Developing a Bring-Your-Own Device Pilot Application for Tower Bridge

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Abstract

The experiences of COVID-19 have encouraged many exhibitions, including Tower Bridge, to explore new ways to provide visitor interpretation through digital media. Tower Bridge was constructed in 1894 to alleviate traffic congestion on and across the River Thames and is now a world-renowned landmark and a popular attraction. The goal of our project was to develop a pilot “bring-your-own-device” (BYOD) application in partnership with the Tower Bridge staff that explores new ways to provide interpretation through digital media. We developed the pilot through observations at several museums and an iterative process of design and testing. We recommend how Tower Bridge staff can refine the app to enhance usability and visitor engagement.

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Introduction

Interpretation of existing assets is an ever-present problem for museums, heritage sites, and exhibitions. Venues carefully select which assets from their collections are displayed and how they are interpreted for visitors. The development of digital technology continually presents opportunities for innovative approaches to interpretation, and many museums have utilized digital technology to engage a wide variety of audiences. The adoption of digital technologies has been accelerated further by the COVID-19 pandemic, as attractions have sought out ways to engage their visitors remotely. Cultural venues must continue to adapt and evolve in a post-pandemic environment to meet the changing expectations and preferences of their target audiences.

A long-standing iconic London landmark, Tower Bridge is an integral part of the transportation infrastructure in one of Europe's largest cities and also a major visitor attraction. The effects of the COVID-19 pandemic have been felt at all visitor attractions in London, including Tower Bridge. Visitation at Tower Bridge dropped from almost 890,000 visitors in 2019 to less than 170,000 in 2020, a painful blow considering it was seeing a steady yearly increase in numbers prior (ALVA | Association of Leading Visitor Attractions, 2020). This decline in visitation is assumed to be temporary, but it has spurred cultural attractions like Tower Bridge to consider the implications for future operations. Dirk Bennett, the Exhibition Development Manager at the Tower Bridge, stated that visitors are changing their behavior and becoming "less hands-on, more distanced, [and] less physically interactive" (Bennett, 2021). Accordingly, Tower Bridge has implemented new interactive media and exhibits. This content provides more than just a 'sanitary' visitor experience - Tower Bridge also seeks a mobile application that provides new experiences that are engaging, entertaining, and educational. This application employs what the industry calls a "bring-your-own-device" system, meaning that the application can be accessed via visitors' personal devices.

The overall goal of our project is to develop a pilot "bring-your-own-device" (BYOD) application in partnership with the Tower Bridge staff that explores new ways to provide interpretation through digital media. The team created five objectives to complete this goal:

1. Determine the best practices and identified potential platforms for a pilot application.
2. Identify target themes and audience.
3. Develop a plan for an entertaining and educational pilot application using storyboards.
4. Develop the pilot application with conceptual ideas and structure.
5. Recommend how the content and functionality of the pilot application can be further improved and researched before final development.

We have conducted background research on best practices for the use of digital technologies in museums and exhibitions and identified the potential platforms and languages to implement in the app, supplementing this background research with site visits and evaluations of apps and digital exhibits in select museums in London. We used an iterative design process to develop the overall design and content of the app and utilized storyboards to present to Dirk Bennett for feedback. As we developed the app, we tested it with fellow WPI students and used the feedback to revise the pilot as necessary. Finally, we compiled our findings and provided recommendations to Tower Bridge for the development of the final application.

Background

Tower Bridge is an iconic London landmark with a rich history. Its primary function has been to act as a fully-functioning bascule bridge and to provide transportation across the River Thames. Since 1982, the Bridge has housed a historic exhibition that attracts visitors from all over the world. As Tower Bridge works to improve its visitor experience, digital interpretation methods have emerged as a central tool. This section will focus on the history of Tower Bridge, the current state of the exhibition, and new possibilities using digital interpretation.

History and Reinterpretation of Tower Bridge

Tower Bridge is a historical monument that was built by the Bridge House Estates, an organization founded in the thirteenth century.[1] This iconic structure has graced the London skyline since its completion in 1894 after eight years of construction. The Bridge was implemented for the sole purpose of alleviating traffic congestion in London while continuing to allow the passage of ships to the Pool of London. The design by Sir Horace Jones, the city architect, and John Wolfe Barry, a civil engineer, was selected from among 50 submitted to a competition in 1884. Bridge House Estates started the construction of Tower Bridge in 1886 with the assistance of five contractors and over 800 workers daily (Tower Bridge n.d). The superstructure of the towers and walkways consists of over 11,000 tons of steel, (Figure 1), and the finished towers including the steel superstructure and stone facings weigh roughly 70,000 tons each (Tower Bridge n.d). Steam-powered hydraulic engines were used as the original bascule lift system but were exchanged for oil-based electro-hydraulics in the 1970s for economic and environmental efficiency (Tower Bridge n.d). These mechanisms remain in place today and operate via computerized control.

In 1982, Tower Bridge permanently opened an exhibition named "The Tower Bridge Experience" (Tower Bridge n.d). Most visitors enter the attraction through the ticket office at the base of the North Tower [1], as shown in Figure 2. Text panels and photographs in the North Tower [1] present the history of the bridge and the people who worked on it. On level four of the North Tower, an orientation space in Victorian style includes a silent movie showing the years after the bridge was completed. Exiting the North Tower brings the visitor onto one of two parallel walkways [2]. Glass panels were installed in the walkway floors in 2013. They offer spectacular views of the bridge and River Thames below (Figure 3) and have been an extremely popular feature of the exhibition. From here, guests walk across to the South Tower [3] to a lift and staircase. There is one intermediate level in the South Tower which serves as a location for resting and reflection. Visitors exit the South Tower and walk outside across the bridge [4] to the engine room and gift shop [5]. Visitor studies indicated that

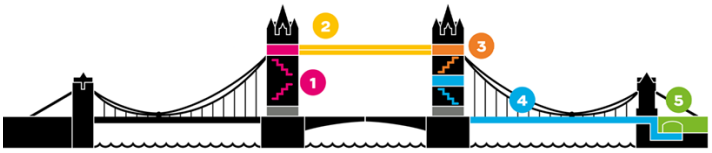


Figure 2: Tower Bridge Exhibition Schematic

Figure 1: Construction of Tower Bridge, 1890s

[1] Supplemental Material A; Tower Bridge and Bridge House Estates Description

Figure 3: Glass walkways in Tower Bridge

visitor numbers fell off by 25% between stations [4] and [5]. This meant that many visitors failed to complete their tour of the exhibition and did not see the engine rooms nor spend time in the gift shop (Bennett et al., 2015, pp. 60).

In 2015, Exhibition Development Manager Dirk Bennett and Tower Bridge engaged in a major effort to rethink the interpretation through an Interpretation Plan. The Interpretation Plan lamented the parlous state of the exhibits at that time saying:

> The current approach leaves much to be desired in terms of interpretive best practice, accessibility, and consistency (in content and design). There is no recognizable narrative structure, interpretive interventions have been added without much thought as to context, readability, suitable heights, and requirements of audiences and there is no recognizable overarching design language holding the whole experience together.
>
> (Bennett et al., 2015, pp.23-24).

Furthermore, the Plan noted that "the most exciting and accessible feature is the glass floor, the other displays almost ignored in comparison" (Bennett et al., 2015, p.23). The stated purposes of the plan are:

> To provide an overall experience that is enthusiastic, engaging, informative and welcoming, with opportunities for formal and informal learning at its heart. To improve the understanding and appreciation of the various aspects the Bridge embodies: historical, architectural, technical, aesthetic, social etc. To deliver an interpretation that is audience-focused, inclusive and layered. To develop an experience that is coherent and consistent. To use modern and lively, but timeless approaches for the delivery and design of the interpretation.
>
> (Bennett et al., 2015, p.5).

More dramatically, Bennett and his colleagues emphasized that "the aim of the interpretation is to make Tower Bridge 'sing' for all our visitors. This means making it relevant to them and appealing to them not only by providing opportunities for formal and informal learning, but engaging with them in a variety of ways: encouraging emotional engagement, dialogue, play, participation and interaction within the parameters set by conservation, curatorial and visitor management issues" (Bennett et al., 2015, p.35).

To provide direction and coherence to the entire endeavor, the Interpretation Plan identified seven themes:

- Ingenious, efficient, beautiful, and enduring – Tower Bridge is the perfect expression of the spirit of the city of London.
- Tower Bridge has been the workplace for people from all over the world for over 130 years.
- Building Tower Bridge was a major construction achievement of its age.
- Since its completion Tower Bridge has been a crucial part in facilitating London's traffic on the water and on land.
- Beauty or beast, Tower Bridge is a living showpiece of Victorian art and architecture.
- Tower Bridge remains a poignant symbol of historical and modern Britain and London.
- Hidden under the architectural magnificence of the Bridge, its engines have been working continuously to this day.

Since the Interpretation Plan was completed in 2015, Dirk Bennett and Tower Bridge staff have been actively involved in applying these themes through new exhibits and visitor instruction.

Visitation at Tower Bridge

COVID aside, the visitor numbers at Tower Bridge have increased steadily over time from just under 500,000 visitors in 2010/11 to almost 890,000 in 2019 (Bennett et al., 2015, p.29; ALVA | Association of Leading Visitor Attractions, 2020). Figure 4 shows that these visitors come from all over the world, but especially from Europe and North America (Gregory, 2020). Bennett described international families as the Tower's "bread and butter" but with the addition of the glass floors in the two walkways in November 2014, there was an increase in 25–34-year-old UK and London attendees.

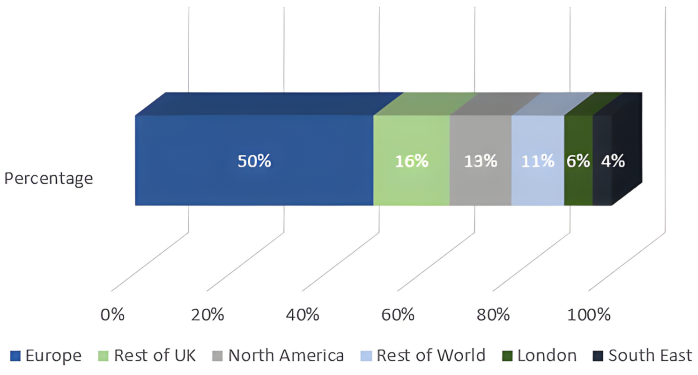


Figure 4: Tower Bridge Visit Origin

BACKGROUND

Audience Segmentation at Tower Bridge

The Tower Bridge exhibition commissioned an audience segmentation study prior to its 2015 interpretation plan to help determine audiences' needs and desires. Museums around the world use such audience segmentation studies to ensure their exhibits and programs meet the needs, interests, and learning styles of their visitors (Awad et al., 2021). The segmentation study revealed (Figure 5) that almost one-third of Tower Bridge's visitors can be classified in the "Expression" segment, which means they are open to different types of art and are "highly culturally active" (Bennett et al., 2015, p. 30). These types of visitors tend to be enthusiastic, creative, and have a wide range of cultural interests (Morris Hargreaves McIntyre, 2019). The "Perspective" (16%) and "Entertainment" (14%) segments were the next largest groupings. Those in the "Perspective" segment like the traditional, historical aspects of life and are interested in museums and historical education (Bennett et al., 2015, p. 30). "Perspective" visitors are self-sufficient and typically driven by their own agenda (Morris Hargreaves McIntyre, 2019). Individuals in the "Entertainment" segment, these individuals tend to engulf themselves in popular events of the arts and culture that they enjoy (Bennett et al., 2015, p. 31). These people tend to be socially motivated, however, their engagement levels are lower than other segments (Morris Hargreaves McIntyre, 2019). Visitors in the "Stimulation" segment tend to "live in the moment" (Morris Hargreaves McIntyre, 2019). As with those in the Entertainment segment, these people enjoy performances of the arts, but unlike the Entertainment crowd, they are drawn to more low-key events, such as street performances, smaller music festivals, and street art (Bennett et al., 2015, p. 31).[2]

Visitor groups tend to have many different learning styles. Using visitor feedback and audience segmentation analysis, Tower Bridge identified a set of general learning outcomes (GLOs) outlined in Table 1. Tower Bridge will also use the GLOs to guide future exhibit development and interpretation and also as criteria by which to measure the success of these efforts. The exhibition hopes that its exhibits will have demonstrable impacts on visitor knowledge, emotions, attitudes, skills, and behaviors.

In addition to achieving these learning outcomes, the newly-added reinterpretation was designed to promote accessibility, create stories to engage visitors, and preserve the Tower Bridge's authenticity while also bringing the exhibits to life, appealing to different learning styles, and using a wide array of technologies to engage audience segments (Bennett et al., 2015).

Given its desire to "apply new and modern as well as the tried-and-tested methods", digital interpretation has emerged as an area of promise. Digital interpretation at Tower Bridge began with the Family Trail app, but more development in this area is warranted, as digital technologies have become more relevant

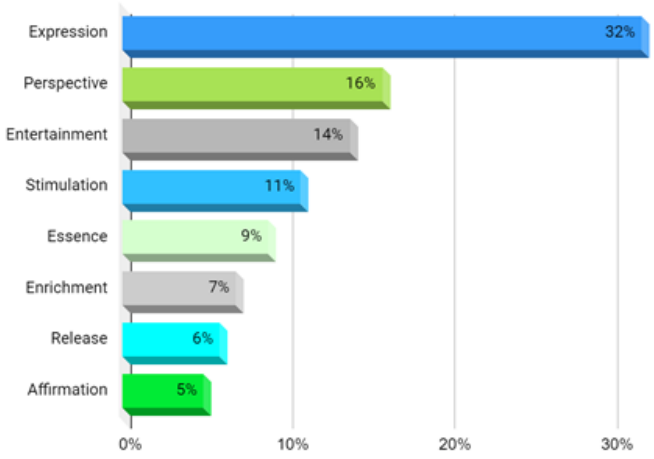


Figure 5: Tower Bridge Audience Segmentation

Table 1: Tower Bridge General Learning Outcomes

GLO	GOALS
Knowledge	• Learn about history, construction and operation of the Bridge and engines • Learn about the Victorian age in London
Emotion	• Be awed by the architectural and technical achievement • Feel inspired by the view and feel a connection to the staff at the Bridge • Have an engaging experience • Be inspired by a wonderful journey along the Bridge
Attitude	• Recognise the hard labor of the people involved in the building/operation • See the Victorians as inventive people as much as we are today • Appreciate Bridge House Estates, City Bridge Trust and Corp. of London • Appreciate the Bridge as more than a bridge
Skills	• Know key dates, names and facts about the Bridge • Understand and explain how different bits of the Bridge work together • Understand and explain how a bascule and counterweights work • Understand the role of the steel structure and the architectural skin • Describe what is so typical of the Victorian style of the bridge
Behavior	• Enjoy passing time on the Bridge • Enjoy spending their time on the Bridge as a family or group. • Make family visitors want to come here. • Support reputation as a major attraction in London people want to see • It is a famous building that they want to see

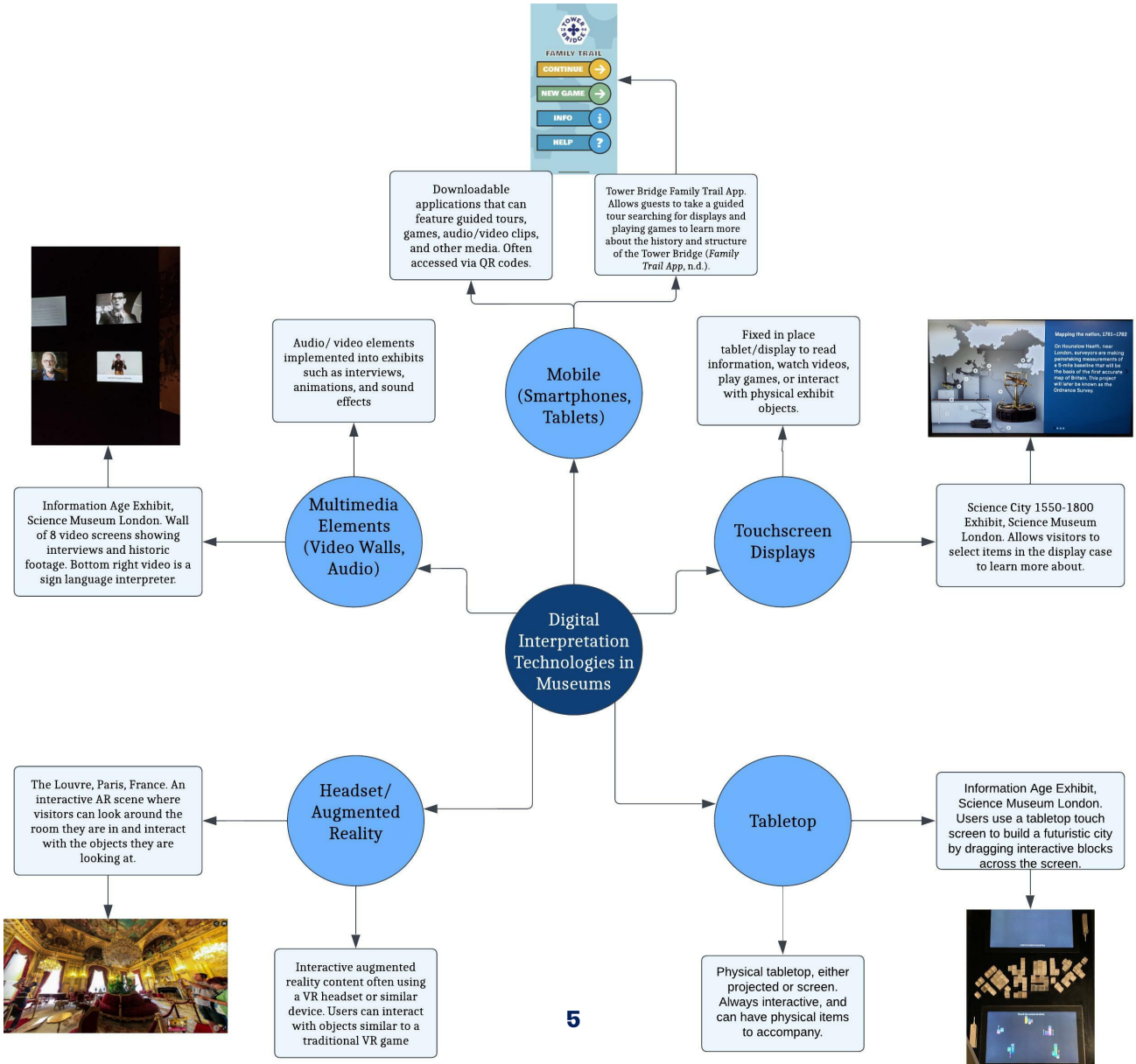
[2] Supplemental Material B; Audience Segmentation

given the COVID-19 pandemic. Visitors are less hands-on and more distanced than they were pre-pandemic. As both a continuation of past initiatives while responding to the pandemic, Tower Bridge has expressed interest in a bring-your-own-device (BYOD) approach to digital interpretation. While such an approach would certainly suit a pandemic environment, it is primed to remain successful post-pandemic given the advantages offered by digital interpretation methods.

The Rise of the Digital Era

Museums, heritage sites, and other visitor attractions have seen several dramatic changes throughout the past decades. For much of the 20th century, museums took a didactic approach to learning by channeling information toward the visitor without much consideration for differences in interests, experience, and learning styles. In recent years, museums have seen a shift in learning styles from this didactic approach to a more experiential, constructivist approach. Visitors expected museums to be an educational audience attraction rather than strictly a learning facility; (Andrews et al., 2010, p. 6) Simultaneously, in the 1970s, the technological capabilities of museums changed significantly; the development of new technologies has allowed museums to address this shift in learning styles with new interpretation techniques. Through the use of digital interpretive devices, museums helped the visitors see the world from the artist's or creator's point of view and grasp the intended message (Hawkey, 2004). In the 90s, some museums adopted websites to increase visitation - in 1994, the Natural History Museum became the first UK museum with a website (Hawkey, 2004). Since then, museums began integrating digital technologies into exhibitions to increase outreach, attract visitors, and showcase larger arrays of objects (Hawkey, 2004). Multimedia devices have been essential in this change and have proven to improve visitor engagement as well as increase the educational value of individual exhibits (vom Lehn and Heath, 2005). Two decades ago, Anderson (1999) observed that museums were becoming increasingly aware of the potential of technology and posited that the sooner they were able to incorporate it, the better equipped they would be to educate a population with a shortening attention span (Anderson, 1999).

Table 2: Digital Interpretation Technologies in Museums



BACKGROUND

Innovative technologies, such as smartphones, tablets, and other digital devices allow visitors to engage with exhibits rather than merely look at them from a distance (Shah & Ghazali, 2018). Each type of device has its own advantages and disadvantages in a museum setting. Visitor evaluation studies have demonstrated that incorporating new technologies increases the interest and engagement of visitors (Ovallos-Gazabon et al., 2020). Table 2 summarizes some of the major attributes of newer technologies, including tabletop displays, augmented reality, and multimedia displays. Increasingly, digital technologies are being implemented in museums because visitors find them engaging and entertaining. In the Museum Innovation Barometer 2021 released by Museum Booster, the consultancy found that 85% of museums use audio and video elements, 68% use projections, and 47% use smart objects or QR codes (Lu, 2021).

One of the most common devices integrated in museums is portable devices like smartphones because most visitors bring these devices with them (Mohd Noor Shah & Ghazali, 2018). A study conducted by the New York Museum of Modern Art found that 74% of people came to the museum with a mobile device (Nolan, 2016). In a survey conducted on 628 high school students, 90.7% of them already utilized mobile devices to learn and 73.8% were in support of introducing mobile devices for classroom learning (Thomas & Muñoz, 2016). A majority of students were in favor due to the fact that phones would allow them to learn from anywhere and allow teachers to personalize lessons which increases student engagement (Thomas & Muñoz, 2016). Currently, about 4% of museums have fully functional applications (Barbosa et al., 2021). In a study for the Museum of London, McDonough et al. (2019) suggest that bring-your-own-device (BYOD) systems that utilize visitor smartphones may be preferred because they promote learning while eliminating the complications of museums managing the provision and maintenance of in-house devices.

While BYOD does alleviate some responsibility from museums, smartphones are often associated with diminished learning. (Hawi & Samaha, 2016). Yet a study on the effects of mobile communication device (MCD) usage among young adults visiting museums offered empirical support of a BYOD approach. In a controlled study of young adults that were and were not provided with MCDs, the MCD group had the highest scores for "mindfulness and perceived learning," while the no-MCD group scored lower (Hughes & Moscardo, 2017). In a similar study at the Museum of National History in Taiwan, students provided with an electronic guidebook spent more time at exhibits than those without. Additionally, students indicated that explanations offered by the guidebook prompted them to examine exhibits with greater attention to detail. A common complaint of participants was the size and weight of the tablets provided, offering further support of a BYOD approach (Sung et al., 2008).

Overall, the argument that digital devices detract attention from the actual exhibits is refuted by multiple studies. Even for demographics notorious for being distracted by smartphones (young adults and college students), the integration of digital devices in a museum experience can increase learning and engagement. Further, both participants and museum staff have expressed a preference for a BYOD system rather than providing museum-owned devices. Two case studies are presented below highlighting the value of incorporating digital technologies into museums.

Case Study 1: The Open Art Application in the National Museum - Krakow, Poland

This study set out to analyze the usability of the Open Art mobile application, a museum guide app centered around accessibility and the idea that "all types of users should be able to use the app on equal terms" (Jankowska et al., 2017). It included narrated explanations of each piece of art accompanied by sign language video interpretations and auditory explanations (Jankowska et al., 2017). Within the National Museum, the *Gallery of 20th Century Polish Art* was selected as the area of study (Jankowska et al., 2017). Thirteen participants were selected for the study with varying levels of visual and auditory accessibility. Participants were provided a device with the application already installed and were sent through three stages of testing: a preliminary instructional stage, a gallery visitation stage, and a memory testing stage (Jankowska et al., 2017).

Most participants indicated they enjoyed the interpretation of the art more than the art descriptions; however, one participant suggested adding an option to skip the art descriptions for those who do not need them. (Jankowska et al., 2017). Participants commented on the quality of the accessible content, stating that the sign language translations were "not dynamic enough [and] showed little emotion", and the voice talents used to describe and interpret the art for the visually impaired were "synthetic" sounding (Jankowska et al., 2017). It is clear that the quality of the accessible content is of high importance to someone who requires it; such concerns may not have been noticeable to someone who is hearing and sighted. These suggestions and concerns could be ideal for our team to consider regardless of who our target audience is.

The study also presented feedback on the bring-your-own-device system, which focused on device learnability. One participant noted that she would have preferred to use her own device over the provided one simply because she already knew how to use it (Jankowska et al., 2017). This is an accessibility consideration as well: all users have different learning capacities and may not be able or willing "to learn a new [system] in every museum" (Jankowska et al., 2017). Thus, it is clear that users would prefer the use of a "bring-your-own-device" system for ease of use.

Figure 5: Sample UI From *Pointillize Yourself* Application

Case Study 2: The Pointillize Yourself Application in the Indianapolis Museum of Art (IMA) and the #NeoImpressed Application in the Phillips Collection

In an effort to develop new and innovative techniques to increase visitor participation, the IMA created a mobile application to accompany their exhibition titled *Face to Face: The Neo-Impressionist Portrait 1886–1904* (Sternbergh et al., 2015). This application, known as *Pointillize Yourself*, provides users with an interactive experience involving artistic portrait editing. Two stationary iPads were provided in the exhibit for visitors, who began their experience by taking a self-portrait of themselves. Guests were then presented with options to edit their portrait according to the Neo-Impressionist style; Figure 5 shows the application user interface (Sternbergh et al., 2015). Finally, users were given the choice to upload their artwork to social media directly from the application (Sternbergh et al., 2015).

The Phillips Collection in Washington DC implemented a modified iteration of the same application into their exhibition, *Neo-Impressionism and the Dream of Realities: Painting, Poetry, Music* (Sternbergh et al., 2015). In collaboration with the IMA, a new application titled *#NeoImpressed* was developed based on *Pointillize Yourself*; its functionality was nearly identical, but visitors at the Phillips stood in front of a Washington Monument image rather than just a self-portrait (Sternbergh et al., 2015).

At the IMA, 777 responses and thirty post-visit interviews were collected (Sternbergh et al., 2015). 29% of participants noted that the reason they didn't use the application was due to "a line of people waiting to participate."(Sternbergh et al., 2015). If all visitors were able to access the Pointillize Yourself software on their mobile devices, significantly more people could create a portrait on any given day, thus increasing overall visitor interaction.

While art applications are not suitable for Tower Bridge, feedback on them is. The basic function of the applications is effective in engaging most visitors and providing immersive experiences; both also solicited overwhelming positive feedback in regards to enjoyment and originality (Sternbergh et al., 2015). These applications allow users to generate their own souvenirs simply by visiting and interacting with the museum; it allows users to develop a connection to the exhibits around them (Sternbergh et al., 2015).

Potential Platforms and Learning Methods

Crucial, however, to the success of an individual BYOD application is its host platform. Numerous platforms are used to support the burgeoning array of apps being developed for museums, but Smartify has emerged as a leader in the field. Smartify has many advantages, but it may not provide the same level of flexibility as a standalone, proprietary application.[3] For an exhibition with limited staff such as Tower Bridge, Smartify may be the most appropriate platform given Smartify's established support network, however, long-term operation of the application would be much easier on Smartify than a self-developed alternative for this reason. Tower Bridge will need to collaborate closely with Smartify professionals to implement customized interactive digital features beyond audio and visual tours.

There are several application structures that encompass a wide variety of possible features. Most museum applications fall into three categories: guided, free roam, and game applications. Each mode has its own advantages and disadvantages, as shown in Table 3.

The free roam mode is the simplest option. It gives the user the flexibility to freely explore the museum while looking at exhibits as they choose, and has been implemented at many museums, including the Natural History Museum in New York and the British Museum (Bambury, 2017). In the app there are options for the different tours you can choose from.

A guided tour mode is nearly the opposite. This mode allows museum staff or curators to design a tour to guide visitors through a museum, visiting all or almost all the exhibits the museum has to offer. Some museums offer tours tailored to people interested in certain topics or themes.

The last mode is a game mode. While it's not as widely used it could be a good way to stimulate younger audiences. Tower Bridge already has implemented a game-esque mode

[3] Supplemental Material C; Platforms

with the Tower Bridge Family Trail application (Bennett et al., 2015 pp.28). Directed toward younger audiences (5-11 year-olds) and families, this app involves children going around Tower Bridge while taking part in a scavenger hunt.[4]

While many apps offering a game mode are directed toward younger audiences, interactive features that are not necessarily games could be used to engage older audiences who still prioritize entertainment and stimulation, as described in the audience segmentation section above. For example, the *Pointillize Yourself* application from Case Study #2 is not a game, but it is also not a tour - it is a standalone feature for a specific exhibit that allows visitors to interact at a deeper level.

In the next section, we will discuss the methods we used to develop a pilot BYOD application for Tower Bridge.

Table 3: Application Structures

Structure	Description	User Type	Age
Guided	Users following a tour through the museum	Users who want a more tailored experience. They are not shown everything the museum offers, just main highlights or themes	All ages
Free Roam	Users walking through the museum at their own pace	Users who are interested in the museum as a whole or one very specific part. Users have the flexibility to choose what they see	All ages
Game	Users play games at certain exhibits	Users who want a more entertaning and immersive experience	All ages, but usually targeted at children

[4] Supplemental Material D; Tower Bridge Family Trail App

Methods and Results

The goal of our project was to develop a pilot "bring-your-own-device" (BYOD) application in partnership with the Tower Bridge staff that explores new ways to provide interpretation through digital media. To achieve this goal, we completed five objectives:

1. Determined the best practices and identified potential platforms for a pilot application.
2. Identified target themes and audience.
3. Developed a plan for an entertaining and educational pilot application using storyboards.
4. Developed the pilot application with conceptual ideas and structure.
5. Recommended how the content and functionality of the pilot application can be further improved and researched before final development.

We used a variety of methods to achieve these objectives which we describe in detail below.

Objective 1: Best practices for museum and heritage site interpretation

To assess current and best practices in interpretation we visited the London Science Museum, the Natural History Museum, the British Museum, the London Museum of Water and Steam, and the Brunel Museum. We chose these museums based on our background research and at the recommendation of Dirk Bennett. In advance of the museum visits, we toured the Tower Bridge Exhibition with Dirk Bennett to develop a better sense of the interpretive approaches he and his staff have been using and their plans for future modification.

At each museum, we observed five elements of the interpretive approach: the use of text, graphics, audiovisual aids, digital interactives, and accessibility.

Among the museums we visited, we found that the Natural History Museum utilized text most effectively. Text descriptions were concise, informative, easy to follow, and digestible. Font sizes were large and used exciting graphic design or 'word art' to catch people's attention and portray messages quickly. Figure 1 shows part of the *Restless Surface* exhibit that features creative word art. The British Museum took a different approach - they relied heavily on explanatory text panels. Most of these panels were long, detailed, and used small fonts. The style of the Natural History Museum seemed more suitable for the content of our app and thus we opted to create concise text panels for our directions and context throughout the tour. This approach accords with the current interpretation style in the Tower Bridge Exhibition, which focuses on providing information for visitors in a concise manner.

Figure 6: Text Displays from the "Restless Surface" Exhibit, Natural History Museum, London

METHODS AND RESULTS

The Natural History Museum was effective in its use of images. Each image was used with an obvious purpose. Diagrams used concise labels and callouts to provide explanations. Images varied in size to maintain interest and color schemes were chosen to match the theme of an exhibition and provide coherence, which we have used while developing our pilot application. This was done quite well in the *Volcanoes and Earthquakes* exhibit, where volcano diagrams with callouts were used often (as seen in Figure 7). We thought a similar approach would work well in the pilot application.

A common theme we noticed throughout each museum was the use of images to substitute for physical artifacts (e.g., volcanoes) that might be too large to incorporate in a museum setting. The Science Museum used this tactic quite frequently given the nature of their exhibits but also chose to supplement static images with more dynamic videos as well. Exhibits such as *Information Age*, *Atmosphere*, and others often used projectors or video walls to display interviews or documentary-style content to enhance a display case or promote a larger concept. The Brunel Museum used video technology to present animations of the construction of the first tunnel under the River Thames. The animation style was of particular interest to our team - small portions of the original construction drawings were animated to show the building process rather than using new drawings. We thought this was a creative idea and planned to animate existing diagrams in the part of the app dealing with the construction of the caissons (discussed further in Objective 4).

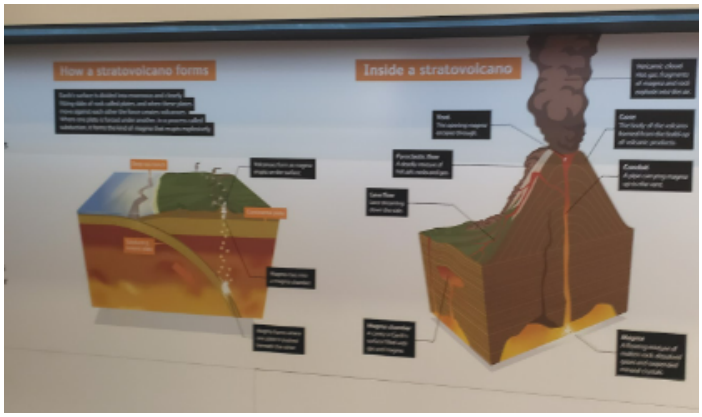


Figure 7: Volcano Diagrams with Callouts, Volcanoes and Earthquakes Exhibit, Natural History Museum, London

The Science Museum utilized digital interpretation the most of all the museums we visited - nearly every room in the museum had an interactive display of some kind including an abundance of tabletop games, projections, and fixed tablets. Some display cases used numbering systems to explain artifacts on display with an accompanying touchscreen display, like the one shown in Figure 8. We thought this was an engaging and effective interpretive approach.

The British Museum was the only museum we visited with its own in-house application - the British Museum Audio app. This app is very well organized and provides many helpful features such as an interactive museum map, exhibit room and artifact search function, and general museum information. A multitude of guided audio tours are included in the application as well. We appreciated that the application included additional features beyond just the guided tours - it enhanced the application's overall ease of use.

Unfortunately, all the guided tours in the British Museum Audio application were behind a paywall (around $2.50 per tour), which might discourage visitors from using the app. The British Museum excelled in other forms of accessibility, however. Their map provides labeling of which areas are accessible or not, as well as the locations of lifts, accessible toilets, and emergency exits. They even offer what is known as a Sensory Map, a unique map that highlights the sensory details of certain rooms such as noise levels, strong smells, or bright lighting (The British Museum, 2019). The British Museum also provided an assortment of museum guides in different languages, but those were an extra charge as well. We believed that our application should be accessible in multiple languages as Tower Bridge attracts many international tourists (Bennett et al., 2015). Additionally, the Science Museum included sign language interpretation videos in some exhibits for those who are hard of hearing; we would be interested in having a similar feature for any videos that have audio included with them, or an auditory explanation for animations that have no sound. These features would benefit the full Tower Bridge app significantly and help the app reach as many people as possible.

Lastly, our team considered another museum feature that we had not anticipated prior to visiting the other museums, namely the incorporation of physical interactives. The London Museum of Water and Steam excelled in this department, with a focus on an assortment of tactile activities such as pumps, faucets, and valves for people to

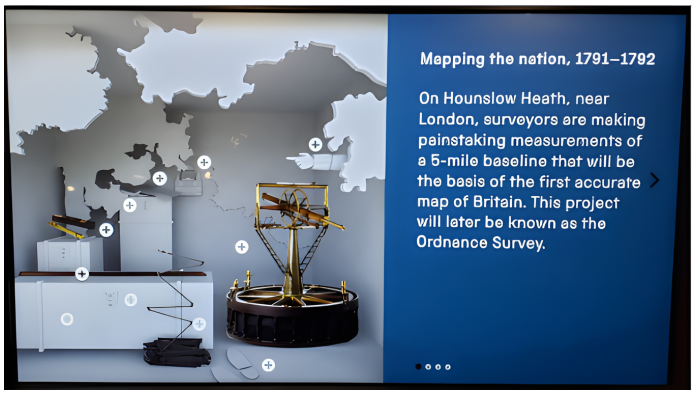


Figure 8: Touchscreen Companion for Artifact Display Case, Science City 1550-1800 Exhibit, Science Museum, London

touch and manipulate. In the steam exhibit, there were four steam engines functioning fully on steam. Visitors can feel the heat from the steam produced and even are sprayed with a bit of water occasionally. We could hear what the engine sounds like with the huffing, chugging, and pressure releases as the real steam engines worked. It required real functioning steam engines for full immersion and helped our team to understand what it would have been like in the Tower Bridge engine rooms. The Natural History Museum utilized similar tactics, with various tactile experiences including rocks to touch and a brain model. Sounds and video in the Volcanoes and Earthquakes exhibit were used to enhance the exhibit immersion. The British Museum had a replica of the Rosetta Stone on display for visitors to touch and feel as well. These types of experiences that appeal to the senses are important to complete exhibition immersion. We anticipated that these would be useful in our application as the Bridge focuses on the very sensory-rich experience of its construction and its powerful machinery.

Table 4 summarizes the best practices from the museums we visited. It notes which museum utilized a specific interpretation style most effectively and then indicates what practices they used which were most effective. Some of these practices were implemented into our pilot app and others were listed as a recommendation.

Objective 2: Identifying audience and themes for our application

We decided to focus on the construction and technology of Tower Bridge through a guided tour including animations and various "levels" or "layers" of explanation the user might select. We wanted to target those fascinated by the building and operation of the Bridge (both professionals such as engineers, architects, and contractors, as well as those individuals curious about the Bridge's history and how it was built). The app would be in English, although the app would rely heavily on visuals, so it could be utilized by virtually anyone. We chose two key themes from the Interpretation Plan to guide the development of the pilot app.

- "Building TB was a major construction achievement of its age"
- "Hidden under the architectural magnificence of the bridge, its engines have been working continuously to this day"

We decided to focus specifically on the foundational caissons, materials of the Bridge's walkways and superstructure, and the Engine Room machinery that powers the lifting of the Bridge. The foundational caissons and superstructure are covered in the North Tower, while the walkways and engines are described on the walkways and in the engine rooms respectively. We wanted the app to further enhance guests' experiences in these areas of the Bridge. Being technically minded, we decided to incorporate our knowledge and interest in the areas of construction and technology to add to the existing interpretive materials. This would help create the pilot application targeting those who want to know more about these areas of the Bridge. We decided our app would target visitors in the "Perspective" and "Expression" audience segments. As we described in the Background, Perspective visitors are those drawn to the history and tradition of the Bridge, and Expression visitors are those highly culturally motivated and enthusiastic to learn about the Bridge and its many features.

Objective 3: Storyboarding the App

To visualize our concept and how users would interact with an app in different parts of the bridge, we created a set of initial storyboards showing ideas for the structure and content of the pilot app. We decided to focus on six stations: North Tower Level 2, North Tower Stairwell, North Tower Level 4, East Walkway, West Walkway, and Engine Rooms. These stations were organized in the same linear path that visitors take through Tower Bridge. Each station included a page with brief directions to the station followed by a few sentences about the context of that part of the bridge. The following page showcased an animation or interactive feature providing more information on the bridge components noted above for their construction or operation. We presented our initial concept to Tower Bridge staff and obtained their feedback over multiple meetings and design iterations.

Table 4: Best Interpretive Practices

Interpretation Element	Most Effective Museum	Interpretive Practices
Text	Natural History Museum	• Easy-to-follow text, concise callouts, and labels • Short text panels on walls • Aesthetic 'word art' portrays a key message quickly
Graphics	Natural History Museum	• Mix of photographs and diagrams providing immersion and education • Minimal explanatory text - instead, uses concise callouts • Images match color scheme and exhibition theme
Audiovisual Elements	Science Museum (S), Brunel Museum (B)	• (S) Projections and video walls of interviews and documentary-style content • (B) Animations of old drawings and images to show construction techniques
Digital Interpretation	Science Museum (S), British Museum (Br)	• (S) Fixed-in-place displays next to display cases • (S) Interactive images of display cases - users select object to learn more about them • (S)Tabletop displays with games and videos • (Br) In-house application with guided tours
Accessibility	Science Museum (S), British Museum (Br)	• (S) Sign Language translations accompanying many videos • (Br) Map labels accessible locations (lifts, emergency exits, accessible toilets) • (Br) Museum guides in many different languages
Physical Interactives	London Museum of Water and Steam	• Steam engine component tactile experiences • Operational engine noises

METHODS AND RESULTS

Level 2 of the North Tower was the first station we storyboarded. We focused on the construction of caissons for the bridge foundations. The caissons were large steel and wood chambers lowered into the river to allow excavation of the river bed. At the start of the project, the North Tower simply showcased the divers who helped erect the foundations underwater and a poster illustrating the construction process. We planned to bring the static poster to life by creating a preliminary animation of the diver excavating and building the caisson. Our initial storyboard depicting the context and directions page and the animation page for the North Tower Level 2 station is shown Figure 8, including it here to illustrate the structure we storyboarded for all stations of the app.

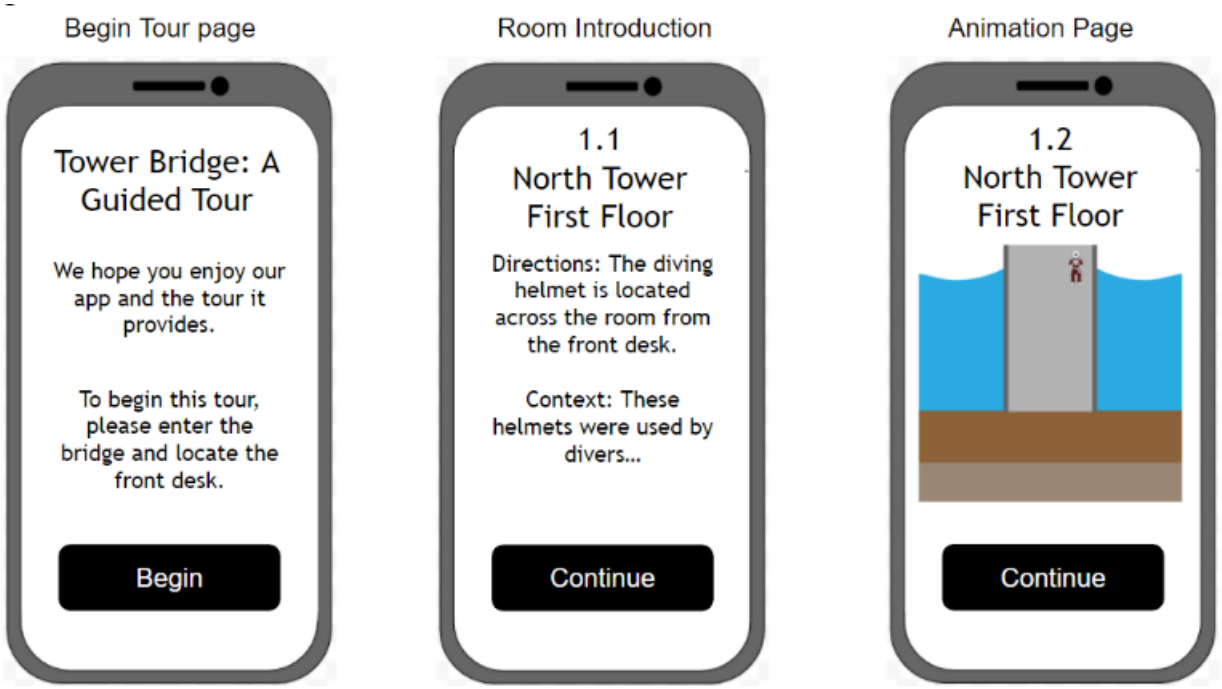


Figure 8: North Tower Level 2 Directions, Context Page, and Animation Page

The North Tower Stairwell and the North Tower Level 4 storyboard contained an animation showing the North Tower steel structure being built on top of the foundation. The initial animation was created using SketchUp.

The East and West walkways storyboard included a slider to compare the London skyline from years past as seen from the walkways. This would provide guests with a way to appreciate the evolution of the city of London through its developing construction.

Figure 9: Panorama Concept

The Engine Rooms already contained various interactive screens to show the different parts of the engines and their functions. However, we wanted to add more to the engine room station by showing an animation of a worker shoveling coal into the burners.

We solicited feedback from Tower Bridge staff in an iterative process of design and development. To begin the development of the application, we used a web-based framework. This allowed us to avoid the complicated process of certification required to sign onto the App Store or the Google Play Store. We also avoided the use of unsigned app packages like an APK (Android Package Kit) or IPA (iOS App Store Package) which would not only be harder to develop with more complex compatibility, but would also be very unprofessional as most are affiliated with malware, viruses, and piracy. Furthermore, users need to change a setting to allow unsigned apps to run on their mobile devices. Wix.com was our first choice in terms of a web-based framework that could work as an app as it is free to use. After some initial development, however, it became clear that Wix could not be adapted to a mobile platform to complete some of our preliminary ideas such as the panorama views slider. Thus, we chose another web-based framework, ReactJS. It is a JavaScript library that implements a mobile User Interface (UI) using different components (ReactJS, 2013). Using this library, we were able to build the general UI and basic elements for the app. We were able to set up a work environment using GitHub so the development of the pilot app could be done seamlessly.

Objective 4: Refining the storyboard and developing a pilot application

We presented the initial storyboards and preliminary application to Dirk Bennett. His feedback was generally positive regarding our choice of audience and themes, but he emphasized the need for more visitor interaction with existing exhibition assets. While some attention will be paid to mobile devices as visitors use the app, it is important they still look up and experience the actual components of Tower Bridge. Mr. Bennett also suggested using more visual information for the Directions sections to aid users in their navigation of the bridge. We also solicited feedback from Adam Blackwell, Principal Exhibition Manager for the City of London Corporation. While Mr. Blackwell also emphasized the importance of visitor interaction with existing museum assets, he pointed out the need for layered content throughout the application, where users had the option to view more general information or to learn more technical details about each exhibit. This would enable the app to cater to different users, some that prefer general, less detailed information, and some that are interested in more detailed technical drawings and information. We added an “Additional Information” page to each station to allow for layered content. These stations were organized following the linear layout of Tower Bridge, as shown in Figure 10. After several rounds of feedback, we honed in on the stations and features shown in Table 5.

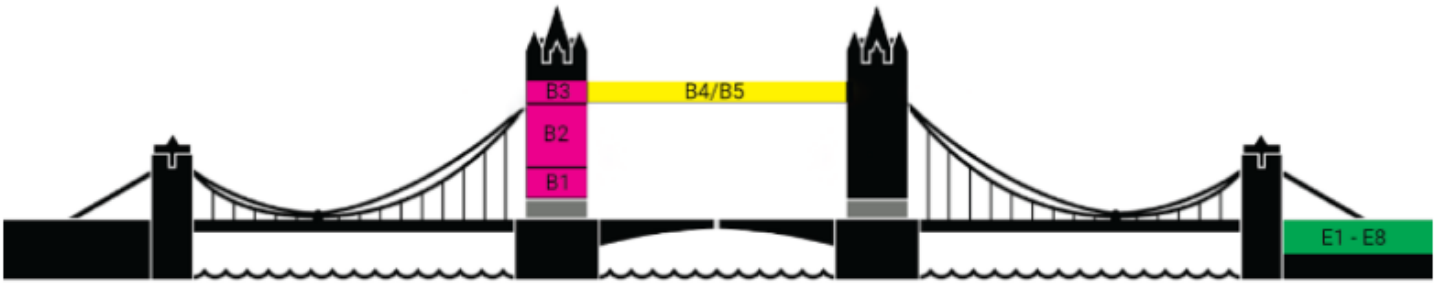


Figure 10: App Stations Layout

Table 5: Application Stations

Station	Feature(s)
B1 - North Tower Base Floor: Caissons	• Animation of foundation construction using caissons • Additional Information: Construction drawings showing the number and placement of the caissons
B2 - North Tower Stairs: Structure	• Animation of North Tower steel structure construction • Additional Information: Tower component dimensions
B3 - North Tower Top Floor: Structure	• Animation of bridge construction and connection to the North Tower • Additional Information: Tower and bridge component dimensions and load-bearing capacities
B4 - East Walkway: Structure	• Animation of walkway construction • Additional Information: Walkway and glass floors facts and statistics
B5 - West Walkway: Skyline	• West Walkway panorama slider • West Walkway panorama comparison • Additional Information: Landmark information, including age and purpose
E1 - Engine Rooms: Boilers	• Tap for more information on boiler components (water pump, water gauges, pressure gauge, and pressure release valve) • Additional Information: Boiler function and facts • Working Conditions: Boiler rooms temperature, smells, and hours of operation
E2 - Engine Rooms: Coal Bunkers	• Coal bunkers function and storage capacity
E3 - Engine Rooms: A Engine	• Tap for more information on A Engine components (pressure cylinders, manufacturer's label and paint, steam governor, self-oiling canisters, left crank pin, flywheel, right crank pin, rotation counter) • Additional Information: A Engine designer and operating cycle

Table 5: Application Stations (continued)

Station	Feature(s)
E4 - Engine Rooms: B Engine	• B Engine working conditions
E5 - Engine Rooms: Water Tank and Force Pumps	• Force Pumps function and operating information • Tap for more information on Water Tanks and Nose Bolts function and operating statistics
E6 - Engine Rooms: Engineer's Gallery	• None
E7 - Engine Rooms: Accumulators	• Accumulator function and weight • Additional Information: Accumulator diagram and statistics
E8 - Engine Rooms: Bascule Drive Engine	• Tap for more information on Bascule Drive Engine components (brake system, cog) • Animation of Bascule Drive Engine braking function

In what follows, we show pages of the app in chronological order, displaying the text and visuals with additional callouts to describe the function of many buttons and the rationale behind many features.

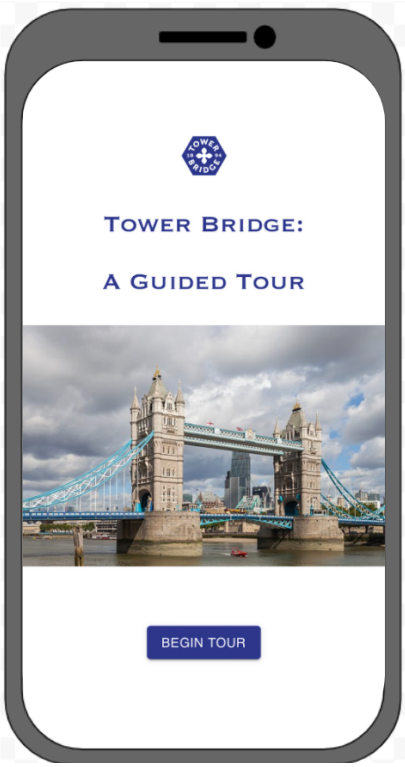


Figure 11: Tower Bridge App First Page

An overview page familiarizes the user with the general app structure to aid in navigation throughout their tour.

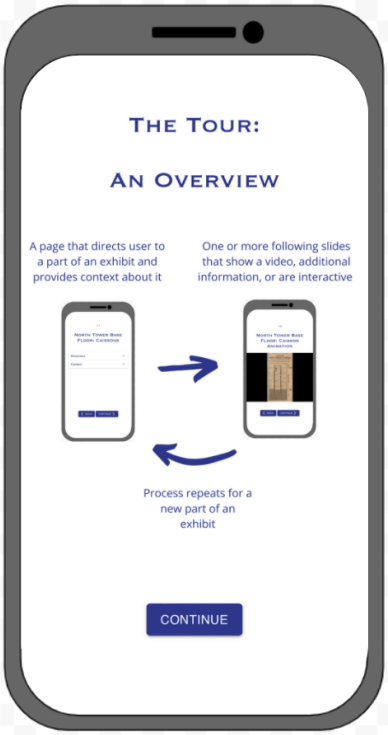
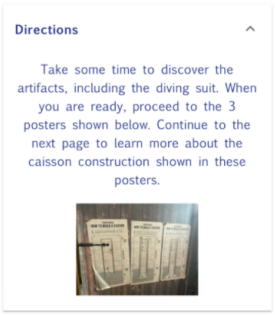
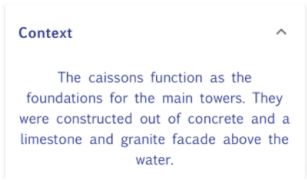


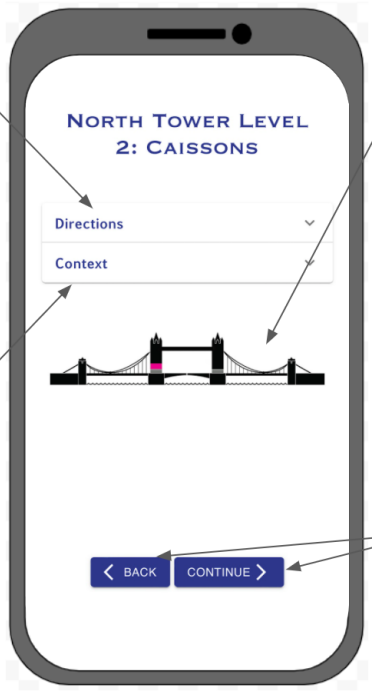
Figure 12: App Overview Page

The directions dropdown displays text instructing the user on what to do next



The context dropdown displays information about the specific section of the exhibition



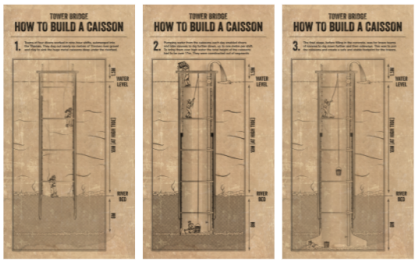


The Tower Bridge schematic displays the user's current location

"Back" and "Continue" buttons allow the user to navigate the app

Figure 13: North Tower Level 2

The animation serves as an extension of the existing posters and maintains a consistent visual language with existing assets. This makes it easier to understand for visitors.



Users are prompted to look at both the posters and animation, encouraging user interaction with existing museum assets.

The "Additional Information" button displays technical drawings of caissons for users interested in more detailed information

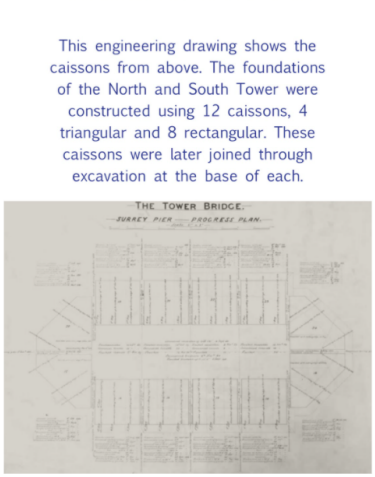


Figure 14: North Tower Level 2 Caisson Animation

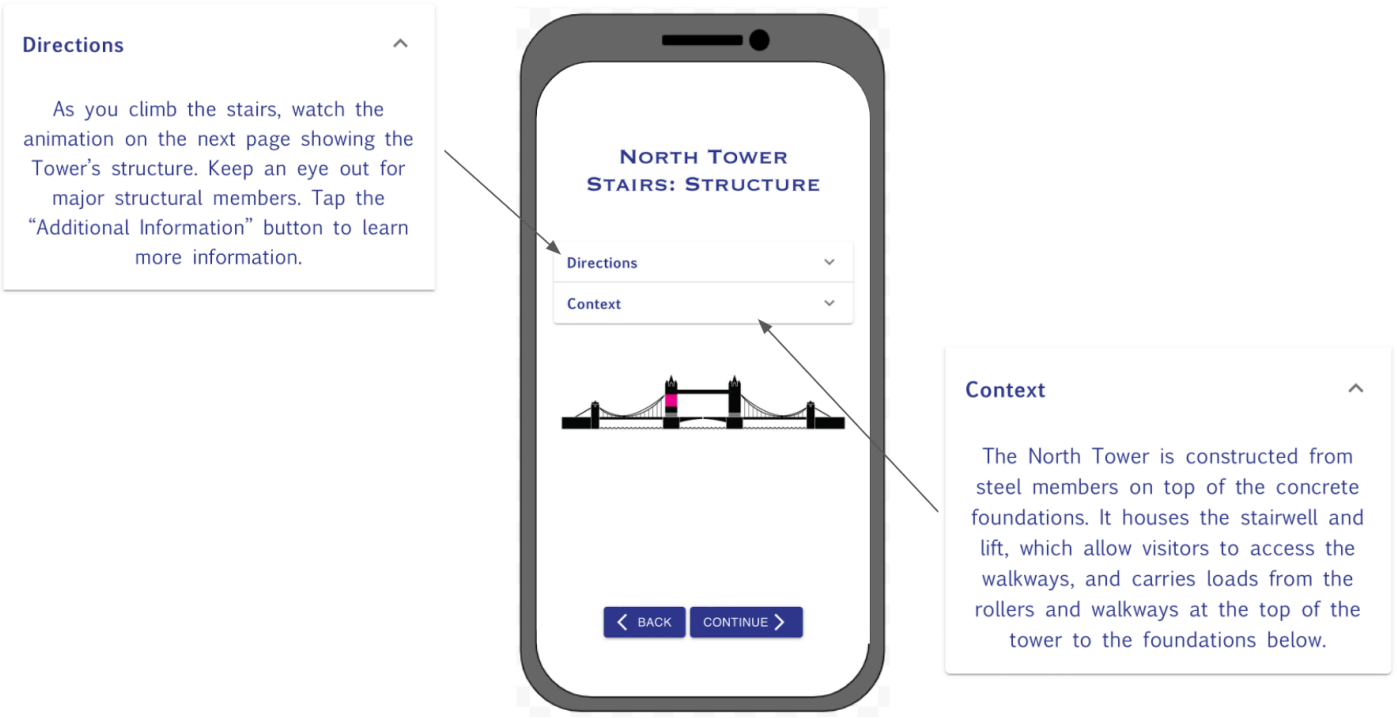
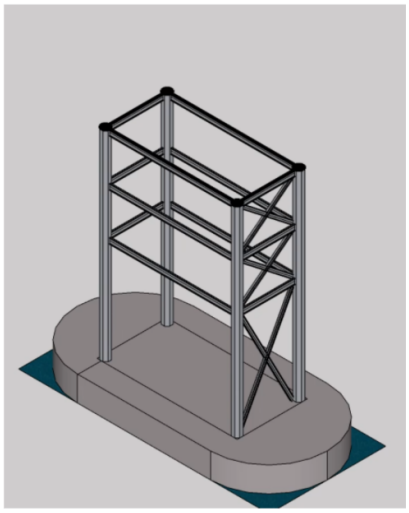
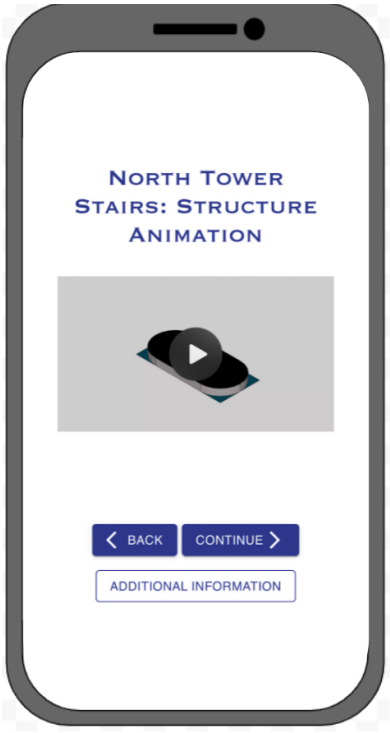


Figure 15: North Tower Stairs

The animation displays the overall structure of the North Tower being constructed from the foundation upward.





The "Additional Information" page displays facts and statistics about the North Tower for users interested in more detailed information. Organizing the data into a table makes it easier to comprehend.

Component	Value (IP)	Value (SI)
Octagonal Columns – 4 per Tower each resting on a granite bed stone	120 foot high 5 foot 6 inches diameter	36.5 metres 1.68 metres diameter
Crests on top of the towers	206 feet above the road 298 feet from foundation base	62.8 metres 90.83 metres
Archway	40 feet high	12.19 metres
Steel Plates – total length in towers & abutments	5 miles	8 Kilometres
L2 (Caisson Exhibition) above road surface (77 steps)	60 feet	18.23 metres
L3 above L2 (59 steps, from Road Surface - 137 steps)	28 feet	8.53 metres
L4 (Walkway Level) above Trinity High Water (from L3 – 70 steps, from Road Surface – 206 steps)	143 feet	43.58 metres
Attics above L.4 (42 steps – incl. 35 steel spiral steps and 7 wooden steps, from Road Surface – 248 steps)	23 feet	7.01 metres
Diameter of Circular Turrets	9 feet	2.74 metres

Figure 16: North Tower Stairs Structural Animation

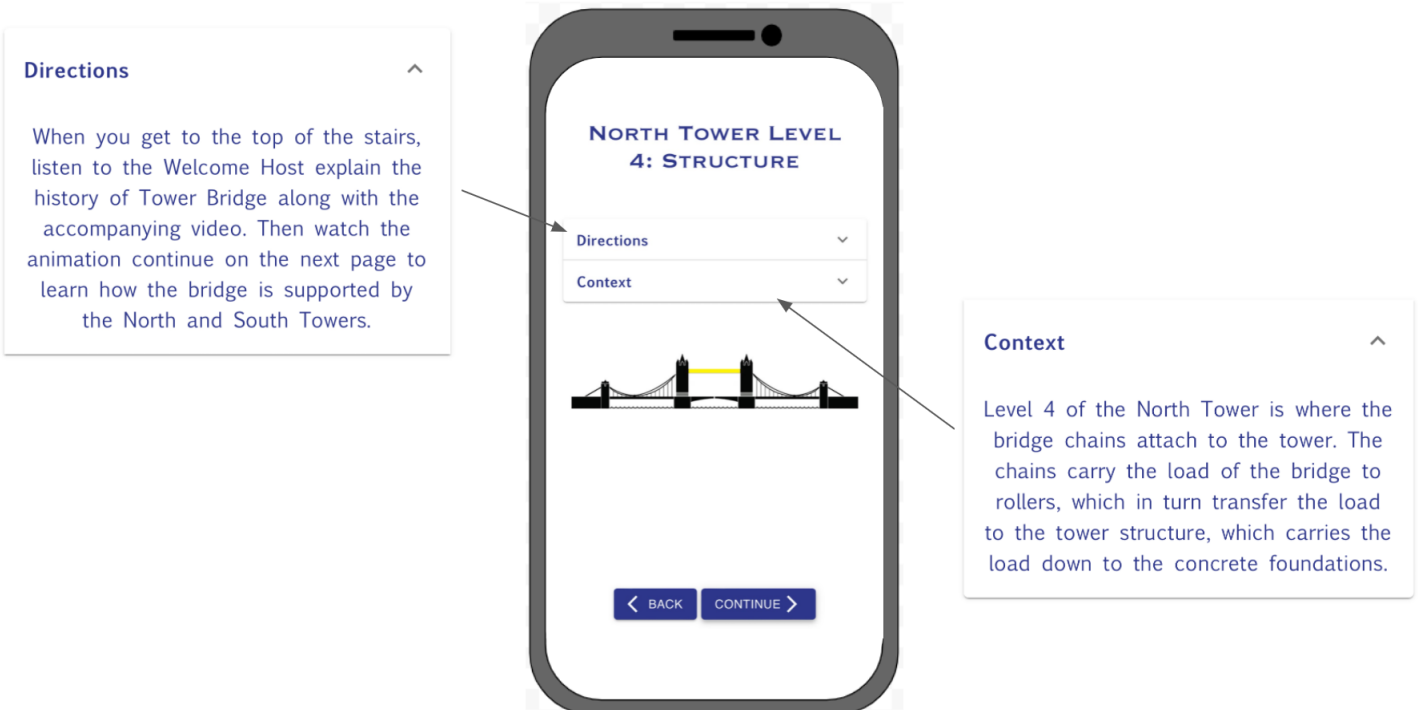
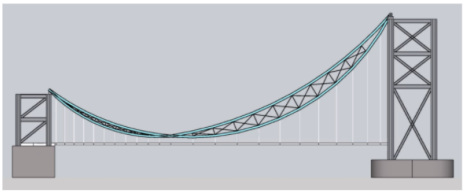
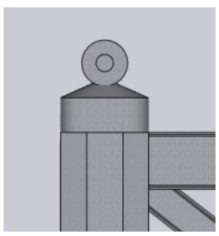
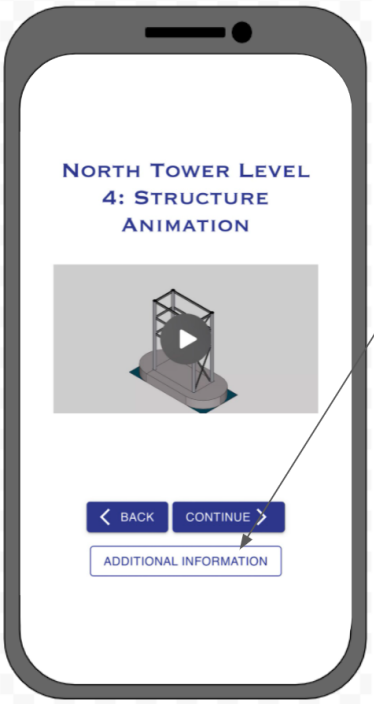


Figure 17: North Tower Level 4

The animation displays the overall structure of the bridge at a more digestible scale, while also zooming in on important components, such as the roller connection.







The "Additional Information" page displays facts and statistics about the bridge structure

Suspension Bridge	Value (IP)	Value (SI)
Rods	5.5 to 6 inches diameter	14-15 cms
Chains (Weight)	1 ton per foot	1 tons per 30 cms
Cross Girders - length	61 feet	18.59 metres
Cross Girders – depth	2 foot 3.5 inches	0.7 metres
Cross Girders - weight	22 tons	19.958 tonnes
The Rollers support a fully laden weight of	1000 tons	907.184 tonnes

Figure 18: North Tower Level 4 Structural Animation

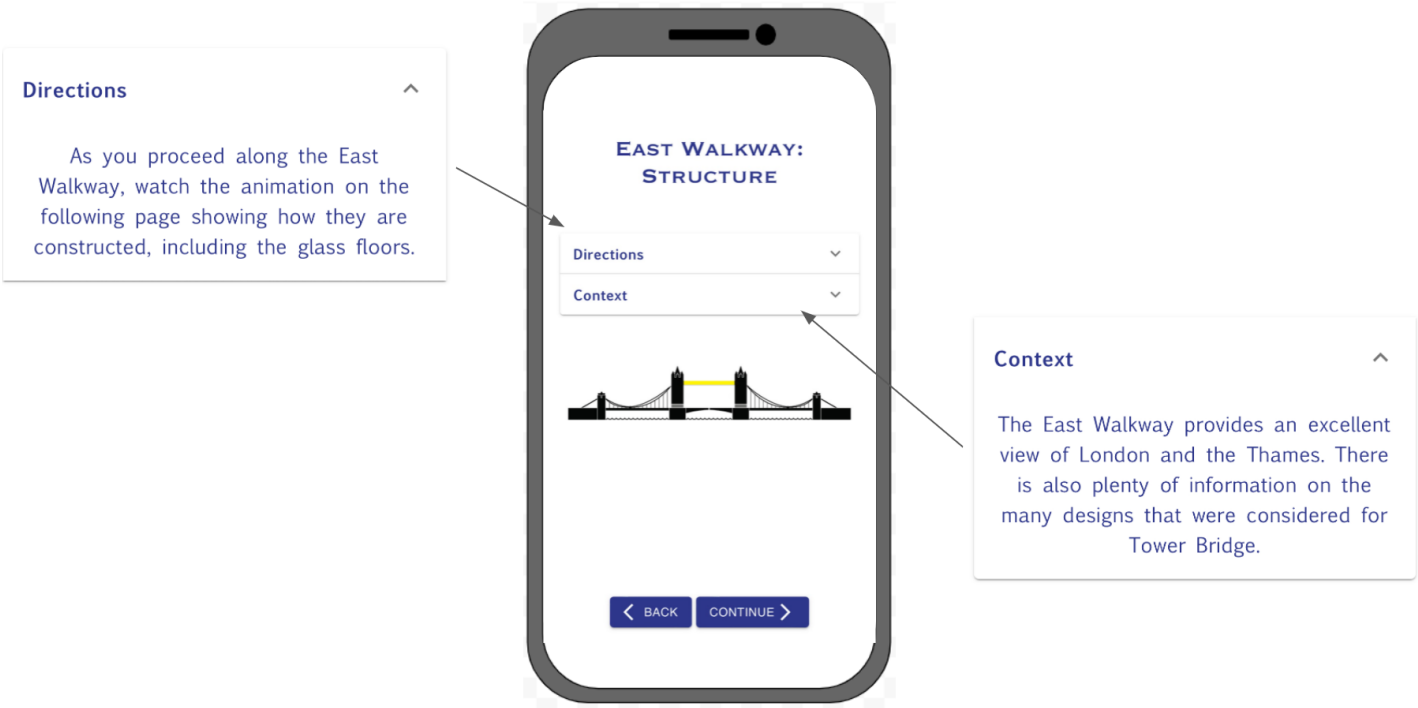
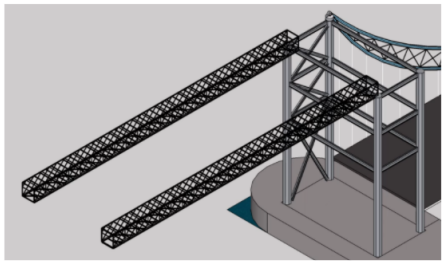
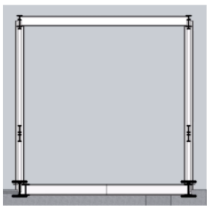
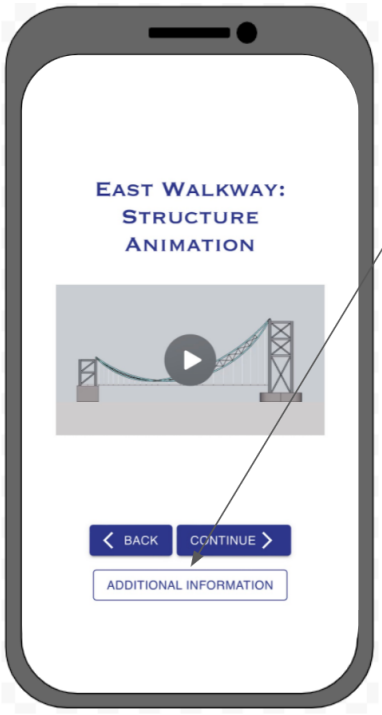


Figure 19: North Tower Level 4

The animation displays the overall structure of the East Walkway with a focus on the glass floors. Zooming in on a section cut of the walkways displays additional detail.







The "Additional Information" page displays facts and statistics about the walkway structure

Walkways	Value (IP)	Value (SI)
Height of walkways above roadway	110 feet	33.53 metres
Height of walkways above Trinity High Water	143 feet	43.59 metres
Width walkways	12 feet	3.66 metres
Length of walkways	230 feet	70.1 metres
Cantilevers	59 feet	17.98 metres
Central Girders	118.75 feet	36.2 metres

Glass Floors	Value (SI)
Dimensions	11.5 x 1.8m
Weight	530kg per panel, ie 3,180kg per glass floor
Weight Bearing Capacity	1.25 tons/sqm 26 tons per glass floor or about 6 male Asian elephants or a tower of £1 coins the height of the Shard
Thickness	80 mm, 7 layers
Cost	Just under £1 million
Funded by	The Bridge House Estates
Glass Specifications	PLANITHERM ULTRA N II low-E laminated glass, DIAMANT extra-flint glass and LITEFLOOR anti-skid glass

Figure 20: North Tower Level 4 Structural Animation

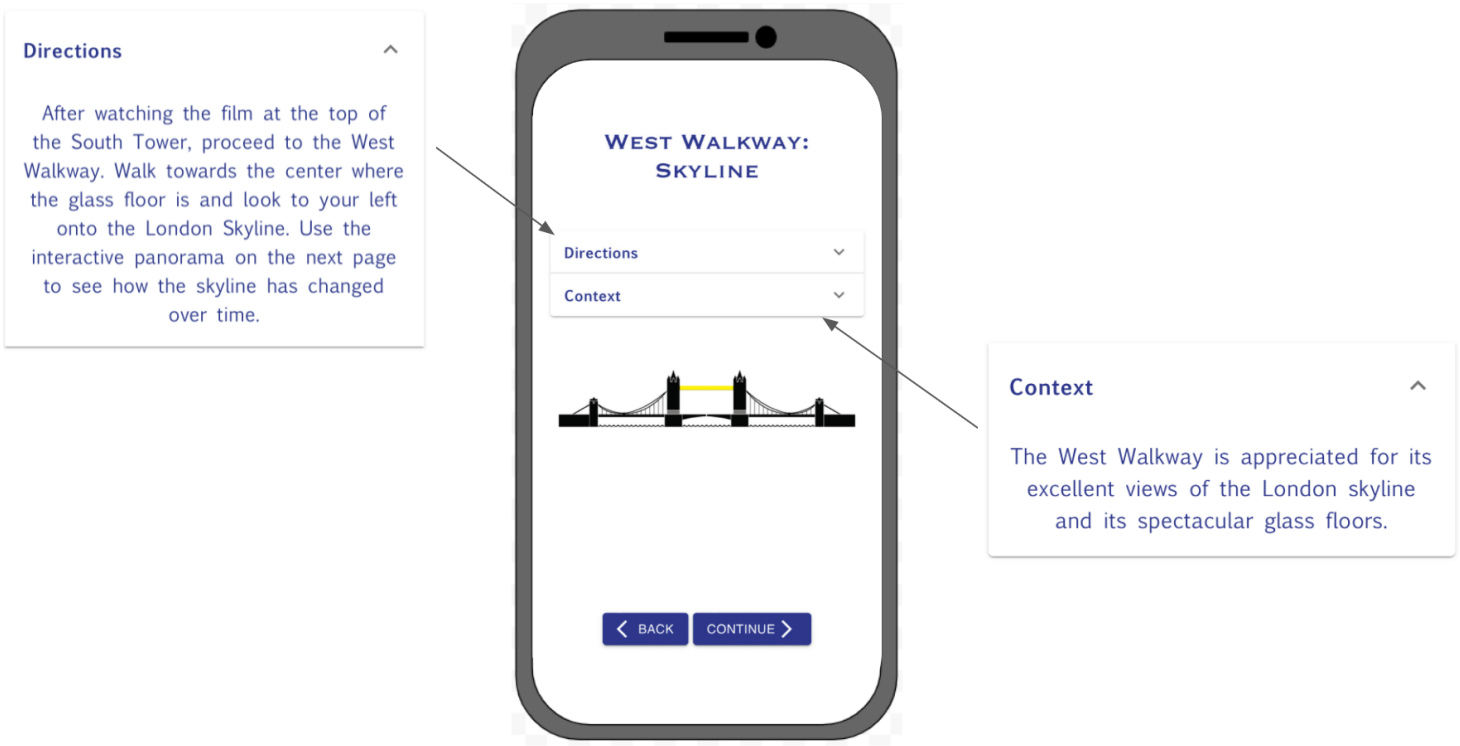


Figure 21: West Walkway Skyline

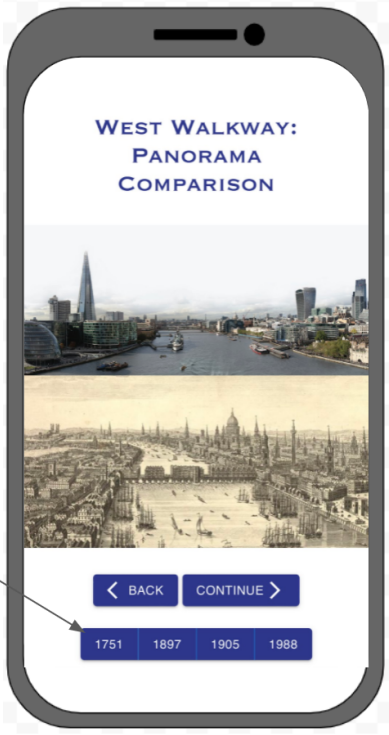
The slider adjusts the visibility of each image

Images can be selected from different years to compare against the present day

The "Label Buildings" switch toggles the appearance of building labels

'Additional Information" displays dropdown menus with more information about famous buildings

Figure 22: West Walkway Panorama



Images can be selected from different years to compare against the present day

Figure 23: West Walkway Panorama Comparison

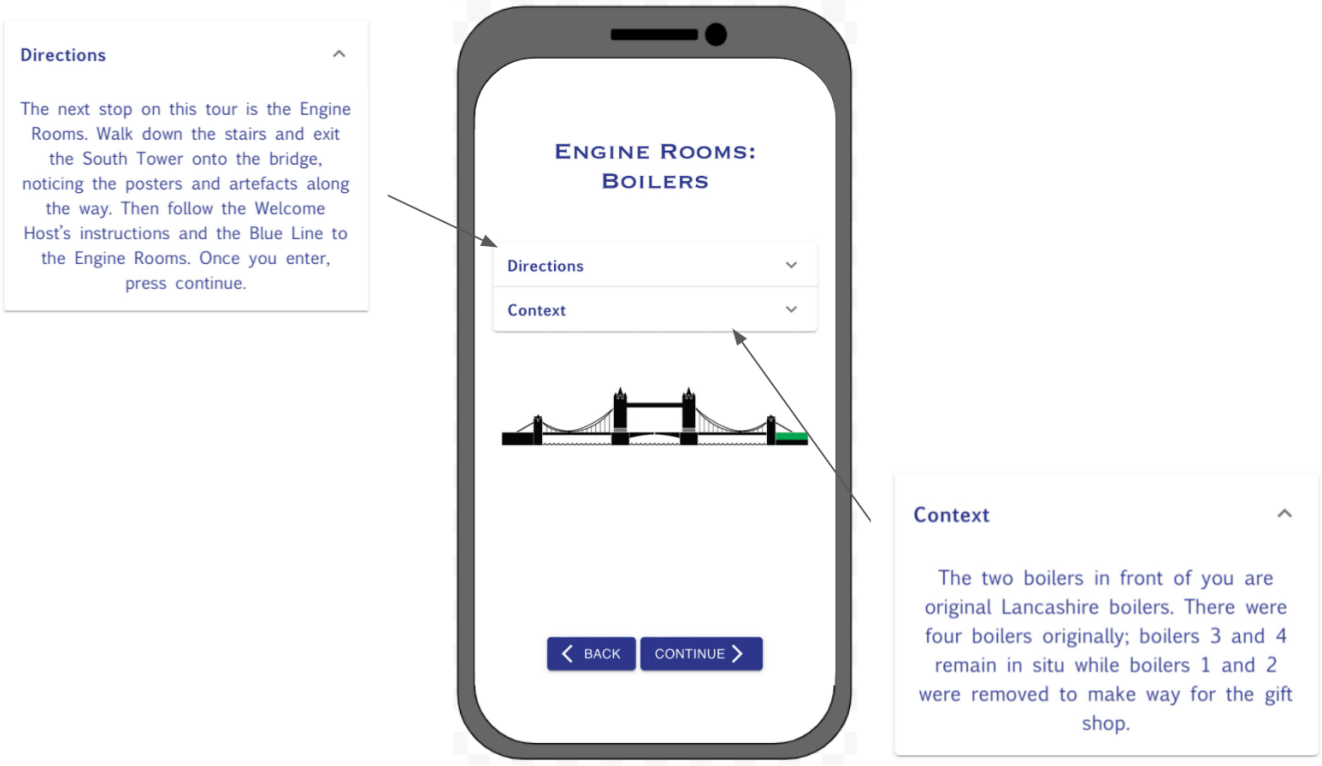


Figure 24: Engine Room Boilers

Users tap on different components to display more information about their function and design. Displaying additional information about existing museum assets encourages users to take a closer look.

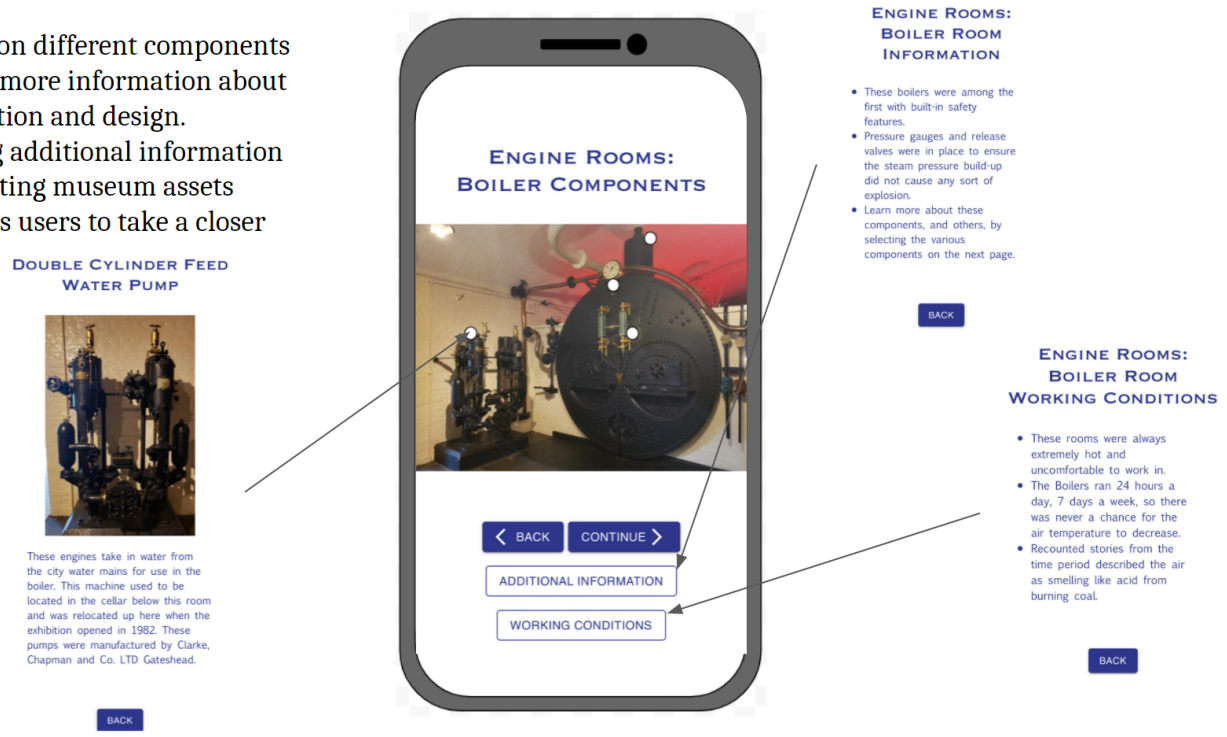


Figure 25: Boiler Components

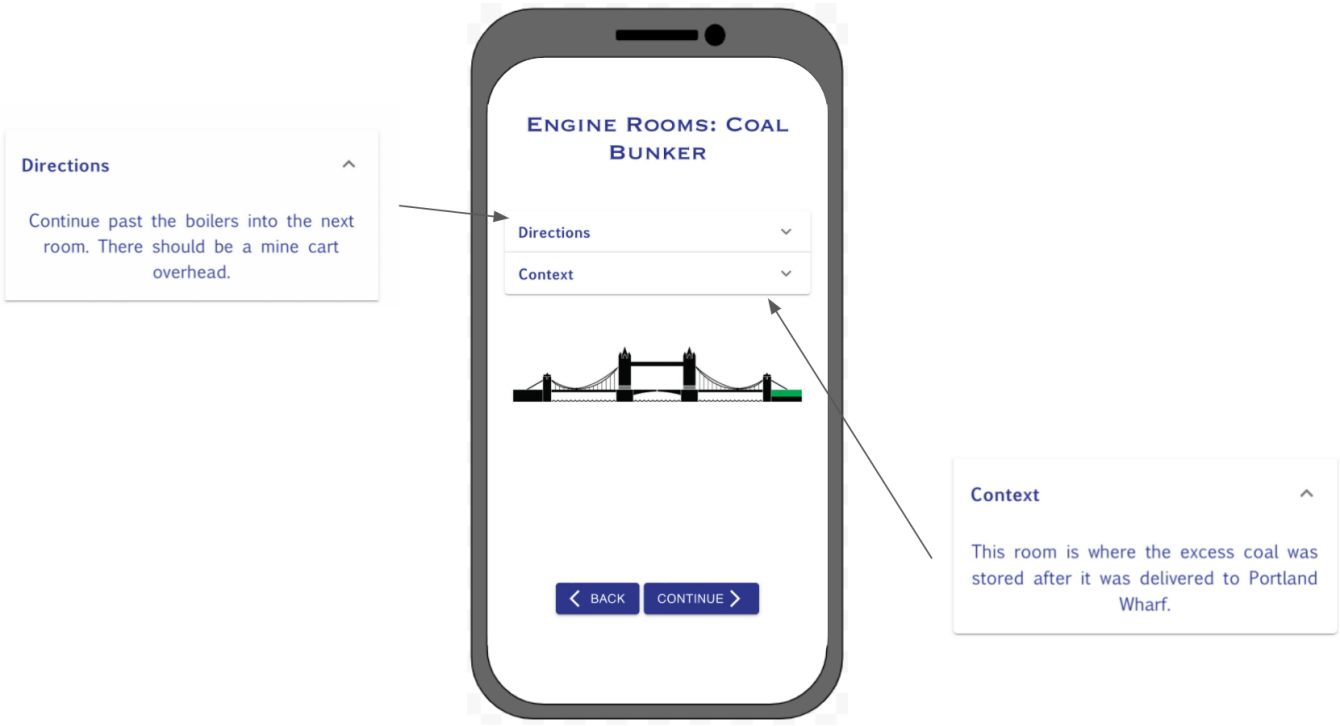


Figure 26: Coal Bunker

Tower Bridge currently contains little information on this section of the Engine Rooms. This information prompts users to slow down and inspect the Coal Bunker.

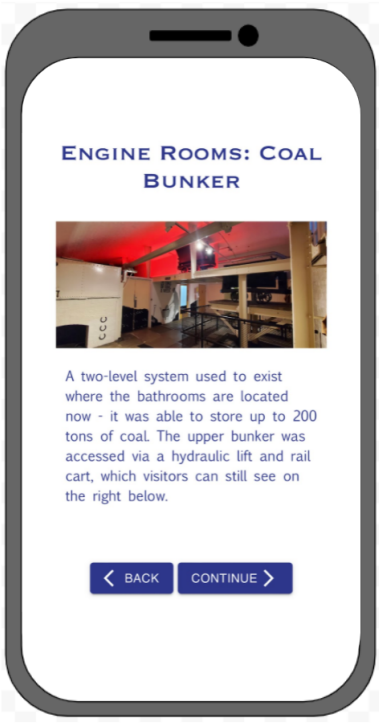


Figure 27: Coal Bunker Information

Organizing text into bullets makes it easier to read.

Figure 28: A Engine Components

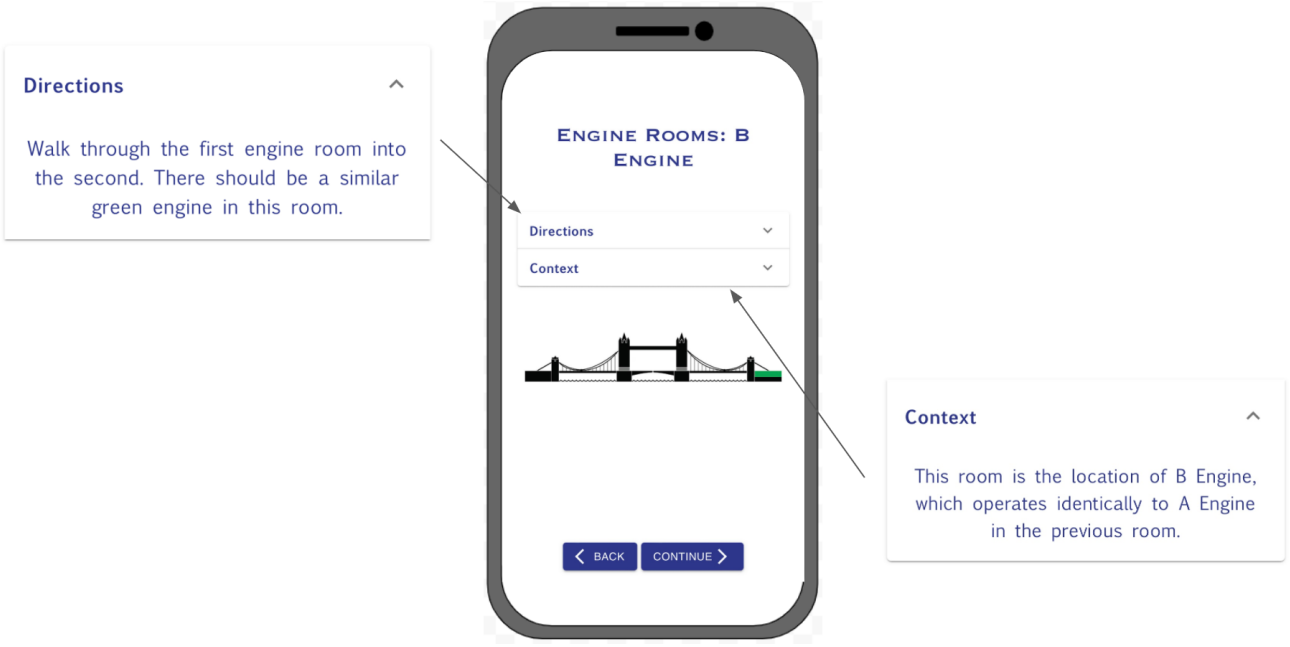


Figure 29: B Engine

Describing multiple senses, in this case touch and smell, creates a more immersive, interesting experience for the user.

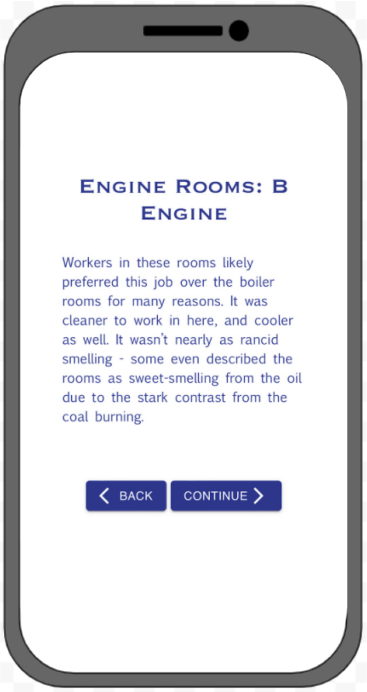


Figure 30: B Engine Information

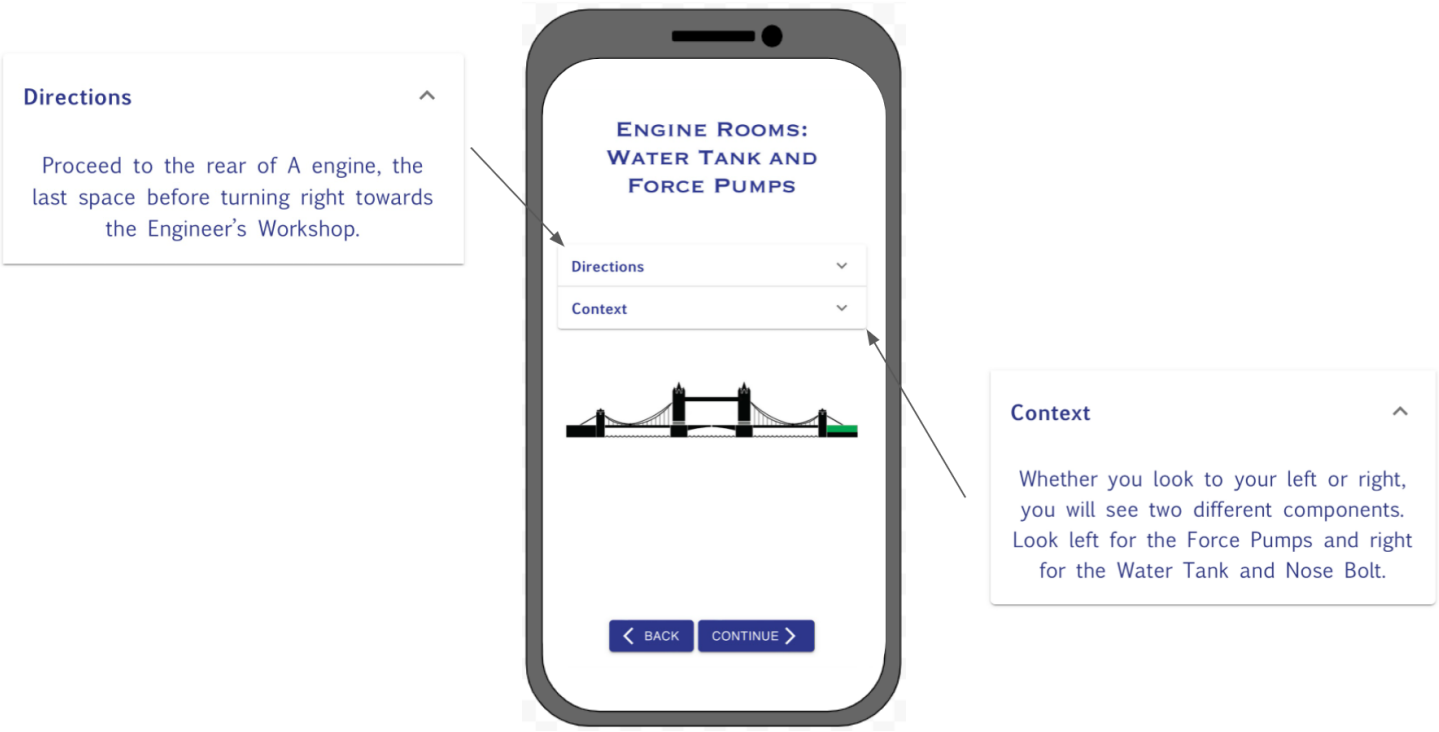


Figure 31: Water Tank and Force Pumps

Tower Bridge currently contains an animation showing the function of the Force Pumps. This information supplements the animation.

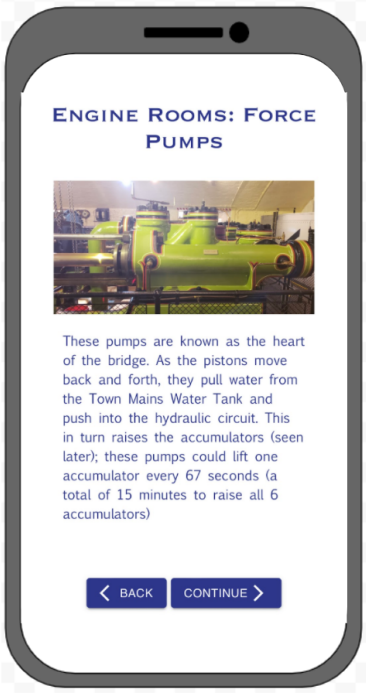


Figure 32: Force Pumps Information

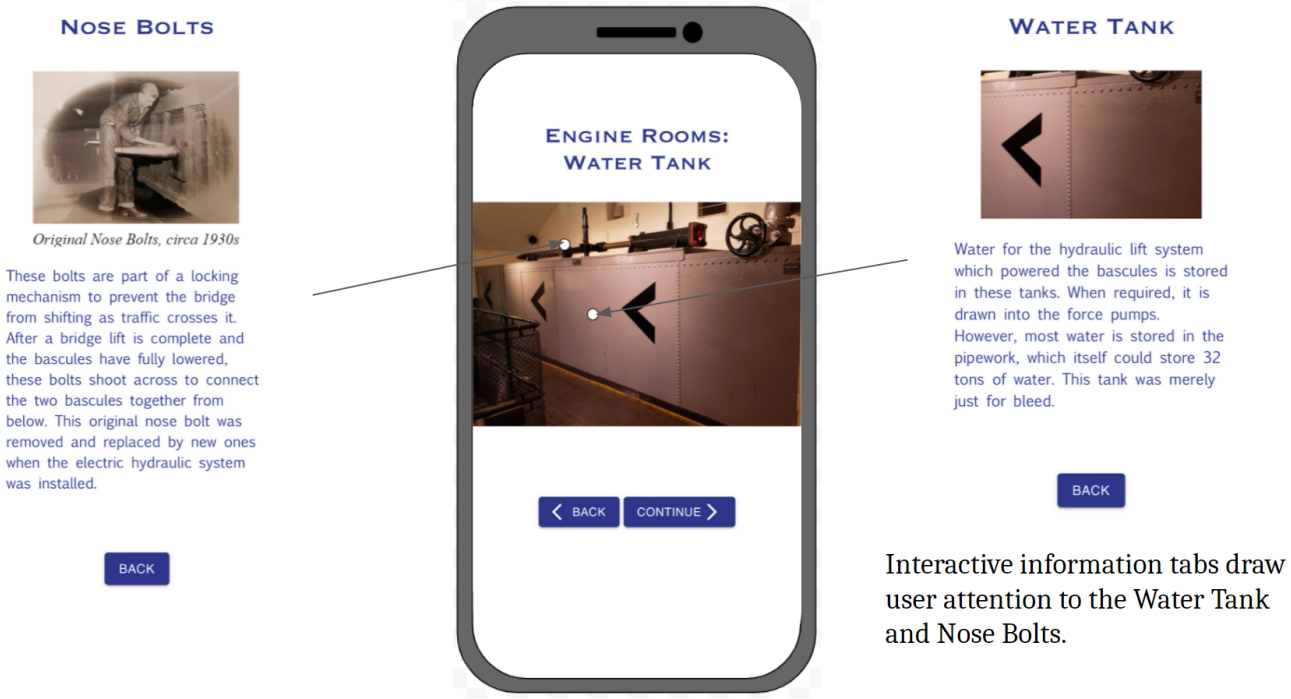


Figure 33: Water Tanks Information

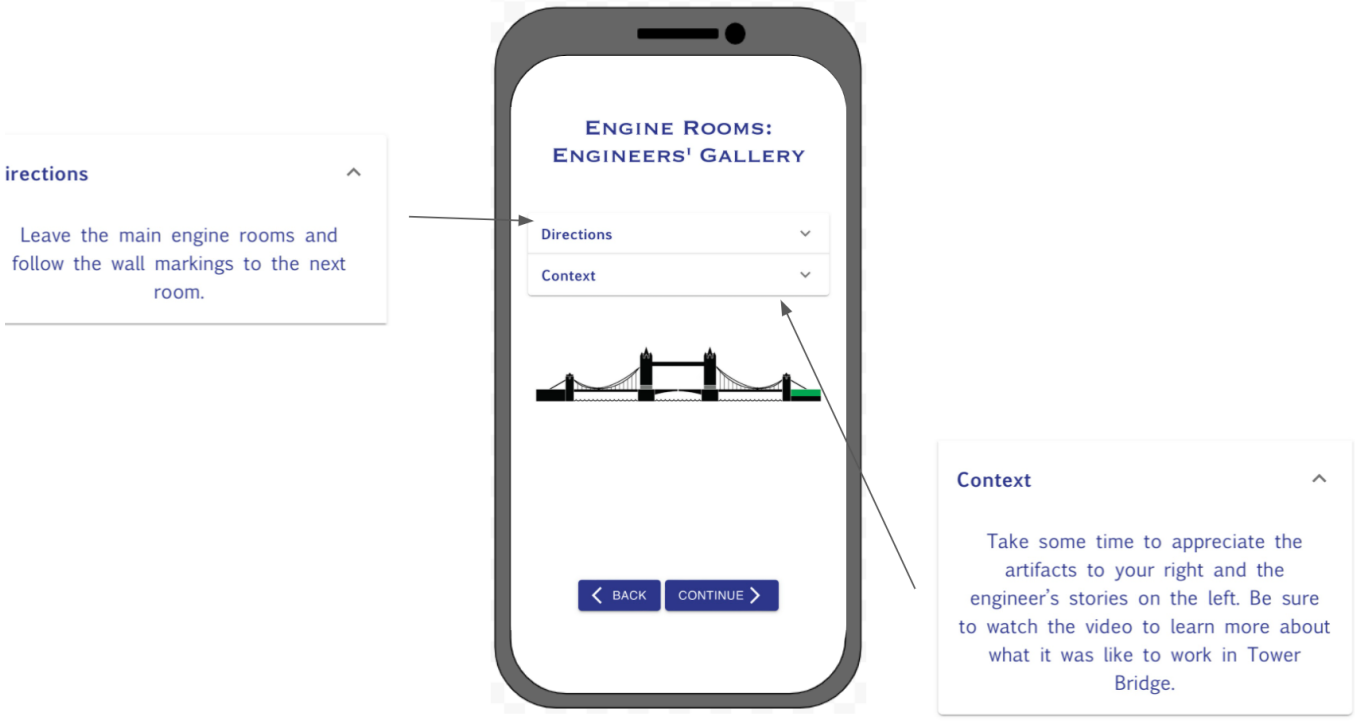


Figure 34: Engineers' Gallery

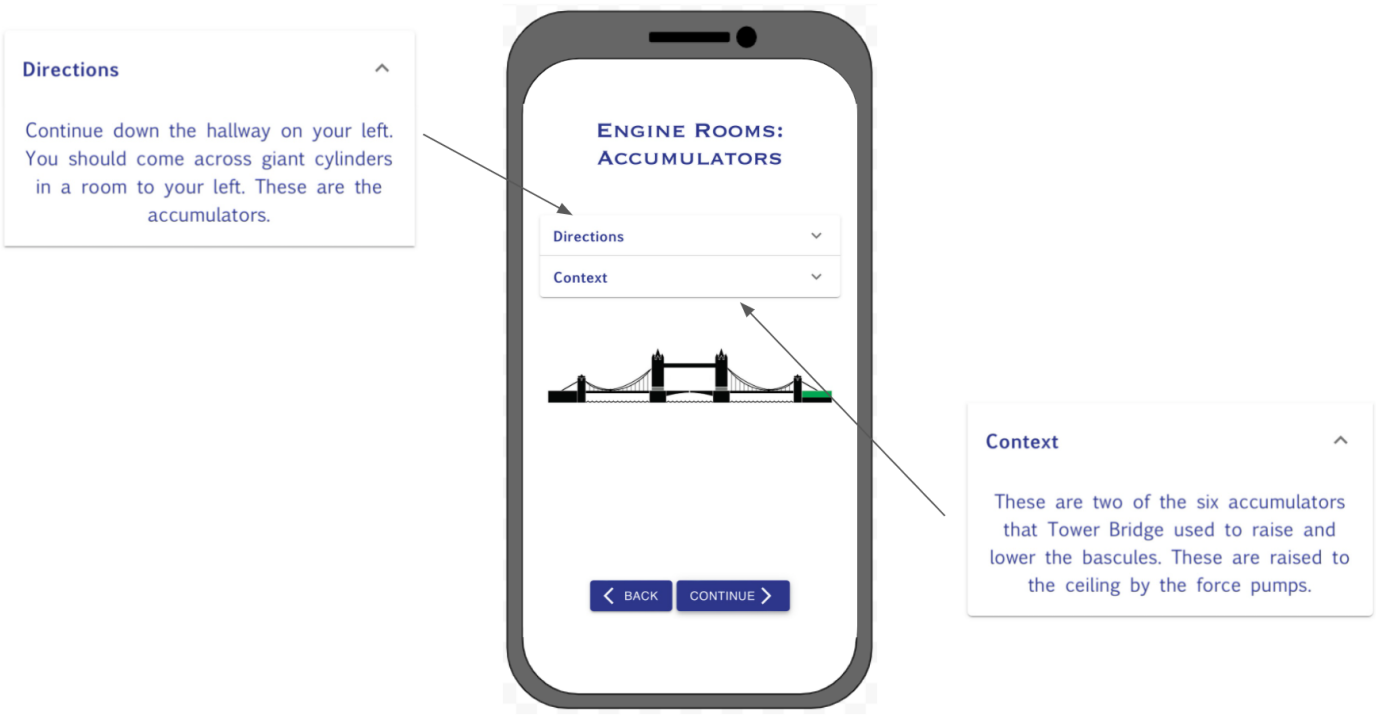


Figure 35: Accumulators

Text compliments the existing animation to further explain the function and design of the accumulators to technically-minded individuals.

Figure 36: Accumulators Information

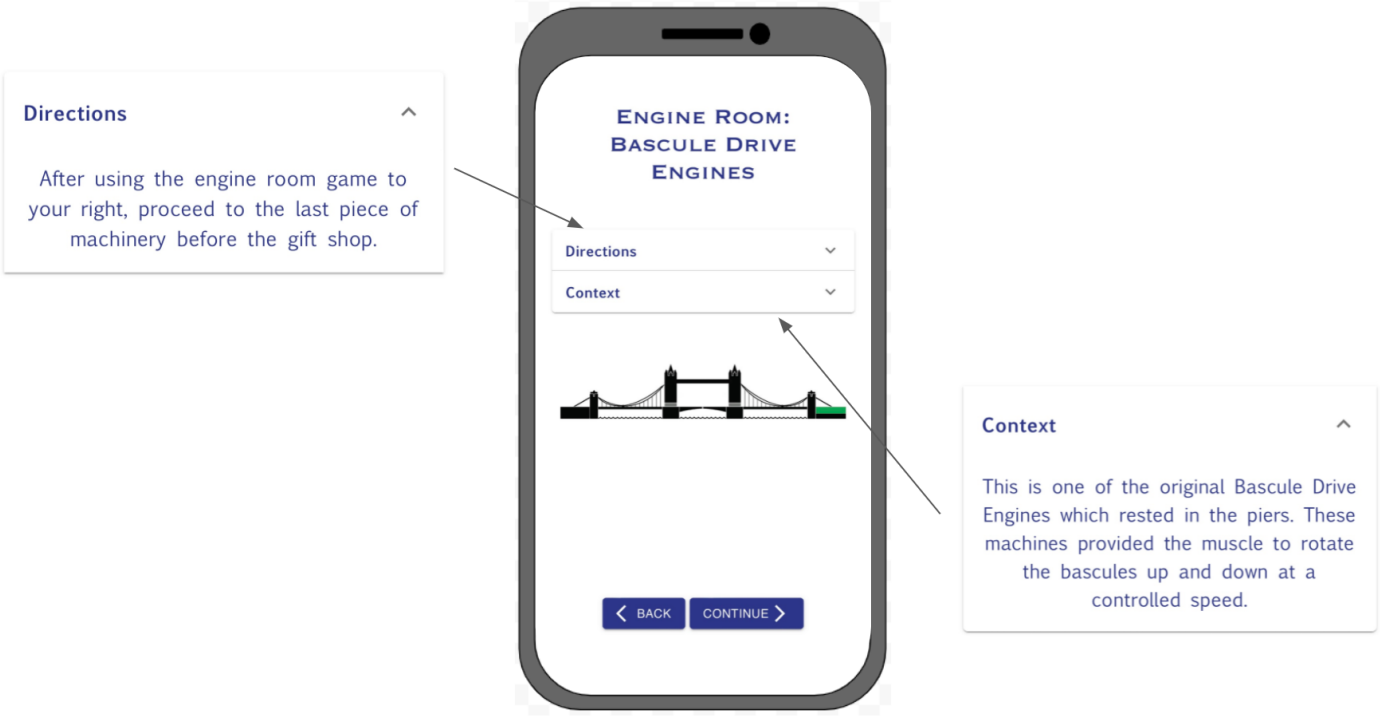


Figure 37: Bascule Drive Engines

Figure 38: Bascule Drive Engines Parts

This preliminary animation displays the braking mechanism of the Bascule Drive Engine. It makes the function of the engine easier to comprehend, as it is no longer functional.

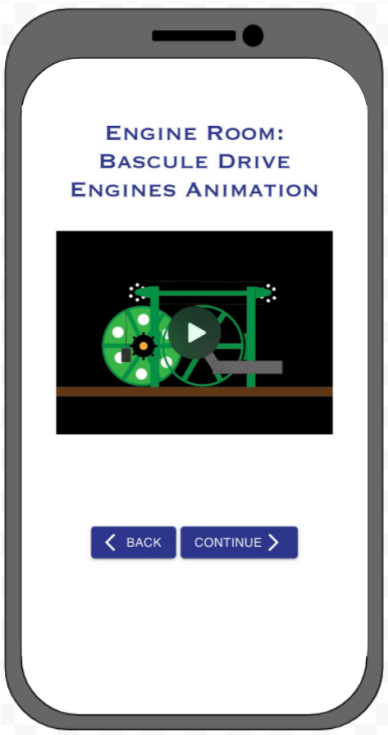


Figure 39: Bascule Drive Engines Animation

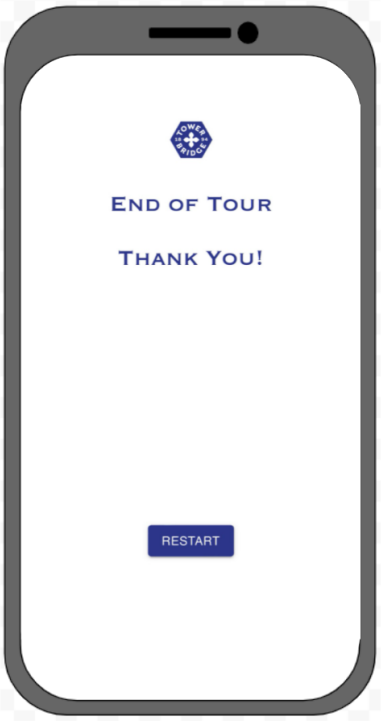


Figure 40: End Page

METHODS AND RESULTS

To test and refine our concept and identify areas for further development, our team asked student colleagues from WPI (engineering students) to use the app and provide feedback afterward. Each student was sent a link to the app to access on their personal device while touring Tower Bridge. Two members of our team accompanied each of the four student testing groups to answer questions such as how to use a feature, where they should be going, or a question on the content. During their tour, we did not ask them many questions aside from check-ins to make sure they accessed all the content on each page. We also noted some brief observations from watching our classmates using the tour, such as if they looked confused or unsure of where to go next.

After completion of the tour, we debriefed each testing group. Discussions were centered around some baseline topics we had identified beforehand, which included app interactivity, navigation and structure, entertainment value, sensory content, application completeness, and recommendations for future development.[5] We structured our discussion as an open conversation where people could discuss the questions and reach conclusions as a group.

Table 6 highlights the most agreed-upon feedback and most frequent suggestions we received from the tour based on the aforementioned topics.

Table 6: WPI Student Focus Group Testing Feedback

Topic	Feedback
App Interactivity	• Being able to touch/select anything to gain information was beneficial • Interactive Engine Room Pictures helped with understanding • Panorama Slider was more interactive than side-by-side images
App Navigation & Structure	• A bit unclear where users were supposed to be at certain points in the app, i.e. when to watch each structure animation in the North Tower, or which walkway someone should be on for certain features • Some didn't notice the "Additional Information" buttons, or didn't feel the need to click on them • Navigation from the West walkway to the engine rooms was lacking before the "blue line" ◦ Needed clarification to go down South Tower first
Entertainment Value	• Ability to interact and tap buttons on nearly every page kept users engaged • Animations were helpful for understanding as well as impressive to watch • Additional Information on Glass Walkways was of particular interest, enhancing attraction
Sensory Content	• Provided another layer of immersion that participants noted they may not have thought about • Lots of opportunities for enhancement of this feature, such as audio of the engines working or even a physical smell pumped into the engine rooms
Application Completeness	• Written content should be fine-tuned • Could go even further with "Additional Information" ◦ More layers of content in more detail • Specifically, B Engine room needs more content- directions and context page is not enough

Recommendations and Suggestions from Student Users	• Virtual Stamp Book that utilizes Smartify's Image Recognition technology
	  ◦ Could also be structured as a scavenger hunt
	• General Tower Bridge Information included (bridge lift times, hours of operation)
	• For bridge structure, schematics and drawings for specific beams/joints in Additional Information
	• Include reference values for engineering facts and statistics
	  ◦ Ex. rollers support a fully laden weight of 1000 tons which is equal to about 200 male African elephants
	• Add wall signage to help users determine where they should be in the app at a given location
	  ◦ Could be as easy as a small number or marker
	• App must be accessible offline

[5]Supplemental Material E; Student Testing Questions

Since our application is still in the preliminary development phase, the feedback presented prior was gathered as a formative evaluation of the application's current status. We used it as a reference for minor modifications as well as more recommendations for the future. We wanted to gauge what features worked well and which may not have, and whether they fit well into the tour concept as a whole. This testing also assisted us in surface-level editing of the application such as typographical errors in the text or minor coding errors such as images or videos not loading. Further testing with exhibition staff and visitors would be required to refine the application and its features.

The goal of our project was to develop a pilot app that would serve as a proof of concept. As demonstrated prior, our prototype application progressed significantly from conception to conclusion, but much remains to take this pilot to a finished product. Figure 41 shows the link and QR code for our pilot application.

https://tower-bridge-tour.web.app

Figure 41: Tower Bridge Pilot Application Link and QR Code

Conclusion and Recommendations

Our main conclusion is that a bring-your-own-device application would be a valuable addition to the interpretive approach of the Tower Bridge Exhibition because it would add to the visitor experience and not detract from visitor interaction with existing assets. Focusing on engineering, our group directed users' attention to the main structure, walkways, and engine rooms while also directing the users to notice or interact with existing interpretive material. We also chose to add features highlighting the views of buildings and skylines through the ages from the walkways. We used a layered approach to give visitors control over the material they did and did not want to learn more about, and we used a consistent format to portray technical information. Visuals, interactive photos, construction drawings, and animations showing parts of the bridge construction are included in the app. We recommend that future app developers add technical details on the materials, construction process, and machine operation of Tower Bridge. Although we developed this type of content fully in some stations of the app to demonstrate the layering concept, we were not able to fully develop other stations. We wanted our project to serve more as a proof of concept, leaving something that professional developers could use to design a completed application in the future, potentially on a different platform.

We have compiled a list of recommendations for Tower Bridge to consider in the final application design. These include, but are not limited to, types of technical content that could be added, how to improve interactivity and the user interface, and how to further enhance sensory elements.

Interactivity and User Interface

- We recommend the animations and photos be designed so that users can tap on connections or beams to learn more information about their purpose, specifications, and operation. This information should include the facts and details presently included under the "Additional Information" buttons in the app. Presented as a table or set of bulleted points, this information could also be obtained by tapping the specific component a user wants to know about, which will better tailor the experience to the user. In order to incorporate this feature, an interactive 3D model will need to be created rather than a linear video.

Additional Technical Information

- We recommend that the caissons (Station B1) should include a drawing of a plan view of the caissons. Additional drawings could be added, perhaps displaying a section cut or elevation of the caissons in order to further describe their construction and function.
- As noted by Dirk Bennett, to humanize the engineering process, we might include more of the British engineers, manufacturers, and architects to the app through a new button called "Architects and Engineers." This page would include names and perhaps descriptions or biographies of the companies or people involved.
- We recommend that the panorama feature (Station B5.1) should include more buildings that the user will be able to tap on and read about. Currently, a button can be used to display the names of several buildings. A developed application should allow the user to tap on individual buildings to see more information about each, rather than displaying information for every building at once. These descriptions should remain concise and only display the most pertinent information.
- For the engine room tour, we recommend improvements to the displayed content for the interactive machinery images; other types of information should be displayed when an item is tapped. We were only able to include small paragraphs of information about these parts, but technical drawings, materials, manufacturers, or other specifications should also be included. As recommended by Dirk Bennett, this content would be presented in a streamlined manner using a table or bulleted list, so each component displays the same categories of information.
- For the engine rooms, we recommend additional interactives and layers of information on the components and functionality of the engines to enhance the experience even further for those who are technically minded. We recommend these layers include new animations or videos of other components that no longer function such as the raising and lowering of accumulators from an interior schematic, or animation of the nose bolts engaging and disengaging before and after a bridge lift. Finally, we recommend an animation or

graphic restoring the coal bunkers to their former glory to help visitors understand what that room is used for. With the installation of the restrooms, it is difficult for visitors to imagine the room filled with coal or having coal carts moving coal around the room. This new feature would help visitors picture what this room looked like during the original operation.

Sensory Elements

- We recommend that there be more sensory elements incorporated into the app to enhance the user experience, similar to what is included already. References to smell were included in the pilot application on the Directions and Context page for the Engine Room Boilers with the smells of the boiler and engine rooms being described to the user. We also encourage visitors to look at the skyline of London, watch videos, and listen to Welcome Hosts.
- Further sensory experiences could be incorporated with users being prompted to feel specific structural members or rivets in the North Tower and East Walkway or to feel the vibrations in the walkway suspension cables. In North Tower Level 2, users could listen to an audio file describing what the divers heard as they descended beneath the Thames. Users will become more immersed in the exhibition with the inclusion of sensory features.

General Additions

- We recommend the completed application include quick access to most of Tower Bridge's essential information such as a map, accessibility guides, opening hours, bridge lift times, and much more. This addition would allow the user to access everything they need to know without swapping between their tour guide application and the Tower Bridge website, which could be a bit cumbersome.
- We recommend incorporating a "digital postcard" feature on the West Walkway, where users could take a photo of themselves and add a virtual background or border. This "digital postcard" could then be posted to social media or shared with friends and family directly from the app. This feature would have the added benefit of providing free marketing for Tower Bridge and the application. However, while this and the feature above could benefit this engineering application, they could be better suited in a different type of application that is more general.

Testing

After a more complete application is developed, it must be tested with members of the target audience and the Tower Bridge staff. Testing should be orchestrated differently from what we were able to do. With more time, a survey at the end of the app could be developed which could test how much the user enjoyed the app, how much they learned, and ask for suggestions. It could also time how long the user was on each page to determine if the app increased interactivity. An iterative design process will result in the best product; the results of each stage of testing should be used to revise the application before it is tested further.

Marketing

With a fully developed application, the next important issue will be to ensure that visitors are aware of its existence and ensure they download and use it. This can be accomplished through various marketing tactics. We recommend that Tower Bridge develop a teaser video showcasing an animation. With the walkways already being a major draw and visually-appealing feature of Tower Bridge, they should be included in this video. We recommend that this preview video be posted to the Tower Bridge Instagram and website, and any other platforms they deem appropriate. This video could also be displayed on the televisions in the Tower Bridge ticket office.

While a preview video should serve to increase visitor awareness of the app, QR codes can be used to further encourage them to download it. QR codes are an effective tool because they are easily recognizable and simplify the process of following a link, or in this case, downloading an app. Still, QR codes aren't visually appealing, and thus should be kept out of the Tower Bridge exhibition as much as possible. Instead, QR codes should be shown in the ticket office to prompt visitors to download the app before they enter the bridge. Displaying the preview video on social media and the Tower Bridge website should also serve to increase app downloads before visitors enter the exhibition.

Overall, our main conclusion is that a bring-your-own-device application would be a valuable addition to the interpretive approach at Tower Bridge. However, the pilot application we have developed is far from a finished product. A fully developed, functioning app will enhance the overall experience of the technically minded visitors of Tower Bridge.

Author's Page

Adam Bartlett, Civil Engineering

Adam researched the case studies for the background section (*Case Study 1: The Open Art Application in the National Museum - Krakow, Poland* and *Case Study 2: The Pointillize Yourself Application in the Indianapolis Museum of Art (IMA) and the #NeoImpressed Application in the Phillips Collection*) and took a lead role in editing and revising the written portions of the project. He developed and synthesized our findings from our research in London museums and wrote the section *Objective 1: Best practices for museum and heritage site interpretation.* He took a lead role in developing the content for the Engine Room section of the tour.

Colin Canniff, Mechanical Engineering

Colin developed and designed the final report booklet using Canva. He also contributed to the abstract and introduction, and assisted in editing and revising the background, methods and results, and conclusion and recommendations sections. He took the lead role in researching and comprising the *Visitation at Tower Bridge* and *Audience Segmentation at Tower Bridge* background sections while creating tables and graphs to support researched data. Colin also helped brainstorm ideas for the initial storyboards and helped conduct testing of the pilot application at Tower Bridge for fellow WPI students.

Jonathan Lopez, Electrical and Computer Engineering

Jonathan did research on the different application modes, the history of Tower Bridge and Bridge House Estates in sections *History and Reinterpretation of Tower Bridge* and *Potential Platforms and Learning Methods.* Taking head of *Objective 3* as well as help write the *Final Conclusions and Recommendations.* In addition, Jonathan took many photos, including the wide angle shots that made into the final application as well as helped set up a GitHub repository for the app to ensure future usability.

Conor McDonough, Computer Science

Conor coded the application. He coded in React and used Firebase to host the website. In addition to this he worked on *The Rise of the Digital Era* in the Background as well as parts of the Recommendations and Conclusions. Conor also helped create and edit the storyboard.

Jake Scalise, Architectural Engineering

Jake created the caisson, structural, and bascule drive engine animations that were included in the application. He also compiled the additional information that was included in Stations B1, B2, B3, and B4. He contributed to the Introduction, the The Rise of the Digital Era and Potential Platforms and Learning Methods sections of the Background section, Objective 4: Refining the storyboard and developing a pilot application in the Methods and Results section, and the Recommendations and Conclusions. He also took a lead role in crafting our final presentation.

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