the nearest to the correct volume, as shown Figure 4.2. Analyzing both the *Water* and *Money* scenarios, Image led to an average volume estimation error of 54.10% and 45.34%, respectively, while AR had 35.60% and 32.67%. Therefore, for the *Water* and *Money* scenarios, we had a volume estimation error reduction of 18.4% and 12.67%, respectively.

4.2 Both infographics types led to a better comprehension compared to textual analogies alone (H2 ✓)

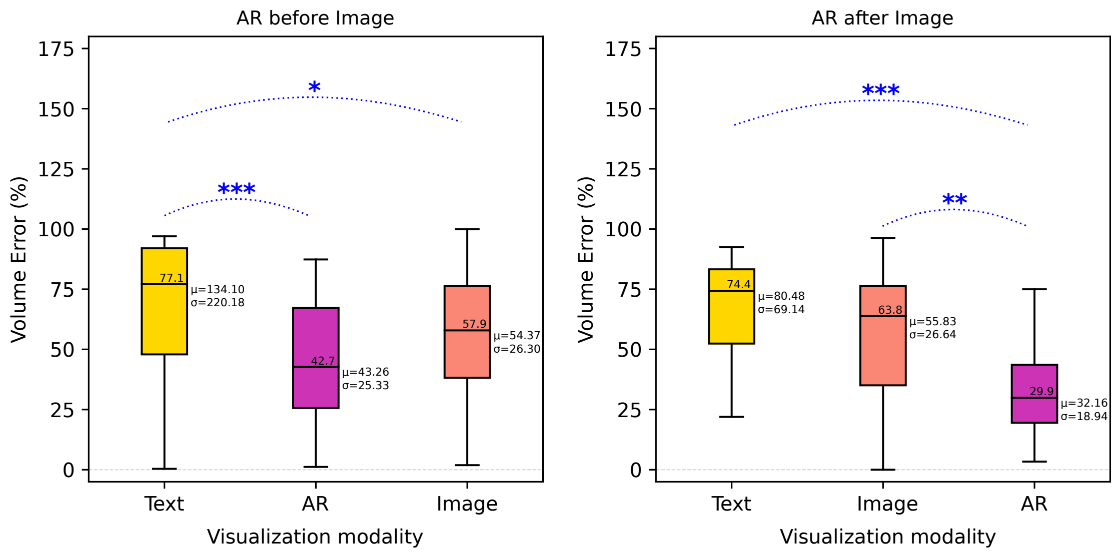
When aggregating data from all case studies, both Image and AR present significantly lower error rates compared to Text. While Text led to an average estimation error of 106.6%, Image resulted in an average error of 55.12% ($**$, a reduction of 48.3%) and AR, 37.57% ($***$, a reduction of 64.8%). Figure 4.1 further reports the median and standard deviation statistics. This result confirms the contribution of both immersive and conventional infographics for volume understanding, thus confirming hypothesis H2. This is not entirely surprising given the long tradition of the use of infographics to complement textual information.

Considering the analysis of the scenarios individually, Image notably led to significantly smaller volume estimation errors compared to textual analogies alone in all scenarios except for *Trash*. AR led to significantly smaller errors compared to Text for all scenarios (Figure 4.1).

4.3 Possible order effect corroborates the larger contribution of AR infographics to volume understanding

We also verified a possible learning effect due to the order in which Image and AR visualization modalities were presented to the users. Figure 4.3-left (*AR before Image*) and Figure 4.3-right (*AR after Image*) show the results of the analysis performed with the users divided into these two groups. We observe that when the news was presented in the *AR after Image* order (Figure 4.3–right), we cannot say that the users were more accurate with the Image than with the Text visualization, but the results with AR are significantly better than with Text ($***$) and Image

Figure 4.3 – Results for all tasks combined divided into two groups (*AR before Image* and *AR after Image*) yielded different patterns, suggesting a possible learning effect due to order. While AR always showed the smallest error volume estimate, AR and Image were significantly different only when Image was experienced first. This suggests that seeing the AR infographic first was apparently more helpful than the opposite way.



(∗∗). On the other hand, Figure 4.3–left shows that the Image visualization is more accurate than the Text(∗), and AR is also better than Text (∗ ∗ ∗) when the AR visualization is presented before the Image. However, this time, we cannot affirm that AR is significantly better than the Image visualization for volume estimation.

Analyzing these results, the Image visualization is only better than the Text when presented after the AR modality. Likewise, the Image is not significantly worse than the AR when the latter is presented before the former (unlike the opposite case). This suggests a potential learning effect, with AR increasing the performance of the Image visualization as the user can memorize the AR visualization and use it to perform the estimation based on the Image modality.

4.4 AR infographics led to the longest task completion times, and static image ones to the shortest

Figure 4.4 shows the average total task completion times for each scenario and condition, as well as for all scenarios combined. This includes the time from the moment the participant started interacting with the infographic or text to the moment they submitted their prism volume estimate. We opted not to decompose the task completion times into "interaction time" and "estimation time" as each participant organized the task execution differently, sometimes starting the estimation cognitive process while still viewing the text or infographic. We further argue that the effort to construct the prism is constant, and any differences between conditions should be attributable to the affordances of the different visualization modalities.

While the data on Figure 4.4 shows the shortest task completion is achieved using static 2D infographics in all scenarios, this is not an indication that it is also the best visualization modality. By combining the times measured and our observation of the experiment sessions, we noticed that the Text modality takes longer due to the time the users took reasoning about the volumes without the help of any visual cue. Conversely, the long time spent in the AR modality was due to the exploration of the data in the physical space. The users move around, exploring the 3D infographics from different perspectives and looking for cues in the real environment that help them to draw the prism. While in the Text modality, the long time spent may be seen as negative (it did not help to better estimate the volume) as show (Figure 4.5), in the AR modality, it is positive. In the Trash scenario, the user that expended more time engaged with the data, in average had more precise volume estimation, in AR modality, as show (Figure 4.5–top).

Indeed, we should say that shortening the time spent by users consuming news is not a goal. Usually, news media prioritize engaging readers by providing them with the best user experience possible, which might be obtained with AR infographics, since as we can see in (Figure 4.5–bottom-right), on average, for all tasks in AR modality, the users spent more time-consuming news if compared with the other modalities.

4.5 Readers tended to underestimate volume sizes before seeing them depicted visually through infographics

Figure 4.6 depicts answers to the question we asked participants at the end of each task: *How big or small was the amount you imagined when reading the news before visualizing it through this infographic?* While shades of green indicate that participants subjectively acknowledged having initially overestimated the sizes, shades of red correspond to the opposite.

Analyzing the results for the *Trash* scenario, we can see that before viewing

Figure 4.4 – Total task completion times in seconds for each piece of news. Task completion comprises the news consumption, the content understanding, the reasoning about the quantities communicated, the interaction with the text/infographic, and the volume estimation. When analyzing all news scenarios combined, Text led to longer times than Image by requiring cognitively estimating volumes without any visual cues, while AR led to the longest times due to the need for spatial interaction.

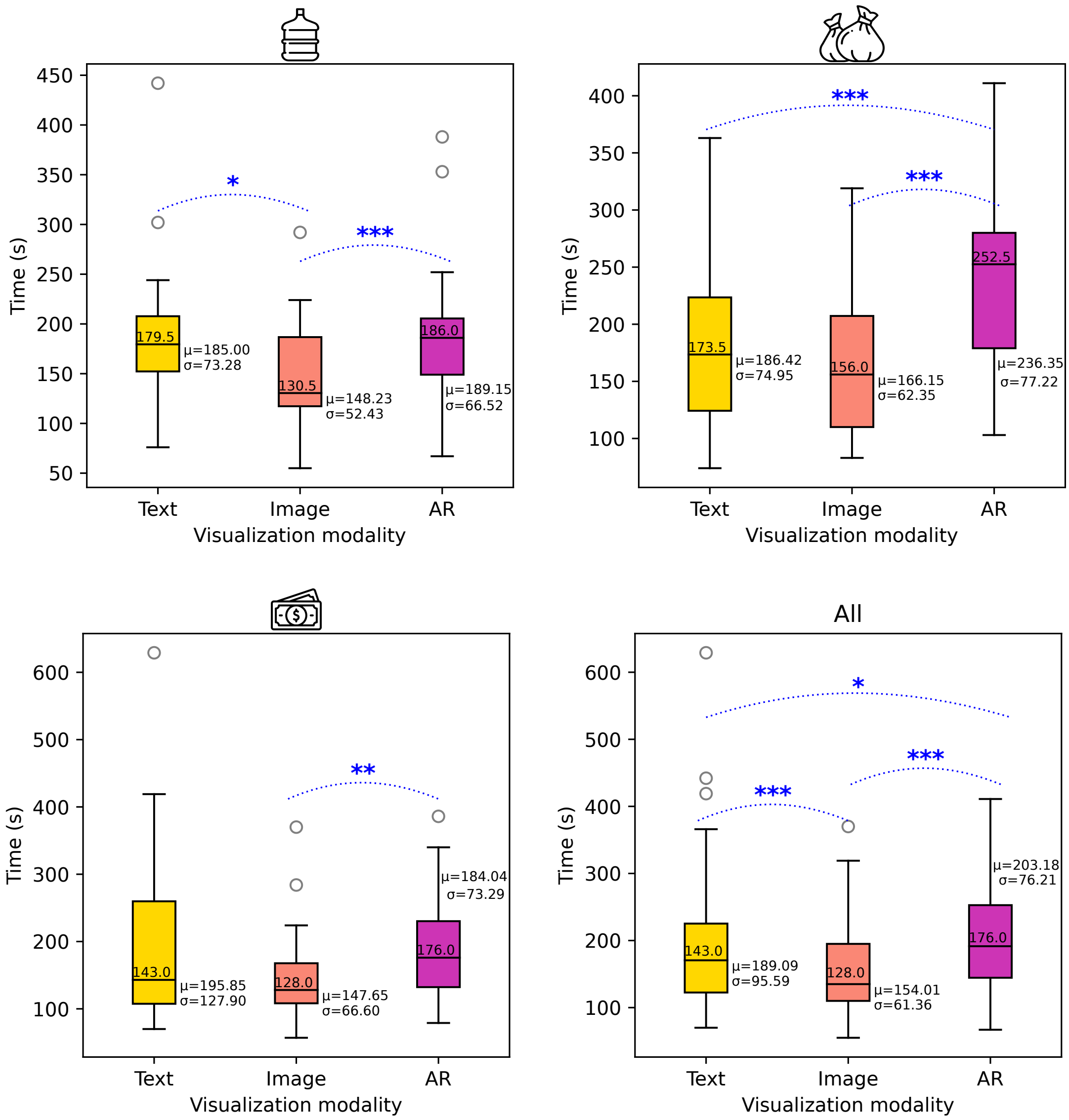


Figure 4.5 – Volume estimation percentage error in Trash scenario. (*top-left*) Time expended in Trash scenario. (*top-right*) Total of volume estimation percentage error combining all scenarios. (*bottom-left*) Time expended in all scenarios. (*bottom-right*)

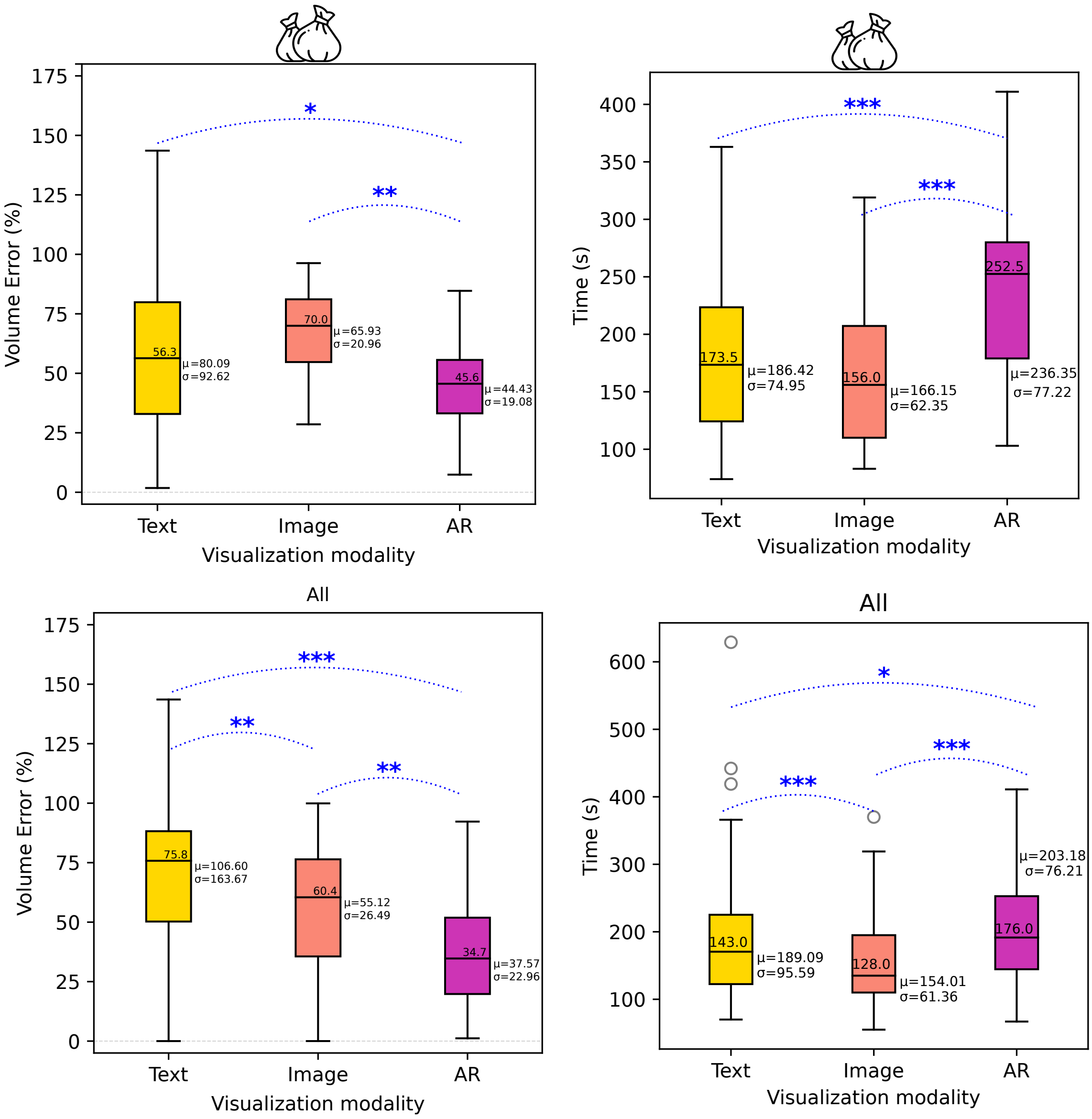
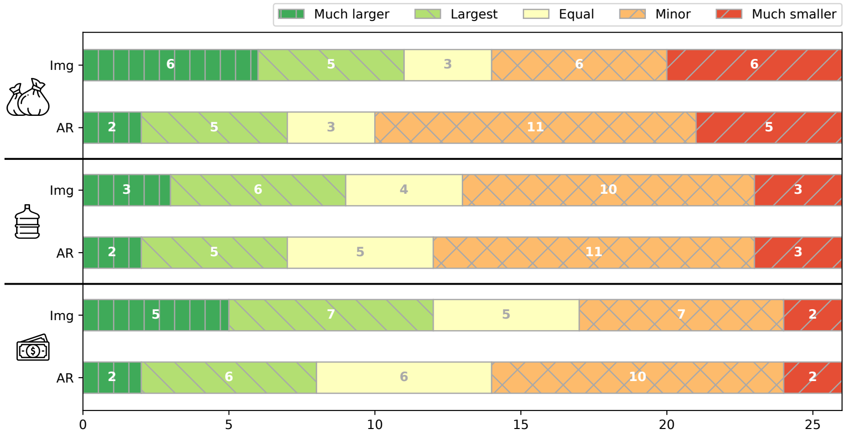


Figure 4.6 – How participants' expectations before seeing each kind of infographic compared to the information in the infographic. Green indicates participants who had overestimated the size, while red indicates underestimations. In general, participants tended to underestimate the information received before seeing the infographics.



in AR, 16 participants thought the volume was smaller or much smaller than it actually was, whereas in the Image visualization, the voting was more balanced, and only 12 thought the volume was smaller or much smaller. However, when we analyze the Figure 4.2, we notice that, in fact, in the Image modality, the participants estimated the volume smaller than in the AR modality, which are $\mu = 1.39$ and $\mu = 2.48$, respectively. In Figure 4.6, we can see that the task with the most votes for equal was *Money* –AR, and checking in Figure 4.2, the –AR task had the best volume estimation. The real value was 1.32 m^3, and the estimated average was $\mu = 1.43$. In this case, the subjective and quantitative perceptions were consistent.

4.6 No major differences were observed in terms of infographic-induced feelings (H3 ✗)

Figure 4.7 shows the results of the *Smile or Scowl* questionnaire for all grouped scenarios. On the results, we can notice that while the participants looked at the news, they felt the Text the most *sad*, *overwhelmed*, *bored*, and *annoyed*, leading to the scowl ranking. However, on the other hand, Text was also the most *excited* and *awestruck*. On average, the Image was the most *surprise* and *content*, categorized as a smile. Also on average, participants felt AR to be more *happy* and *shocked*. Although in the taxonomy by (Lan et al., 2021) *shocked* is classified as a scowl, in our experiment, it can be interpreted as a good result since it indicates the most visceral method.

Our hypothesis H3 is "Interacting with an AR infographic will lead to a higher degree of *concerned*, *sadder*, and *awestruck* reported feelings compared to both text and image". We defined this hypothesis because we thought that when the users visualized the news in AR, they would feel more *concerned*, *sadder*, and *awestruck* about the real volume of the waste of trash and water and be impressed with the money's real size. The experiment results show that *sad* and *awestruck* were led by the Text format if compared with the Image and AR visualizations. Moreover, the Image led to more *awestruck* feeling than the AR, but the AR led to *sad* if compared with the Image. Also, there are no differences in *concerned* feeling across the three formats. So, we can not confirm our hypothesis H3.

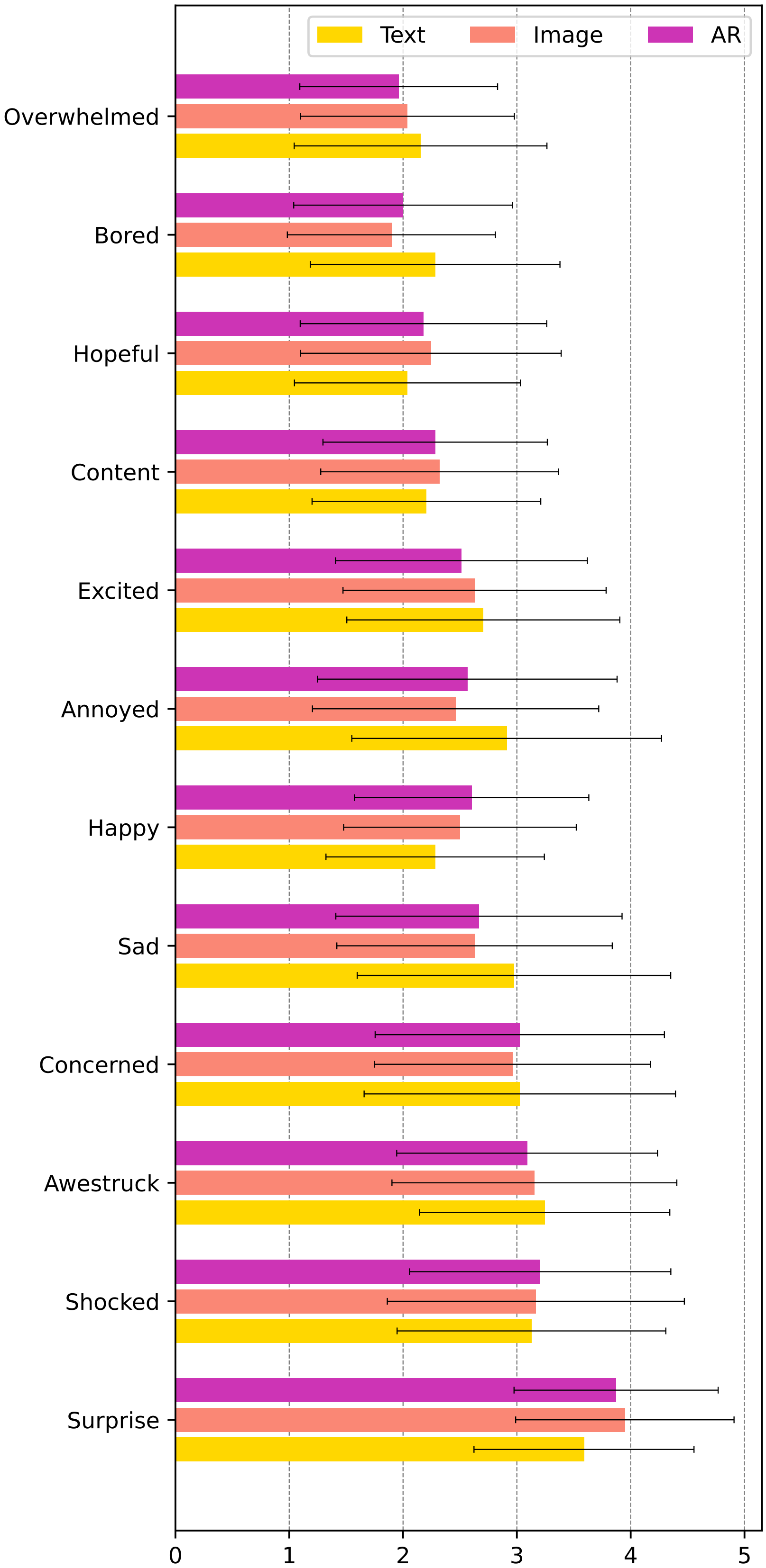
4.7 Participants' feedback suggests interest in the use of immersive infographics to support news pieces

When we asked the participants what they thought about viewing the news in AR, they were very positive. For example, P6 stated that *"Very interesting, the opportunity to view news is curious and attractive for different audiences, a new approach, and vision of the same."*, while P10 affirmed *"Interesting to have a more realistic view of the news."*. We asked if they thought that the immersive visualization of the infographics helped with their perception of the volume, and one of the participants said *"It makes much sense for news that involves the environment. It is quite difficult to visualize quantities like trash in normal news."* [P7]. When we asked what it was like to estimate the volume, they said, *"It would be better to have a button to change the size of each face of the prism individually.'* [P25], *"It would be nice to be able to lock the prism manipulation axis."* [P8], and *"Apart from the difficulty of handling the prism, it is an exciting tool for understanding quantities.'* [P17].

4.8 Participants demonstrated similar strategic behaviors during the experiments

When estimating the volume using the AR tool, we noticed two behaviors of the participants. When estimating the volume after reading the news in the Text

Figure 4.7 – Distribution of users' feelings obtained through the *Smile or Scowl?* questionnaire related to the three formats for all three scenarios. Contradicting our hypothesis H3, no major differences were observed between conditions in terms of infographic-induced feelings.



visualization, some of them imagined and spoke out aloud about the suggested unit and mentally built a 2D matrix on the floor. Only later, when they viewed the infographics, they realized that they could stack the objects, and from then on, they started to think about 3D matrices. Another interesting behavior was that some users, while drawing the prism and moving when the prism rotated, also lowered their bodies to better see the height and check whether it was accurate by comparing it with the objects in the environment (e.g., tables and chairs).

5 DISCUSSION: CONTRIBUTIONS, LIMITATIONS, AND PERSPECTIVES FOR FUTURE STUDIES

Our findings allowed us to identify clear benefits of immersive concrete scales infographics for volume understanding against conventional infographics for both the *Trash* scenario and across all scenarios. Moreover, we could confirm that concrete scales infographics, in general, always significantly outperformed textual analogies alone. These findings are a relevant contribution to the literature on concrete scales infographics and immersive concrete scales infographics and also support the current trend of the growing use of AR visualizations in the news media.

Considering the fact that we have investigated three different examples of news articles conveying information of varying scales, we believe these findings are also likely to be confirmed for other information domains by employing comparable metaphors. Regardless, it should be noted that these findings constitute an initial investigation of immersive concrete scales infographics, and further research is needed to better understand the effect of associated factors. In particular, we can identify the following components as potentially linked to the findings obtained in our study.

5.1 Study design

In our user study, we asked participants to estimate the information volume in the same environment where they viewed the immersive infographics. One could claim that this could introduce bias in favor of this condition because it would allow users to memorize relationships between the information and the space. We argue, however, that this is the key rationale of immersive concrete scales infographics by design: it allows people to use their environments and familiar physical objects as references to understand the information they are receiving. Regardless, future studies should investigate to what extent the gained comprehension is retained once the user moves to a different environment.

5.2 Choice of condition counterbalancing

In the design of our experiment, we deliberately decided not to fully counterbalance our conditions because we considered that assessing textual analogies alone would only make sense before the user had seen a visual depiction of that same information. As a result, we always presented text analogies first, and this result served mostly as a baseline for the other two. It is important to emphasize that the textual condition provided limited information for the subsequent modes, as the participants were not shown any confirmation of how correct their estimation was. Further, the added gain in system experience should be minimal given that a training session had already been performed in the beginning of the experiment. Regardless, we acknowledge that this decision should be kept in mind when assessing our second hypothesis. Exploring full counterbalancing, or any other counterbalancing approach, could be an interesting direction for future work.

5.3 Choice of study device

In our study, we opted to use a tablet device for all conditions. According to a 2012 study from Pew Research, tablets are more commonly used for in-depth reading of news articles than smartphones (Rosenstiel and Mitchell, 2012), and they also offer better support for AR due to the larger display. However, future studies could also evaluate if similar findings extend to smartphone AR, as these devices are also widely used for information consumption. Similarly, they could also assess the use of AR head-mounted displays, which are expected to become more common in the future.

5.4 Technical limitations

While our tablet-based AR prototype worked well, as confirmed by our findings favoring AR, technical limitations in the environment and marker tracking sometimes led to minor glitches that may have caused user frustration and added noise to the subjectively reported infographic-induced feelings, for example. Future studies can investigate the effect of such limitations. Moreover, newer mobile devices, such as those including LiDAR scanners, are likely to improve the AR experience, potentially leading to even better results for AR infographics. Devices with more processing power can also permit more photo-realistic infographics with a similar expected impact.

5.5 Choice of volume specification apparatus

In our study, we provided participants with an AR volume specification tool to indicate their estimations for the volume of information reported in the news. We considered this approach ideal as it allowed users to fully control their volume specification, visualize the resulting estimation, and compare it to their expectations. Given that users had the opportunity to train the use of the tool beforehand, we do not anticipate a significant bias being introduced by this tool in favor of any condition. Still, future studies could experiment with alternative measuring systems.

5.6 Choice of data analogies

When designing an immersive or conventional concrete scales infographic, a relevant design choice is determining the most appropriate metaphor. For example, small water bottles, larger water gallons, or simply a cubic water tank could represent liters of water. Other quantities, such as garbage, are particularly difficult to represent, as the information is often conveyed in terms of mass instead of volume, and a visual representation must select an approximate density, which may differ from the reader's expectation. In all our examples, we iteratively worked to select the metaphors we deemed most adequate for representing the scale of the data while remaining widely familiar to the participants. Our observation from the study's results is that this was achieved. However, it is conceivable that alternative analogies could lead to different performances, and future studies should investigate this.

5.7 Design of the static infographics

For the Image condition, we sought to reproduce a style commonly found in media infographics, representing quantities in terms of familiar units and contrasting them to a referent of known size. We organized these objects in a 3D space and offered a 3D perspective to clearly indicate all dimensions since we considered that a purely 2D infographic, while still realistic, would make it even harder for the participants to comprehend the information in terms of volume. Investigating alternative designs (for example, with different perspectives or different referents) for the Image condition could also be the object of future studies.

5.8 Design of the immersive concrete scales infographics

Similarly, numerous possible designs could be conceived as immersive concrete scales infographics, adopting different metaphors, 3D models, or spatial organizations. Future studies should investigate the most effective designs for such representations. As discussed in section 2.3, immersive concrete scales infographics can also assume other forms, such as miniature-scale comparatives, which also warrant comparisons to full-scale ones.

5.9 Choice of study environment

Our user study was conducted in a university hall environment, a relatively large space that could accommodate representations of all scenarios. We selected this location as it represented a familiar location to most participants and contained several physical objects that could serve as scale references while still offering reasonable space to position the virtual objects and for the participants to move around them. Of course, people consume news articles in varied spaces, and future work should investigate the effect of varying environment sizes.

5.10 Participant demographics and sample size

Our participant sample was reasonably large (26 participants) and included people with varying degrees of familiarity with AR. However, participants were recruited from a relatively homogeneous academic setting, with a mean age of 25 years—the 18-29 age group is known to be the one more accustomed to digital news (Shearer and Mitchell, 2021). Our participants were recruited on the University campus, mainly in the buildings where computer science students have classes or research labs. Although this is usual in most VR/AR research, we acknowledge the limitations and bias that such a sample might induce. Future studies should investigate whether similar findings extend to other demographic groups.

5.11 Future Studies

For future research, consider conducting the experiment across varied scenarios to assess the impact of these alterations on user comprehension. Explore the potential enhancement in reader comprehension by testing immersive concrete scale infographics on alternative platforms such as Oculus Meta Quest 3 and Apple Vision Pro. Additionally, investigate the efficacy of immersive concrete scale infographics across various scales, not limited solely to a 1:1:1 ratio. Improving the scope of experimentation, we can gain deeper insights into the optimal use and impact of immersive concrete scale infographics for news visualizations.

6 CONCLUSION

In this research, our primary objective was to assess the effectiveness of immersive infographics in facilitating the public's understanding of quantitative information embedded in news articles, employing volumetric objects as a pivotal element. To rigorously examine the impact of our immersive infographics, we crafted a set of three prototypes, each subjected to comparison against traditional textual analogies, conventional image-based infographics, and AR immersive infographics. Through our user study, the results from our analyses affirmed the potential of immersive infographics.

Remarkably, our findings demonstrated a statistically significant enhancement in comprehension when participants engaged with immersive infographics, particularly notable in the context of the Trash scenario. This compelling outcome validated our primary hypothesis on the domains where immersive infographics excel, such as conveying information related to environmental issues. Furthermore, the broader analyses, encompassing all scenarios, consistently favored immersive infographics, establishing them as a formidable means of conveying information across diverse topics.

In essence, our research contributes not only to the field of information visualization but also resonates with the evolving landscape of journalism. The ascendancy of immersive infographics suggests a transformative potential, highlighting augmented reality (AR) as a dynamic and engaging framework for journalists to elucidate the intricacies of news stories. Beyond the confines of our tested scenarios, the implications ripple across various domains, signifying the broader transformative influence that AR could wield in revolutionizing the communication and comprehension of news.

In conclusion, our study shows the great potential of immersive infographics. It points towards a paradigm shift in how journalists may harness AR to empower readers with a nuanced understanding of the scale and complexity inherent in news information. As technology advances, the symbiotic relationship between journalism and augmented reality appears poised to redefine the essence of news dissemination in the digital era.

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APPENDIX A — QUESTIONNAIRES USED IN THE EXPERIMENT

A.1 Pre-testing questionnaire

Before we started the experiments, we asked the participants these questions.

1. Are you? One answer only.
   - left-handed
   - right-handed
   - ambidextrous
2. What is your scholarship level? One answer only.
   - high school
   - undergraduate
   - graduated
   - post-graduated
3. Have you ever used Augmented Reality on your cell phone or other devices? It could have more than one answer.
   - Yes, on a smartphone.
   - Yes, on a tablet.
   - Yes, on Nintendo 3DS.
   - Yes, in another device.
   - No, I never used it.
   - No, I don´t know what augmented reality is.
4. Which of these devices do you usually consume news on? It could have more than one answer.
   - Smartphone
   - Tablet
   - Computer (Desktop/Laptop)
   - TV
   - Radio
   - Newspaper

5. How often do you read news on your smartphone? One answer only.
    - Always
    - Often
    - Occasionally
    - Rarely
    - Never

A.2 Pos-testing questionnaire

A.2.1 Smile or Scowl questionnaire

The questions for the Smile or Scowl questionnaire had 12 possible feelings: Overwhelmed, Bored, Hopeful, Content, Excited, Annoyed, Happy, Sad, Concerned, Awestruck, Shocked, and Surprised. For each of these feelings, the participants had to enumerate how intense the feeling was using a Likert scale from 1 to 5, where one means strongly disagree and five means strongly agree.

Trash

1. How did you feel reading the news about the trash?
2. How did you feel viewing the trash infographic?
3. How did you feel viewing the AR trash infographic?

Water

1. How did you feel reading the news about the water?
2. How did you feel viewing the water infographic?
3. How did you feel viewing the AR water infographic?

Money

1. How did you feel reading the news about the money?
2. How did you feel viewing the money infographic?
3. How did you feel viewing the AR money infographic?

A.2.2 Questions about visualizations in Image and AR

For each one of these questions, the participants had to enumerate using a Likert scale of 1 to 5, where one means strongly disagree, and five means strongly agree.

Trash

1. The trash seen in the infographic looked like real trash.
2. Seeing the trash in the infographic helped you understand the volume of trash reported in the news.
3. The trash seen in the AR infographic looked like real trash.
4. Seeing the trash in the AR infographic helped you understand the volume of trash reported in the news.

Water

1. The water gallons in the infographic looked like real jugs.
2. Seeing the gallons in the infographic helped you understand the volume of water reported in the news.
3. The water gallons in the AR infographic looked like real jugs.
4. Seeing the gallons in the AR infographic helped you understand the volume of water reported in the news.

Money

1. Were the virtual R$100 bills similar to the real ones in the infographic?
2. Did seeing the R$100 million in the infographic help you understand the amount of money reported in the news?
3. Were the virtual R$100 bills similar to the real ones in the AR infographic?
4. Did seeing the R$100 million in the AR infographic help you understand the amount of money reported in the news?

A.2.3 Questions about virtual objects scales in Image and AR

For the following questions, the participants had these possible answers:

- Much larger
- Largest
- Equal
- Smaller
- Much smaller

Questions:

Trash

1. The size of the trash bag in the infographic compared to a real trash bag.
2. What was the amount of trash you imagined when reading the news story before viewing it in the infographic?
3. The size of the trash bag in the AR infographic compared to a real trash bag.
4. What was the amount of trash you imagined when reading the news story before viewing it in the AR infographic?

Water

1. The size of the gallon of water in the infographic compared to a real gallon was in the image.
2. What was the amount of gallons of water you imagined when reading the news story before viewing it in the infographic?
3. The size of the gallon of water in the infographic compared to a real gallon was in AR.
4. What was the amount of gallons of water you imagined when reading the news story before viewing it in the AR infographic?

Money

1. The size of the virtual R$100 bill compared to a real bill was in the image.
2. What was the volume of the R$100 million bill that you imagined when reading the news before viewing it in the infographic?
3. The size of the virtual R$100 bill compared to a real bill was in AR.
4. What was the volume of the R$100 million bill that you imagined when reading the news before viewing it in the AR infographic?

APPENDIX B — RESUMO EXPANDIDO

Ao ler notícias, seja no papel ou por meio de um aplicativo ou site de notícias, frequentemente encontramos infográficos, ou seja, visualizações enriquecidas com ilustrações e anotações para apresentar informações (Burns et al., 2022). *Infográficos imersivos* em realidades aumentadas (RA) ou virtuais (RV) podem aumentar a compreensão das informações, usando narrativas para oferecer uma perspectiva alternativa, compreendendo, em nossa opinião, uma das aplicações mais interessantes de Análise Imersiva (Marriott et al., 2018). Em particular, por meio de infográficos baseados no conceito de *escalas concretas* (Chevalier, Vuillemot and Gali, 2013), podemos fornecer aos usuários a sensação de *visceralização de dados* (Lee et al., 2021), transmitindo volumes ou dimensões que muitas vezes podem ser difíceis de estimar apenas por meio de números abstratos.

Visceralização é algo que normalmente se refere a reações instintivas e sentimentos emocionais. Por exemplo, quando assistimos a um filme de ação em que o ator está escalando uma montanha colossal e sentimos medo, ou quando assistimos a um comercial de TV pedindo ajuda a crianças pobres, nos sentimos tristes. Esse tipo de sentimento que evoca uma resposta sólida e rápida é uma experiência visceral. Embora coisas viscerais sejam amplamente utilizadas na mídia de entretenimento, elas também podem envolver os espectadores na visualização de dados. O conceito de *visceralização de dados* introduzido por (Lee et al., 2021), que é uma mistura de visualização de dados com experiência visceral, não é apenas uma maneira de mostrar dados em grandes dimensões ou volumes, mas também é um técnica para mostrar informações que podem causar sentimentos viscerais nos espectadores.

Usar infográficos para envolver leitores também pode evocar uma experiência visceral nos espectadores. Infográficos são amplamente usados para informar mensagens que precisam ser compreensíveis, fáceis e rápidas. Assim, os infográficos devem ser intuitivos e diretos; às vezes, a mensagem deve ser visceral para invocar uma resposta rápida dos leitores. No entanto, a perspectiva visceral pode ser prejudicada quando usamos infográficos para apresentar, por exemplo, a quantidade de resíduos produzidos em um ano usando uma imagem. Portanto, se os mesmos infográficos fossem mostrados agora como um infográfico imersivo usando RA, esse método de visualização alternativo pode aumentar a experiência visceral quando estamos tentando informar o volume de quantidades abstratas.

Não é de surpreender que as empresas de mídia tenham investido nesse tipo de aplicativo como uma forma de melhorar as experiências de seus leitores, como exemplificado, mais proeminentemente, pelo The New York Times (NYT) (Clark et al., 2022). O NYT começou a explorar relatórios de RA em 2018 (Roberts, 2018) e desde então publicou pelo menos 31 exemplos de "narrativa de RA" (Development, 2022), incluindo muitos que podem ser classificados como *infográficos imersivos*. A maioria deles foi produzida em parceria com o Instagram e funciona por meio do popular aplicativo Instagram como um "filtro de RA" (He, 2020). Eles complementam artigos de notícias onde infográficos convencionais e animados também são apresentados, oferecendo a oportunidade para uma perspectiva diferente. A empresa de notícias também declarou a intenção de mirar em headsets de realidade mista no futuro (Clark et al., 2022).

As oportunidades criadas por visualizações imersivas para compreensão de informações e narrativas também foram discutidas na literatura recente sobre visualização de dados (Isenberg et al., 2018), particularmente da perspectiva da *visceralização de dados*, ou seja, experiências de dados que evocam sentimentos viscerais para facilitar a compreensão de medições e quantidades físicas (Lee et al., 2021). Infográficos imersivos podem tirar proveito de tais sentimentos, por exemplo, para educar os usuários sobre o impacto ambiental de seus hábitos de consumo (Assor et al., 2024; Assor et al., 2023). No entanto, até onde sabemos, ainda há pesquisas limitadas avaliando os benefícios quantitativos e qualitativos fornecidos por tais representações.

No decorrer deste trabalho, após uma revisão de conceitos fundamentais e literatura pertinente (conforme delineado no Capítulo 2), desenvolvemos um estudo de usuário controlado projetado para avaliar o impacto de infográficos imersivos na compreensão de dados volumétricos (esclarecido no Capítulo 3). Neste estudo, nosso principal objetivo é analisar infográficos imersivos em escala real, utilizando um aplicativo de realidade aumentada (RA) para tablets. Simulando uma abordagem de visualização de notícias em 3D, similar àquela empregada em aplicativos de notícias modernos.

Nossa hipótese central é que infográficos imersivos em escalas concretas estão prontos para melhorar significativamente a compreensão dos indivíduos de grandes quantidades numéricas, superando a eficácia de analogias textuais ou infográficos estáticos em formato de imagem, tudo isso mantendo o usuário dentro dos limites de um dispositivo singular sem necessitar de transição para plataformas alternativas, como um óculos de reliadade virtual.

Para investigar essa hipótese, em nosso estudo comparativo, pedimos a 26 participantes que indicassem o volume que imaginavam ao ler notícias sobre grandes volumes de lixo, dinheiro e água por meio de uma ferramenta de especificação de volume de realidade aumentada. Os resultados dessa investigação comparativa são apresentados no Capítulo 4, enquanto uma discussão e interpretação abrangentes de nossas descobertas são fornecidas no Capítulo 5. Dada a afirmação de nossa hipótese central, somos compelidos a afirmar que infográficos de escalas concretas de RA móvel prometem substancialmente aumentar a compreensão dos leitores sobre o conteúdo informativo disseminado pela mídia de notícias (conforme exposto no Capítulo 6).

Em suma, nossa pesquisa se esforça não apenas para examinar empiricamente a eficácia de infográficos imersivos dentro do escopo da compreensão volumétrica, mas também para ressaltar sua utilidade potencial como uma ferramenta transformadora dentro do cenário do jornalismo contemporâneo, promovendo maior engajamento e compreensão entre consumidores de notícias.

Como resultado do nosso estudo, a Figure 4.1 mostra a porcentagem de erro de estimativa de volume para cada um dos exemplos de notícias e modalidades de visualização, bem como uma agregação de todos os testes de estudo em todos os exemplos. Enquanto isso, Figure 4.2 mostra a distribuição das estimativas de volume absoluto para cada cenário de notícias com seus respectivos valores de volume real indicados por uma linha rosa.

Estávamos particularmente interessados em observar como a RA se compararia à Imagem, ou seja, até que ponto os infográficos de RA seriam mais úteis para a compreensão do volume do que os infográficos convencionais.

Agrupando todas as tarefas, conforme mostrado em Figure 4.1–inferior-direito, a porcentagem de erro é significativamente diferente em todos os formatos. Os usuários foram mais precisos na estimativa de volumes para notícias apresentadas usando Imagem do que Texto ($**$); o mesmo vale para RA quando comparado a Texto ($***$) e Imagem ($**$). Enquanto a Imagem resultou em um erro médio de 55,12%, a RA levou a um erro médio de estimativa de 37,57%, ou seja, uma redução de 31,8%. Essas descobertas confirmam a nossa hipótese principal, indicando que a RA supera Texto e Imagem para compreensão de volume.

Também analisamos os três cenários de notícias diferentes individualmente. No cenário *Lixo* (Figure 4.1 –superior-direito), nosso estudo também foi capaz de identificar uma melhoria significativa na precisão da estimativa ao usar RA em comparação com Image (∗∗). Neste cenário, Image levou a um erro médio de estimativa de volume de 65,93%, enquanto RA resultou em 44,43%, uma redução de 32,6%. Nos cenários *Água* e *Dinheiro*, não foi possível dizer que RA foi melhor que Image, pois não conseguimos encontrar significância estatística entre eles. No entanto, a estimativa de volume do RA *Dinheiro* foi a mais próxima do volume correto, conforme mostrado Figure 4.2. Analisando os cenários *Água* e *Dinheiro*, a Imagem levou a um erro médio de estimativa de volume de 54,10% e 45,34%, respectivamente, enquanto RA teve 35,60% e 32,67%. Portanto, para os cenários *Água* e *Dinheiro*, tivemos uma redução do erro de estimativa de volume de 18,4% e 12,67%, respectivamente.

Nesta pesquisa, nosso objetivo principal foi avaliar a eficácia dos infográficos imersivos na compreensão de informações volumétricas quantitativas em artigos de notícias, utilizando objetos volumétricos em realidade aumentada como elemento central. Para uma análise rigorosa, desenvolvemos três protótipos distintos e comparamos cada um deles com analogias textuais tradicionais, infográficos convencionais baseados em imagens e infográficos imersivos em RA. Os resultados de nosso estudo de usuário confirmaram o potencial dos infográficos imersivos para melhorar a compreensão do público sobre informações volumétricas.

Concluindo, nosso estudo revela o grande potencial dos infográficos imersivos. Ele aponta para uma mudança de paradigma em como os jornalistas podem utilizar a realidade aumentada para proporcionar aos leitores uma compreensão mais profunda da escala e da complexidade das informações noticiosas. À medida que a tecnologia avança, a relação simbiótica entre jornalismo e realidade aumentada parece estar pronta para redefinir a essência da disseminação de notícias na era digital.