



UNIVERSIDADE D
COIMBRA

Marcelo Fernandes Coelho

TANGIBLE VR BOOK

IMMERSIVE EXPLORATION OF LLOYD'S REGISTER SHIP
PLANS

Dissertation in the context of the Master's in Design and Multimedia, advised by
Professor Jorge C. S. Cardoso and Professor Paul David Hardman and presented to
the Department of Informatics Engineering of the Faculty of Sciences and
Technology of the University of Coimbra.

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DEPARTAMENTO DE
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FACULDADE DE
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UNIVERSIDADE D
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Abstract

This dissertation investigates how tangible and immersive technologies can support the presentation and understanding of complex archival material in educational contexts. Developed in collaboration with Lloyd's Register Foundation, the project uses a Tangible VR Book as its central artifact, a physical book with visual markers that triggers a web-based VR application on smartphones. As users turn pages, the experience displays different images, 3D models, animations, video, and audio narration. A custom web-based editor was developed for setting up the content for each page.

The work presented covers contextual research, technical evaluation of web-based marker tracking technologies, and prototyping. The system was evaluated through user testing with 24 participants, assessing information transmission across three spatial content distributions: distributed around the user, central frontal placement, and marker-anchored versus unanchored content. User comfort and VR-sickness were also assessed. Findings provide practical insights into how spatial content placement affects comprehension and comfort in tangible VR experiences for education.

Resumo

Esta dissertação investiga de que forma tecnologias tangíveis e imersivas podem apoiar a apresentação e compreensão de materiais de arquivo complexos em contextos educativos. Desenvolvido em colaboração com a Lloyd's Register Foundation, o projeto utiliza um Livro de VR Tangível como artefacto central—um livro físico com marcadores visuais que aciona uma aplicação VR baseada na web em smartphones. À medida que os utilizadores viram as páginas, a experiência exhibe diferentes imagens, modelos 3D, animações, vídeo e narração áudio. Foi desenvolvido um editor web personalizado para configurar o conteúdo de cada página.

O trabalho apresentado abrange investigação contextual, avaliação técnica de tecnologias de rastreamento de marcadores baseadas na web e prototipagem. O sistema foi avaliado através de testes com 24 participantes, avaliando a transmissão de informação em três distribuições espaciais de conteúdo: distribuído em torno do utilizador, colocação frontal central, e conteúdo ancorado versus não ancorado ao marcador. O conforto dos utilizadores e o potencial enjoo associado à VR foram também avaliados. Os resultados fornecem perspetivas práticas sobre como a disposição espacial do conteúdo afeta a compreensão e o conforto em experiências de VR tangíveis para a educação.

Keywords

Tangible Interaction, Virtual Reality, Immersive Learning, Digital Archives, Marker-Based Tracking.

Statement on the Use of Artificial Intelligence Tools

This dissertation was reviewed and refined with the assistance of Large Language Models, such as ChatGPT, which helped check grammar, correct typos, and enhance clarity. Any Artificial Intelligence-generated text or content is clearly indicated within the document and is used only to a limited extent. The overall content, research, methodology, findings, and ideas remain solely the responsibility of the author.

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Chapter 1

Introduction

The foundation for this dissertation begins with the material of the Lloyd's Register archive, that contains ship plans and documents, and the pedagogical challenge of making technical historical materials accessible to broader audiences. Our rationale is that there is a growing opportunity to explore how immersive media can bridge the gap between complex archival content and contemporary user expectations.

To investigate this potential, we developed the Lloyd's Register Tangible VR Book, a physical book about the story of Fullagar, the world's first fully welded ship, alongside a framework capable of displaying and managing the associated VR content. To ensure the approach is replicable, we also created an authoring tool that allows others to produce their own Tangible VR Books. Finally, we conducted a user study to evaluate content distribution strategies, the use of marker-attached content, and the extent to which the experience induced cybersickness.

We aimed to make this technology as accessible as possible, projecting for widely available consumer devices and web-based technologies.

1.1 Context

Lloyd's Register of Ships is one of the most extensive and continuous collections documenting maritime activity, ship design, and safety standards. Its materials include ship plans, surveys, technical diagrams, and reports that reflect the evolution of naval architecture and engineering practices over more than two centuries.

While these documents are invaluable for specialists, they are difficult to interpret for non-expert audiences. The information is typically presented in static, highly technical formats that require prior knowledge to decode.

Schools and heritage institutions face the problem of presenting complex archival material in ways that align with modern pedagogical expectations. There is growing institutional interest in interactive and digital tools that can enrich traditional resources and support experiential learning.

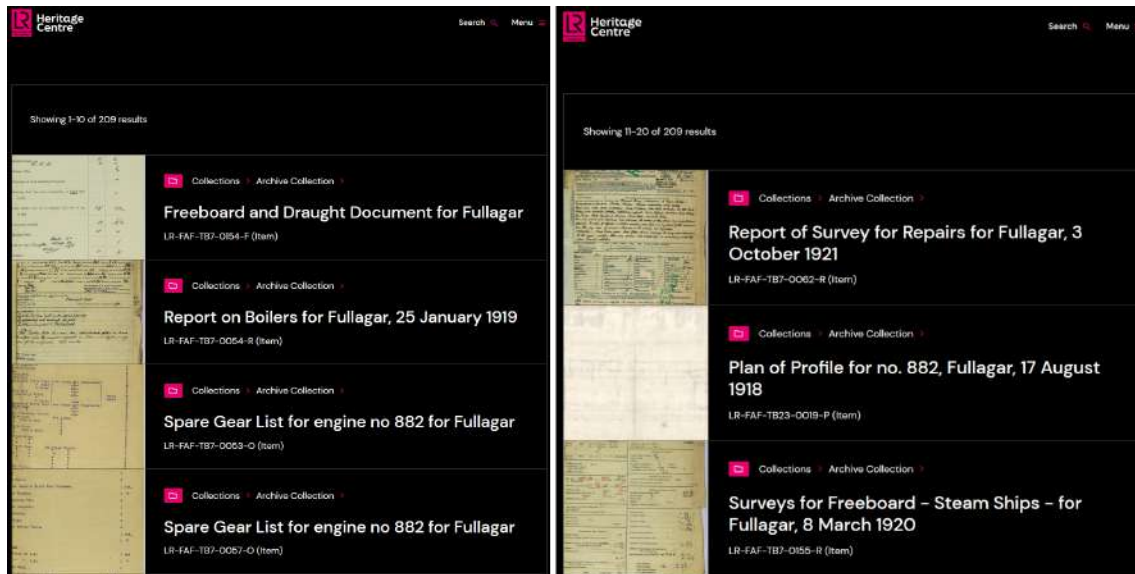


Figure 1.1: Lloyd's Register Foundation Heritage Centre Archive

Much of Lloyd's Register's history, including its origins, has been preserved in the organization's Archives which contain an estimated 1.1 million documents, of which 200,000 have been digitized ¹ including ship plans and surveys. This includes the very early volumes of Lloyd's Register of Ships. Dating from 1764, by the 1870s, these early records hold details of merchant vessels over 100 gross tonnes, which were self-propelled and sea-going, regardless of classification. These volumes became the 'universal standard' of shipping information [Lloyd's Register Foundation, 2026].

Lloyd's Register Foundation's 2024-2029 strategy includes grant open calls that support initiatives that strengthen heritage research, equity, safety, and public access. This master's thesis project, funded under a Lloyd's Register grant mechanism, aligns with the Foundation's aim to inspire and inform future generations.

1.2 Motivation

This project is motivated by evidence that immersive and augmented technologies can improve how users engage with complex information. Rather than replacing traditional documents, these approaches allow digital interpretation to coexist with physical sources, enabling new modes of exploration without restructuring the underlying material.

Systematic reviews, such as that by Bacca-Acosta et al. [2014], show that Augmented Reality (AR), particularly marker-based approaches, can improve learning outcomes by overlaying interactive digital information onto physical documents. Studies in Virtual Reality (VR) further support this direction. Makransky and Lilleholt [2018] found that immersive VR enhances presence, motivation, and perceived learning value, while Alhalabi [2016] showed VR improves achieve-

¹heritage.lrfoundation.org.uk/stories/from-woolwich-to-the-web-the-journey-of-digitisation

ment in technical subjects like engineering.

However, most immersive educational tools remain costly and complex to deploy. This creates a gap between proven benefits and practical adoption in real-world educational settings. This project addresses that gap by exploring a low-cost and accessible alternative, using smartphone-based VR.

1.3 Scope

This dissertation focuses on the design and implementation of a functional prototype of a Tangible VR Book, using selected materials from the Lloyd’s Register archive as a test case. The prototype consists of a physical book embedded with visual markers and a web-based VR application that runs on standard smartphones.

The project does not involve the development of VR hardware, optical systems, or mobile headsets; instead, it relies on existing, mass-produced devices to ensure a low barrier to entry. Interaction design is restricted to smartphone-based VR, marker tracking and simple gaze-based (“look-to-trigger”) interactions. Advanced techniques such as gesture recognition, hand tracking, or full-body interaction are outside the scope of this work because these are not available in smartphone-based VR systems.

Rather than producing a single, fixed educational artifact, the project aims to define a modular system. The Lloyd’s Register materials serve as a test case for a framework that can be adapted to other subjects and archives. User testing is conducted to assess usability and engagement, providing insight into the system’s suitability for educational contexts.

1.4 Objectives and Contributions

This project addresses the challenge of making complex archival materials accessible by lowering the barrier to entry for immersive learning. The work was guided by the following objectives:

- Create a low-cost, modular system capable of converting technical archives into tangible VR experiences.
- Prototype Development: Build a functional Tangible VR Book using the Lloyd’s Register archive (specifically the history of the *Fullagar*) as a test case.
- Authoring Tool: Develop an accessible tool that allows non-experts to easily produce their own Tangible VR Books.
- User Evaluation: Conduct a user study to assess usability, engagement, cybersickness, and the impact of spatial content distribution strategies.

By fulfilling these objectives, this dissertation provides the following contributions to the field of immersive learning:

- A smartphone-based VR framework ready for real-world adoption.
- An authoring system that allows creation of other marker-based VR experiences.
- Empirical insights regarding how spatial content distributions and marker-attached content affect user experience.
- Demonstration of a preliminary prototype at the European Researchers' Night 2025 and demonstration of the final system at the Interactive Entertainment Showcase track of ICEC 2026 ². Submission article in (Appendix A).

1.5 Structure of This Document

This dissertation is organized into the following chapters:

- Chapter 1: Introduction sets the background information on the heritage material and technological components, identifies the research problem, and outlines the objectives of the Tangible VR Book project.
- Chapter 2: Related Work reviews existing literature on tangible interfaces, immersive VR, and their integration in educational contexts.
- Chapter 3: System Design and Implementation details the development of the custom web-based editor, the marker tracking technology, and the architecture of the Tangible VR Book.
- Chapter 4: Methodology describes the experimental design, covering the implementation of the three spatial configurations (Distributed, Centralized, and Center + Marker) and the data collection process.
- Chapter 5: Evaluation presents the rigorous analysis of quantitative metrics (workload, VR sickness, performance) and qualitative data gathered from user interviews and observations.
- Chapter 6: Discussion interprets the results through the lenses of cognitive load theory and spatial presence, providing design recommendations for tangible VR applications.
- Chapter 7: Conclusion summarizes the core findings, reflects on the research outcomes, and suggests potential avenues for future work.

²Accepted to the 25th IFIP International Conference on Entertainment Computing (CNAM Paris, 6th–9th October 2026). The submitted video is available at: <https://vrlab.dei.uc.pt/lrvrbook/>. Publication in the conference proceedings is pending.

Chapter 2

Background

This chapter outlines the intersection of the Lloyd's Register archival materials and landscape of immersive mobile technologies, including smartphone-based VR, passthrough capabilities, and educational AR applications, that enable the development of the Tangible VR Book.

2.1 Lloyd's Register Archive Content

The archive brings together several interconnected document types, each offering a distinct perspective on the history of ship safety and regulation.

At the core are the Register Books (2.1), published annually since 1760. These volumes catalog every classed vessel using a dense alphanumeric code. A single entry records hull quality, rig, construction, and equipment status. The books track a ship's lifecycle, noting alterations, provenance, and later, machinery and modern features. The codes evolved from simple 18th-century grades to 20th-century notations.

G											
101	George	Bg	J. Wilcox	1011	Yruth	1010	W. Palmer	1010	Lo Bream	A 1	
2	—	S	C. Whipple	165	Amer.	11	Virginia	14	Lo Tread	5	
3	—	Sw	J. Wilcox	1445	Scott's	14	Allen	12	Da Noy	A 1	
4	—	Sp	J. Wilcox	1380	French	17	Mullins	12	Li Africa	A 1	
5	—	Bg	Whanbeck	87	Plymk	18	Bodnonke	10	Lo Hambr	E 1	
6	—	Sw	G. Waite	220	N. Eng.	8	Beck & Co	13	Lo Philad	A 1	
7	—	Ann	Bg	J. Fowler	60	Hicmsh	10	G. Loorin	10	Lo Lincir	A 1
8	—	Sp	J. Hoder	65	Ypdm	3	Capt. & Co	9	Ex. Lond.	A 1	
9	—	Clinton	Bg	S. Wheeler	102	N York	7	T. Holding	1	Gr N. Yel	A 1
110	—	& Dorothy	T. Nadfon	721	Sndrid	12	W. Spencer	13	Lo Bream	E 1	
1	—	& Harriet	S. Ferme	161	Dodon	11	J. Harris	15	Li Virgin	E 1	
2	—	& Jane	Bg	Bl. Sinton	175	By the	18	Emmerlon	11	Lo Hambr	E 1
3	—	& James	Bg	S. Dunce	92	Scott's	6	A. Leitt	11	Lo Bream	A 2
4	—	& Kitty	Sr	Clemens	83	Sherm	1	Capt.	10	Lo Gemo	A 2
5	—	& Margaret	Bg	T. Total	66	Heml	4	Capt. & Co	9	Li	A 1
6	—	& Mary	Bg	Gordon	170	Amer.	11	Lo Balm	E 1	El	
7	—	—	S. Loret	475	Amer.	11	Gilbert & Co	14	Du Lvrp	A 1	
8	—	Bg	J. Mauck	122	Leith	9	Waters & C	10	Li Hambr	A 1	
9	—	Bg	T. Glover	83	Wells	39	Fairland	9	Lo V. York	A 1	
120	—	S	R. Wilkin	215	French	14	Baronty	13	Hi Gmle	E 1	
1	—	Ann	Bg	Davidson	1441	British	36	Hindman	11	Be Virgin	L 1
2	—	& Sophia	Bg	J. Dennis	31	Scott's	16	Capt. & Co	8	Du Bifal	E 1
3	—	Sr	A. Johnson	105	Amer.	9	Capt.	10	Da Bifal	A 1	
4	—	Sp	N. Morison	908	Amer.	23	C. Bernig	9	De Grock	L 1	
125	—	& Wilhelm	H. Schorten	200	Hol. Lo	20	Schaars & C	10	Lo Hambr	L 1	
126	George	W. L.	J. Metcalf	81	Yruth	1010	W. Palmer	1010	Lo Bream	A 1	
7	—	Barely	J. Beath	355	N York	10	New York	16	Lo N York	A 1	
8	—	Ludwig	G. H. Ewick	156	Embr	5	Capt. & Co	5	Lo Sval	A 1	
9	—	Philip	G. Slombeck	162	Ancm	5	Ancm	11	Lo Hambr	A 1	
10	—	Wallington	J. Sampson	296	Mryhl	7	Thorow	10	Lo Mryhl	A 1	
11	—	Georgiana	S. Brith	306	Malco	9	Enderby	15	Lo S. Fih	A 1	
12	—	S. S. C.	H. Len	376	Schmtr	12	E. Ind. Co	15	Lo E. Ind.	E 1	
13	—	Gerhard	S. S.	350	Himbr	21	Capt.	15	Du New	L 1	
14	—	Gericht	Sp	P. Laught	87	French	17	H. Jansen	10	Lo Dink	E 1
15	—	Germania	Bg	J. Behren	220	Heven	15	Brewer	13	Lo Bream	E 1
16	—	German	Pac.	W. Field	94	Hell	9	Field & Co	12	Hi Hambr	A 1
17	—	Geicheverend	P. Siger	204	Dante	3	Dunzie	15	Li Dante	A 1	
18	—	Griffith	St	J. Mafker	70	Dutch	10	Capt.	6	Lo Embr	E 1
19	—	Gevnia	Bg	Gesler	473	Finlad	3	W. James	14	Be Barce	L 1
140	Gezellschaft	G. J.	Ratjen	138	Borr	18	T. B. Berrie	13	Lo Hambr	L 1	
1	—	G	H. Reas	200	Embr	5	Bucker	10	Hi Hambr	L 1	
2	—	Gibraltar	Bg	J. Adams	75	Sitmb	5	T. Boll	5	Lo Lond	A 1
3	—	Packet	Bg	W. Moser	136	Amer.	Campbell	12	Lo Gelin	E 1	
4	—	Gil Bond	Bg	Hanken	154	Denb	7	L. Scom	14	Be	A 1
5	—	Gilwell	S	C. A. Shoon	420	Beigal	1	Law & Co	18	Lo Indle	A 1
6	—	Giply	S. C. P.	Benet	282	Hull	4	E. Herpen	15	Be Hgdr	A 1
7	—	Sp	C. M. Tugger	75	Lanchr	9	Bichies	9	Gr Lihon	A 1	
8	—	S. C. J.	Somers	201	Lanchr	13	Dunlon	13	Co S. Embr	A 1	
9	—	Glinde	Bg	P. Linberg	174	Finlad	4	Baldeman	12	Co St Uls	A 1
130	Glmorgan	S. J.	Warren	280	North	13	Capt.	15	Lo Antign	E 1	

Y 1

Figure 2.1: 1803 register book, page 196

The symbolic language requires specialist knowledge to interpret, as these volumes catalog every classed vessel using a dense, abbreviated alphanumeric code. For example, a single entry might combine 'A' (top-tier hull), 'Bk' (Barque rig), and 'SD' (Single Deck). The system also tracked the ship's lifecycle, noting alterations like 'len.' (lengthened) or equipment status like 'A.&C.P.' (anchors and chains proved). Evolving from simple 18th-century grades to complex modern notations, this dense symbolic language requires specialist knowledge to decode.

Ship Plans and Technical Drawings (2.2) form another essential component. These large-format engineering documents include sheer plans (side profiles), body plans (hull cross-sections), deck plans, and detailed technical schematics. As precise engineering diagrams, they define a vessel's hull geometry and structural arrangement, though they assume a high level of expertise in naval architecture to interpret their lines, sections, and technical notations.

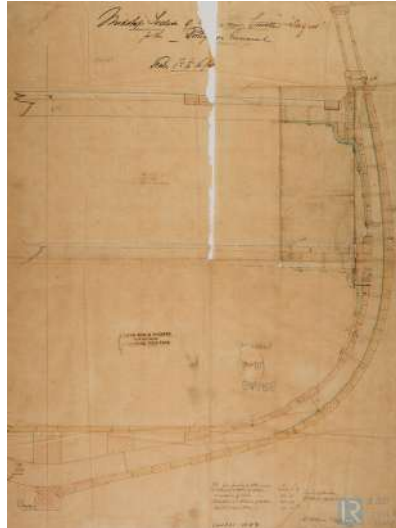


Figure 2.2: Plan of half midship, Sagres 1858

Survey and Inspection Reports (2.3) record detailed examinations of ships at various stages, including damage surveys, repair certifications, and special surveys for experimental features. These documents provide critical evidence of safety practices and technical evolution over time.

[illegible]

Figure 2.3: Report of survey for repairs, Damao 1917

Freeboard Documentation (2.4) addresses one of the most critical safety processes in maritime regulation. Freeboard is the vertical distance from the waterline to

the deck. Under bad weather, or if a ship is overloaded beyond its assigned freeboard, the deck can go under the waterline, leading to catastrophic flooding and loss. The allowable freeboard varies with water type and weather conditions, and these documents certify that a ship will remain afloat under specific conditions.

ONCE CEMENTO.

I have to report that the Freeboards as given below, assigned by the Committee to this ship, have been correctly marked on the ship's sides, in accordance with the printed instructions:—

Freeboard Amounts from Top of Deck Line.	From Centre of Deck.
Tropical Fresh Water	xx 73 m/m. 156 m/m. above
Fresh Water	xx 151 m/m. 78 m/m. above
Tropical	xx 151 m/m. 78 m/m. above
Summer	xx 229 m/m.
Winter	xx 307 m/m. 78 m/m. below
Winter North Atlantic	xx 356 m/m. 129 m/m. below

Figure 2.4: Section of freeboard verification form, Secil 1934

Memoranda and Correspondence (2.5) capture the decision-making processes behind classification rules. These internal and external communications include technical debates about new construction methods, policy discussions, and procedural clarifications that contextualize the formal rules.

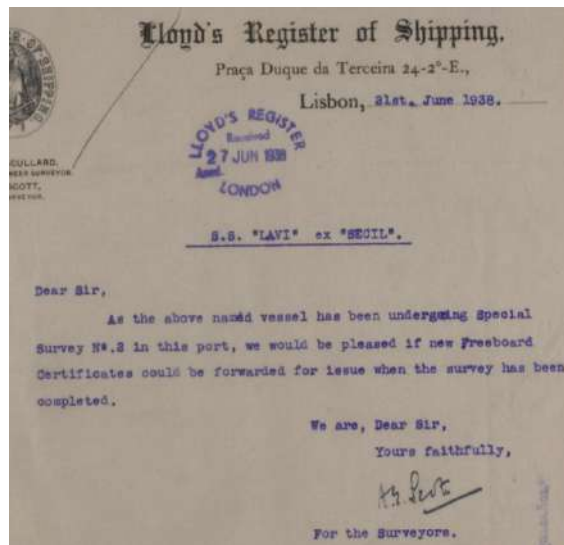
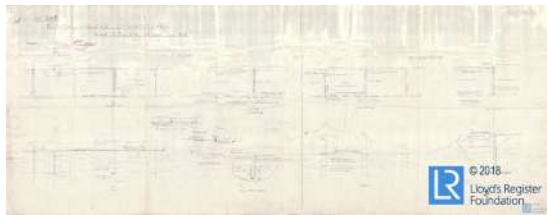
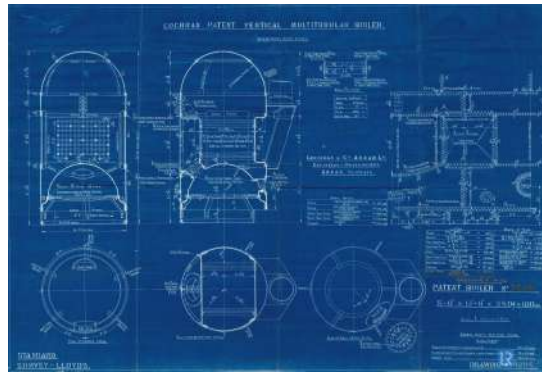


Figure 2.5: Letter from Lisbon Surveyors to the Secretary for Lloyd's Register regarding freeboard, Lavi 1938

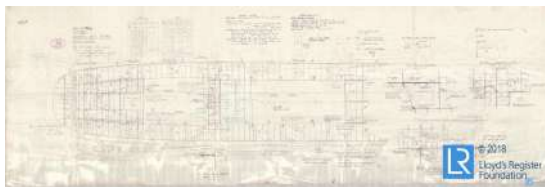
Finally, Reports of Total Loss (2.6) document final vessel casualties. These official records supply critical evidence for investigating safety breaches and updating regulations, frequently including corroborating "sources of information" such as news cuttings.



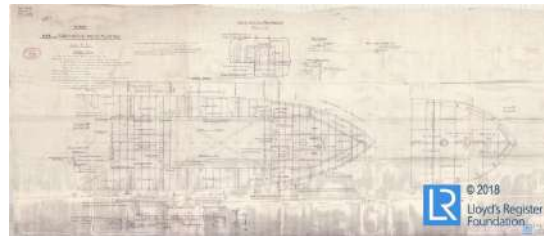
(a) Welded connections plan showing the innovative electric welding techniques used in Fullagar's construction



(b) Vertical multitubular boiler plan detailing the propulsion system that powered Fullagar throughout its service life



(a) Quarter deck plating plan illustrating the structural layout of the ship's deck



(b) Main forecastle deck plating plan showing the forward section of the vessel

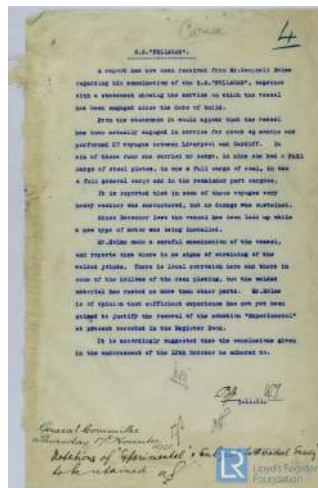


(a) Profile plan providing a complete side elevation, establishing the ship's dimensions, hull form, and general arrangement

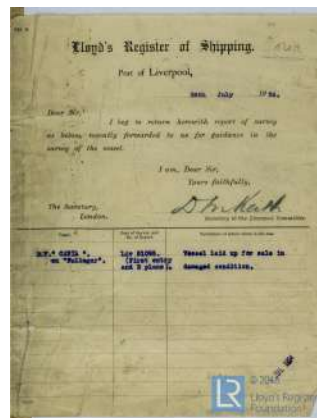
Figure 2.9: 1918–1919 technical drawings of the Fullagar

2.1.1 Regulatory Correspondence: Early Service, Accidents, and Transatlantic Journey

These operational records and survey reports from 1921 to 1926 detail the vessel's early career, including a grounding incident on a sandbank, its subsequent sale, a transatlantic voyage to Canada, and its renaming to *Shean*. The correspondence documents the systematic oversight maintained by Lloyd's Register during these transitions.



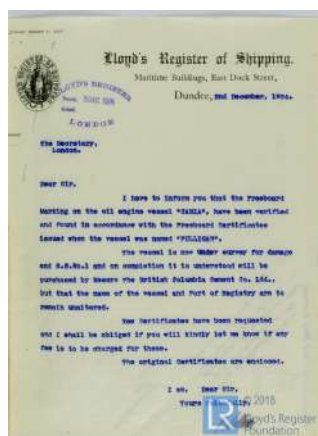
(a) 1921 memorandum revealing the regulatory standards Fullagar was required to meet



(b) 1924 survey letter confirming Fullagar's compliance with classification requirements



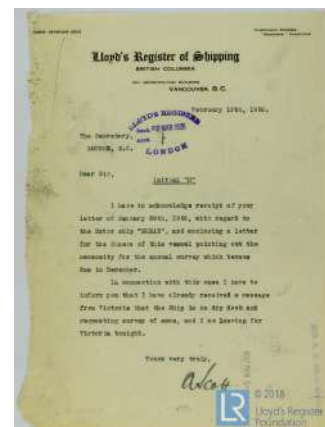
(c) Letter documenting Fullagar's voyage to Canada, situating the vessel within transatlantic shipping



(a) Letter revealing that Fullagar experienced damage requiring formal investigation and recertification



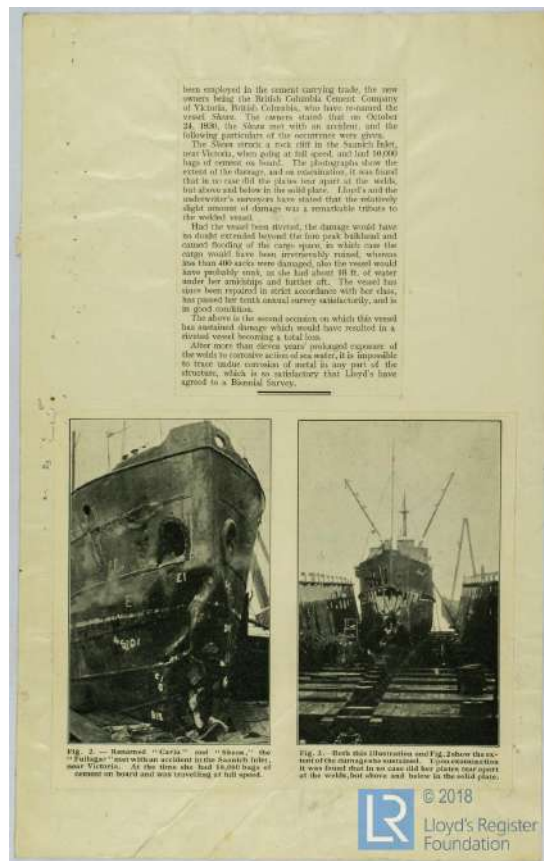
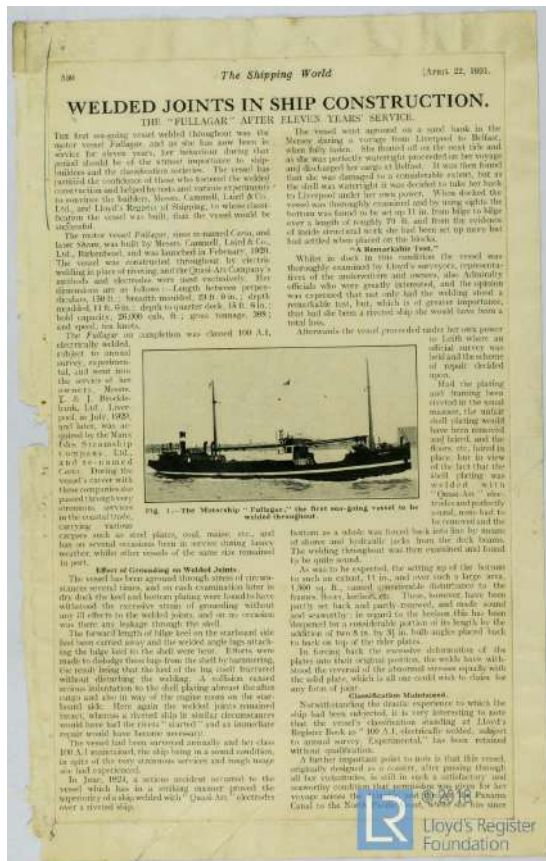
(b) 1925 memorandum illustrating the systematic regulatory oversight maintained by Lloyd's Register



(c) 1926 telegram highlighting the global reach of Lloyd's Register's surveyor network

2.1.2 Collision Documentation and Validation: The Ultimate Test

These 1931 records document a severe operational incident where the ship struck a rock cliff at full speed. Instead of fracturing, the welded joints held, providing contemporary engineers with empirical proof of the durability and resilience of fully welded hulls under severe impact.



(a) 1931 journal article establishing Fullagar as a notable case study in electric welding adoption

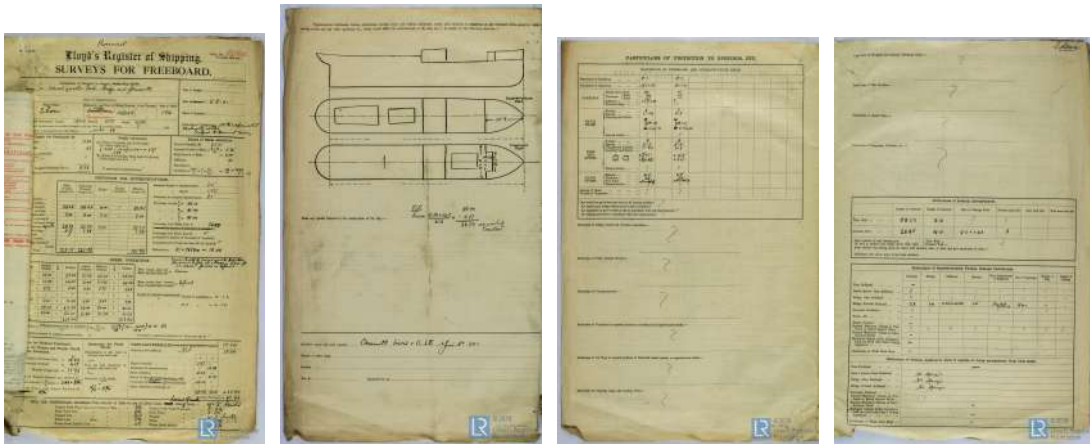
(b) 1931 journal section reporting on Fullagar's resilience following a collision



(a) Photograph providing visual evidence of how the ship's welded construction responded to impact

2.1.3 Freeboard Survey Documentation: The Transitional Phase

These four survey pages comprise the formal assessment of the vessel's load line limits. They contain the data, technical calculations, and surveyor observations required to re-verify seaworthiness and loading capacity prior to its next change of ownership.



(a) Provisional survey for freeboard report page 1, establishing load line certification

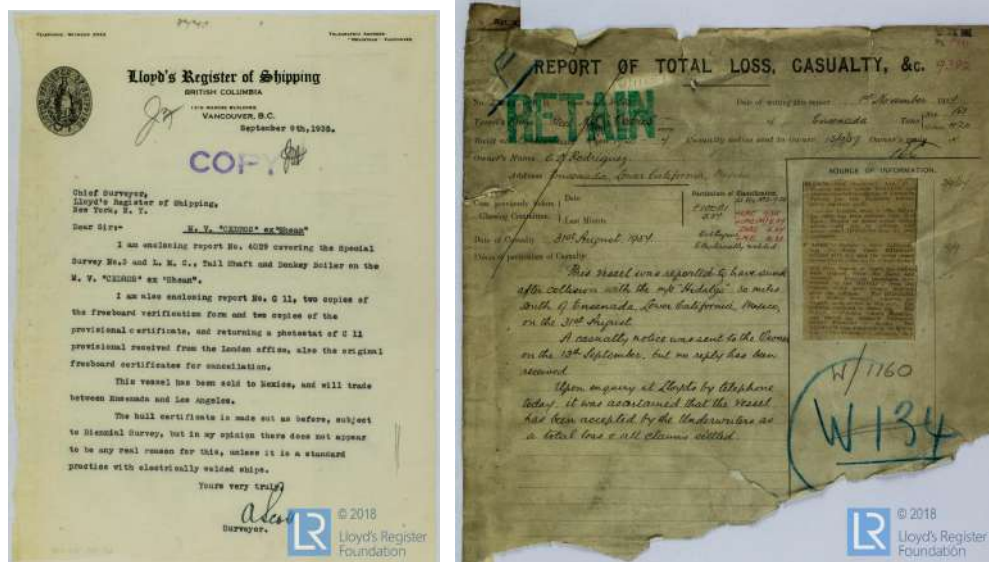
(b) Page 2 including measurements and calculations determining safe loading capacity

(c) Page 3 containing additional survey data and surveyor observations

(d) Page 4 providing the certification decisions and official approvals for the vessel's operation

2.1.4 Ownership Transfer and Final Fate: The Tragic Conclusion

These closing documents record the ship's final operational phase, including its transfer to the Mexican registry under the name *Cedros* and the official 1937 report confirming its total loss following a fatal collision at sea.



(a) Letter documenting Fullagar's transfer from British to Mexican registry

(b) 1937 report of total loss providing conclusive evidence of Fullagar's fate

2.2 Mobile VR

This section examines the current state and use of immersive mobile VR technologies, with a focus on headset-based applications. The Tangible VR Book lies at the intersection of Augmented Reality (AR) and Virtual Reality (VR): it employs a physical book and markers (common to AR), but delivers the experience through a mobile VR headset. While mobile AR is more commonly associated with 2D, screen-based interaction, this project employs hardware explicitly termed “mobile VR headset” and situates the user in an immersive, stereoscopic, head-tracked environment. For these reasons, we classify the system under the broader category of VR.

Mobile VR Headsets like the Google Cardboard [Google, 2026] (Figure 2.16), and similar low-cost viewers are simple devices that provide a physical interface to hold a smartphone in front of the user’s eyes. These holders normally use plastic or cardboard construction with adjustable lenses that display the smartphone screen in a stereoscopic view. Many feature head straps and adjustable interpupillary distance, making them accessible to diverse users.



Figure 2.16: google cardboard

These devices are widely available in stores, including supermarkets and considered widely known. There are many types of content that implement, or even require their use, like YouTube VR videos, VR tours (such as "Visit Alentejo" by Alentejo 2020 [2026]) or VR mobile games. The demand for consuming entertainment in VR is such that YouTube implemented a feature to play videos in stereoscopic mode ¹ (Figure 2.17).



Figure 2.17: krusty krab tour VR view

¹<https://www.youtube.com/watch?v=msI5VFPMmSE&t>

The button to activate this feature has the icon of a mobile VR headset and can be seen in Figure 2.18. This video in particular has 70 million views, and while amassing these views does not necessarily mean it was exclusively consumed through a VR headset, the high volume of engagement indicates that platforms recognize and cater to a viable user base for low-cost mobile VR experiences.

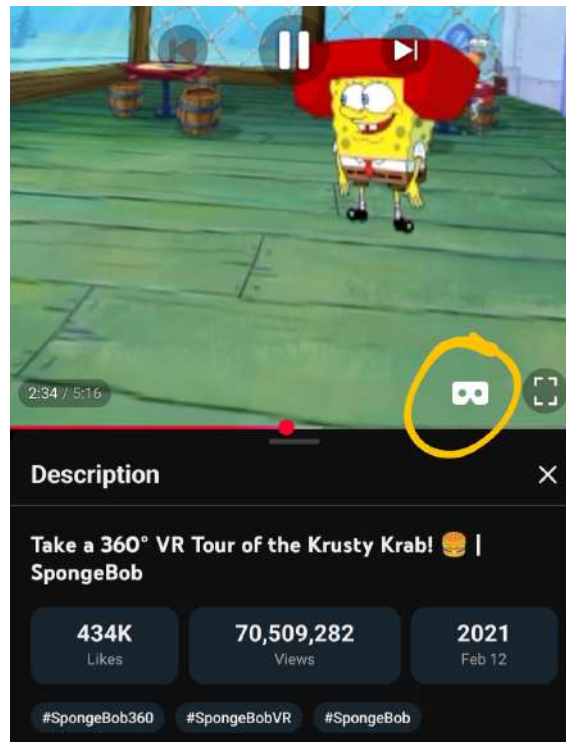


Figure 2.18: krusty krab vr tour button

Some other types of mobile VR implementations include a custom VR headset in a kit, such as Zapbox [Zapbox, 2026] (Figure 2.19).



Figure 2.19: zapbox

The Zapbox is a mobile VR kit with headset, controllers, and dedicated apps that support media, games, and creative experiences. Applications include Zapbox Media Player, Spatial TV, Open Brush for mixed-reality painting, 3D Model

Viewer, and interactive games like House Party Pool and Chess. This suite demonstrates Zapbox’s versatility for both entertainment and educational use.

However, at around €65 per kit, it is not easily mass-deployable in schools, as the cost and reliance on custom controllers create a significant barrier to entry. In contrast, the Tangible VR Book system avoids custom hardware, using AR.js barcode markers and existing, cheaper mobile VR headsets with simple “look-to-trigger” interactions, reducing costs to a fraction of commercial VR kits while remaining accessible for educational use.

2.2.1 Passthrough

Passthrough is a term typically used to describe a mixed reality experience where the physical space is made visible to the user through the cameras of a VR device. In the context of the Tangible VR Book, this feature allows users to remain visually connected to their physical surroundings while wearing the headset, as demonstrated in Figure 2.20.



Figure 2.20: passthrough

A shortcoming of mobile VR is that, unlike in dedicated VR headsets that use dual cameras for stereoscopic passthrough, smartphones only have cameras on one side. This presents a monoscopic feed to both lenses, which reduces depth perception. Despite this, it still allows users to see their physical surroundings, which is crucial for interacting with tangible objects like, for example, the physical book in this project.

There are very few well-known platforms that use and support mobile VR with passthrough. One of them is DeoVR [2026], which is mainly a 360 VR video platform that can be found on mobile app stores, as well as the Steam game store.

The purpose of mobile passthrough in this case is basically allowing transparent background videos to play, while the user can look around (Figure 2.21). This use of passthrough isn’t very flexible, as it’s only made for playing video, but it shows that mobile VR with passthrough is in use today.



Figure 2.21: DeoVR transparent background video

2.3 Marker Detection and Tracking Technologies

Reliable tracking is the foundation of any augmented or virtual reality book. In addressing this, projects generally choose between the robustness of highly visible, structured markers and the aesthetic elegance of invisible, image-based tracking.

Cardoso and Ribeiro’s Tangible VR Book prioritizes tracking reliability by using visible barcode markers (AR.js) [Cardoso and Ribeiro, 2021]. Our own prototype testing confirms this rationale: high-contrast barcodes maintain tracking stability exceptionally well, even when the book is in motion or partially obscured. Figure 2.22 shows their book-based interface in a synthetic VR environment.



Figure 2.22: Cardoso and Ribeiro’s Tangible VR Book: A book-based interface in synthetic VR

Taking the concept of visible markers a step further into physical space, Fong et al. experimented with 3D-printed markers that users can touch and reconfigure [Fong et al., 2022]. While these modular tangibles are clever and invite playful

interaction, their bulk makes them unsuitable for integrating into a standard, flat page-based book, as shown in Figure 2.23.



Figure 2.23: Fong et al.'s modular 3D-printed tangible markers

Conversely, several projects have pursued tracking systems that avoid obtrusive glyphs altogether. As early as 2011, Papagiannis [2011] demonstrated this approach with the AR pop-up book "Who's Afraid of Bugs?". This work was significant because it achieved markerless tracking directly on mobile devices by using image recognition of the book's own illustrations, anticipating modern image-tracking frameworks (Figure 2.24).

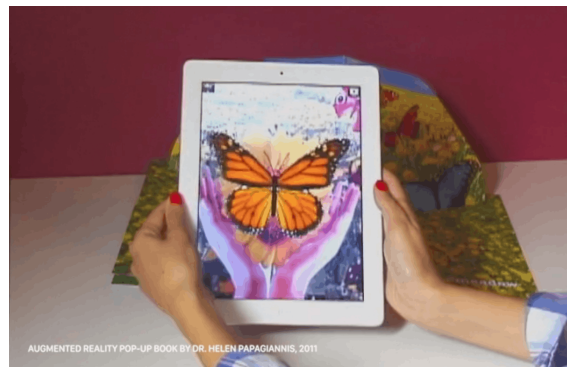


Figure 2.24: Papagiannis's AR pop-up book "Who's Afraid of Bugs?" using image recognition on mobile devices

Similarly pursuing seamless integration, the MagicBook uses the book's natural page design as invisible markers [Billinghurst et al., 2001]. Figure 2.25 illustrates how this natural feature tracking enables smooth, uninterrupted transitions between AR and VR. However, the trade-off for this "invisible elegance" is a supposed higher sensitivity to environmental conditions; image-based tracking generally demands more consistent lighting and specific viewing angles compared to standard high-contrast barcodes.

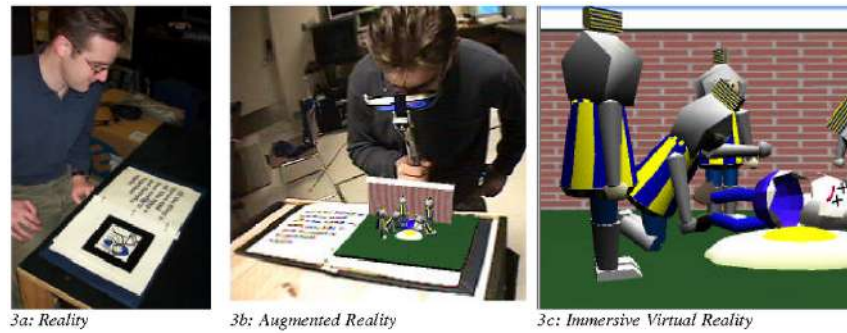


Figure 2.25: The MagicBook interface, enabling transitions between AR and VR

2.3.1 AR/VR in Education

AR/VR in education is a growing industry, with commercially available projects like CLASSVR [2026] (Figure 2.26) offering VR headsets preloaded with “...thousands of pedagogically sound, curriculum-aligned VR and AR resources including content, downloadable lessons plans, guides and worksheets to boost student engagement in every lesson” [STEMfinity, 2026].



Figure 2.26: ClassVR content showcase

Universities are also developing AI-driven educational tools. HKUST recently launched Asia’s first AI virtual lecturer program, featuring animated versions of Albert Einstein and Nobel laureate John Nash teaching game theory (Figure 2.27). Developed using a proprietary 3D generation system alongside Midjourney, ChatGPT, and Bing, these virtual instructors deliver content through VR headsets (Figure 2.28). According to HKUST’s Metaverse Research Center, AI lecturers bring diversity and immersive narrative to the classroom.



Figure 2.27: AI-generated virtual Einstein delivering a lecture on game theory



Figure 2.28: Students experiencing a VR lecture at HKUST

2.4 Interaction Design and User Interface

We adopt a "look-to-trigger" approach. Users gaze at a button to activate it.

The MagicBook pioneers fluid movement between reality and virtuality, users can "fly into" a page [Billinghurst et al., 2001]. This inspires our goal of smoothness during use.

It also supports multiple users sharing a virtual space, a compelling direction for future collaborative learning, even as our current focus remains individual.

The AR pop-up book by Papagiannis [2011] offers a different interaction model: touching the virtual 3D spider causes it to attack, while touching the ant hyperlinks to educational content. This touch-based interaction is well-suited to tablet-based AR but is not feasible in a mobile VR headset where the user cannot see their hands. Our "look-to-trigger" gaze interaction is a deliberate adaptation to the constraints of VR hardware, prioritizing accessibility over the direct manipulation that Papagiannis demonstrated.

2.5 Educational Application and Domain Specificity

Most projects are general-purpose toolkits. Ours targets a specific educational need.

Works like the MagicBook or Fong et al.'s modular tangibles are frameworks for any content [Billinghurst et al., 2001; Fong et al., 2022]. In contrast, we apply

the book format to solve a concrete challenge of improving learning of heavy complicated subjects.

However, Papagiannis [2011] offers an instructive counterpoint: her AR pop-up book was directly inspired by AR psychotherapy studies for phobia treatment, specifically arachnophobia. This shows how AR books can address domain-specific educational and therapeutic goals, a direct parallel to our use of the Lloyd's Register archive to teach maritime history and safety practices. Papagiannis explicitly frames her work as "a playful method for exposure and learning through story and technology," a framing that resonates with our narrative-driven approach to the *Fullagar* story.

Similarly, Borsuk and Bouse [2016] demonstrates how the augmented book format can serve artistic and literary education, inviting readers to "print and bind their own copy and create their own augmented reality poems using our DIY tools." This DIY ethos, providing tools for others to create their own augmented books, directly anticipates our project's modular framework deliverable. Borsuk's work shows that the ability to customize and extend AR book systems is not merely a technical convenience but a pedagogical feature in its own right.

Chapter 3

Methodology and Work Plan

This chapter describes the approach for developing the Tangible VR Book, focusing on iterative design, continuous testing, and structured evaluation.

3.1 Methodology

The development of both the functional prototype and the modular authoring framework followed an iterative design methodology. The project progressed through continuous cycles of prototyping, testing, and refinement, where each major feature, from tracking technology selection to physical book design, was explored through functional prototypes.

To structure this process, the work was divided into five main methodological phases:

- Initial exploration of web-based AR frameworks, curation of historical documents, and the creation of early proof-of-concept prototypes for tracking and interaction.
- Comparative evaluation of AR tracking technologies, resulting in the selection of the core framework and refinement of the interaction model.
- Iterative design and implementation of the Tangible VR Book specific to the Lloyd's Register Foundation archives, moving from technical tests to a polished experience with spatial content layouts.
- Generalizing the system architecture to build a web-based interface (Content Maker) that allows non-experts to generate their own experiences.
- Assessing the system's viability through an experimental user study and finalizing the academic documentation.

Regarding Phase 5, the evaluation was structured as a formal experiment. It employed a controlled user study to compare different spatial configurations of digital content, focusing on usability, engagement, and the spatial experience.

3.2 Work Plan and Timeline

The specific tasks and milestones of the project are detailed below, mapped to the overarching phases established in the methodology. Note that Phase 1 began earlier than the typical academic schedule due to early project financing from the Lloyd's Register Foundation.

During the final quarter of 2025, tasks focused on establishing the technical foundation of the project.

- **September 26, 2025:** Presented the first tracking prototype at the European Researchers' Night, collecting informal user feedback.
- **October 30, 2025:** Implemented the first look-to-trigger interaction prototype supporting zooming and moving digital documents.
- **December 21, 2025:** Implemented the first prototype supporting 3D model visualization and finalized the selection of AR.js as the primary framework.

The period after that involved iterative development of the physical and digital components of the *Fullagar* prototype.

- **January 12, 2026:** Submitted the intermediate report and presentation of dissertation progress.
- **January 29, 2026:** Completed the second A4 prototype with larger barcode markers, improved look-to-trigger interaction, and preliminary visual design.
- **February 16–March 2, 2026:** Refactored application architecture and implemented the JSON-based content structure.
- **March 6–19, 2026:** Designed the physical book structure, visual identity, and finalized the physical book design.
- **March 14, 2026:** Combined 3D models, historical narrative, AI-generated narration, and thumbnail carousel navigation into a single build.
- **March 24, 2026:** Finalized the JSON schema and implemented the three spatial content layouts (Centre, Centre+Marker, and Distributed).

With the prototype functional, tasks shifted toward making the system modular and preparing for the user study.

- **April 18, 2026:** Developed the Content Maker web interface. Submitted the ICEC 2026 demonstration paper and accompanying video.
- **May 10, 2026:** Simplified the VR book content to ensure user study sessions fit within a ten-minute window.

- **May 25, 2026:** Conducted a pilot study validating the system's logging, VR screen capture, and OBS recording setup.

The final tasks focused on executing the experimental methodology and consolidating the text.

- **June 1–26, 2026:** Conducted the formal user study with 24 participants.
- **June 26–July 6, 2026:** Analysed evaluation results and performed the final dissertation revision. (Note: Dissertation writing occurred iteratively throughout the project, culminating in this final push).

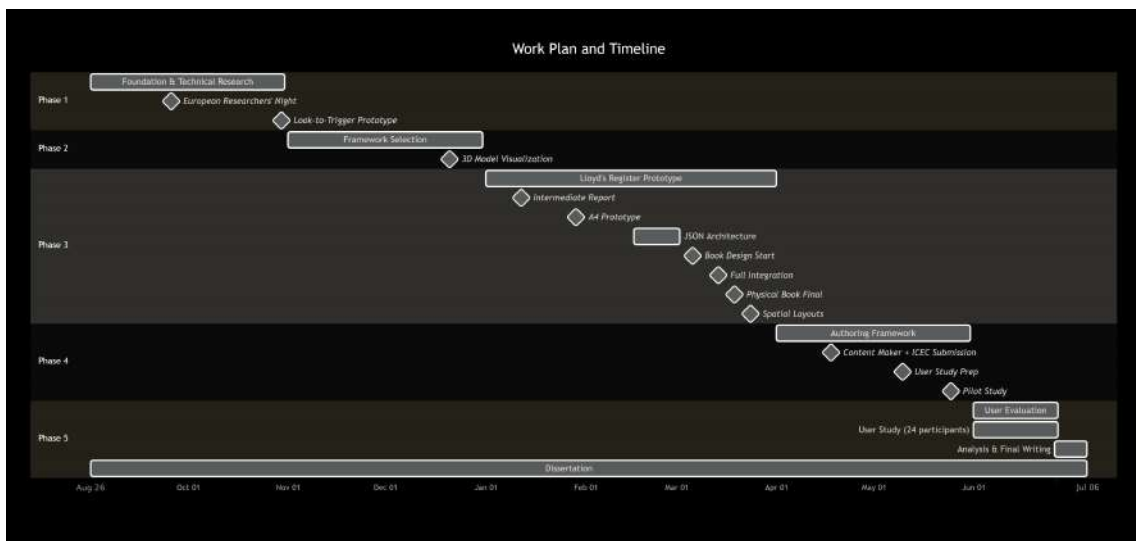


Figure 3.1: Project Timeline and Milestones

Chapter 4

Lloyd's Register Tangible VR Book

The Lloyd's Register Tangible VR Book is a mixed reality book designed to be experienced through a smartphone-based VR headset. It augments a physical book with dynamic, interactive digital content, bridging the gap between traditional media and immersive technology.

The physical book uses the old English standard octavo page size, a format chosen for its historical resonance with archival and literary contexts. It is bound with a metal spiral, ensuring ease of reproducibility in any standard print shop.

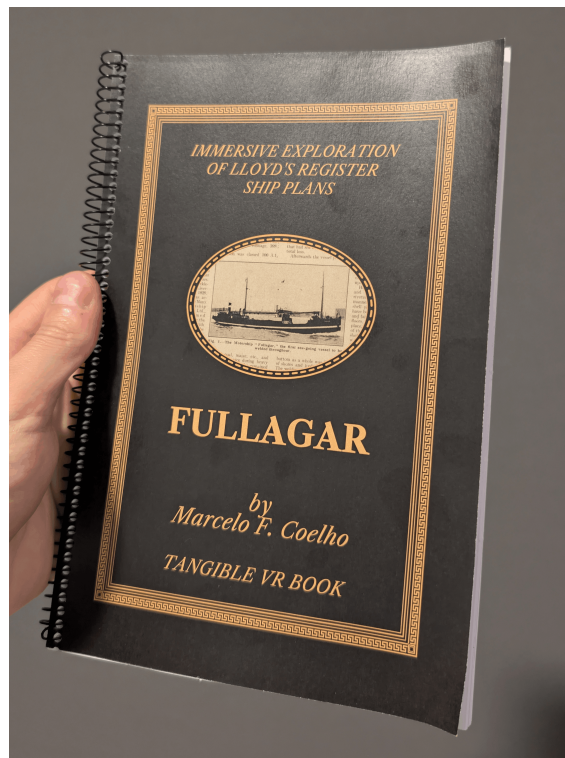


Figure 4.1: Final cover design inspired by 1920s books and Lloyd's Register archive volumes

4.1 Introduction

The book starts with instructions and a brief introduction that explain how to use the system: visit a URL on your smartphone, enter VR mode, and place it in a headset. Looking at a page through the headset triggers AR content: images, videos, or 3D models, that appears on the marker or to your left, front, or right. You interact using a red cursor to control playback, mute, zoom, and expand thumbnails.

The introduction then explains that this book accompanies my master's thesis, *Tangible VR Book: Immersive Exploration of Lloyd's Register Ship Plans*, funded by the Lloyd's Register Foundation. It presents a physical book enhanced with digital content via barcode scanning, using the story of the Fullagar — the world's first fully welded ship, with materials sourced from the Foundation's archive.

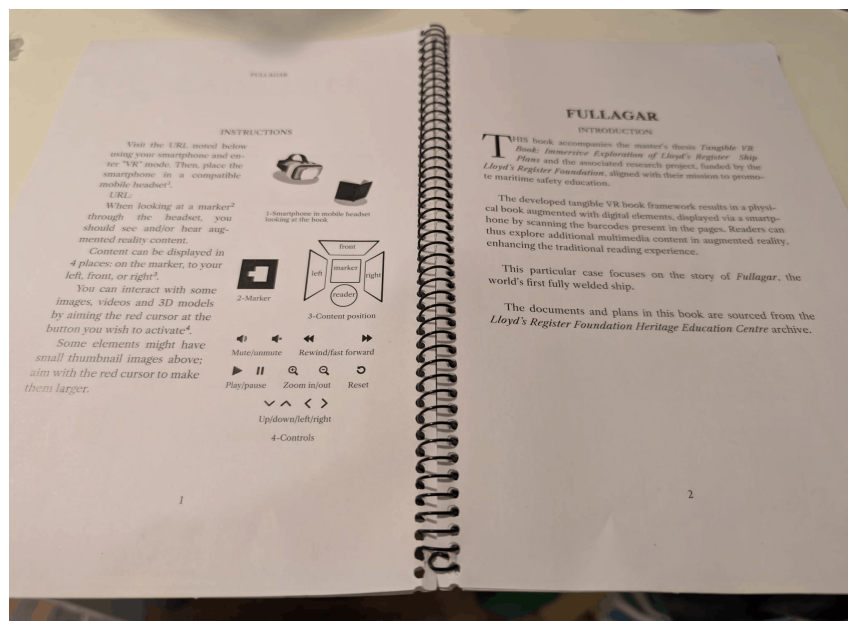


Figure 4.2: Open book showing instructions and introduction pages

The text is printed in Caslon, a classic serif font that evokes early twentieth-century printing. The cover design draws inspiration from 1920s-era books and original Lloyd's Register archive volumes, creating visual continuity between the physical object and the historical content.

The first two page spreads present Fullagar, launched to sea in 1920, with one of its ship building plans, specifically about its welded connections. This first marker also presents two visual representations of the ship and one 3D model.

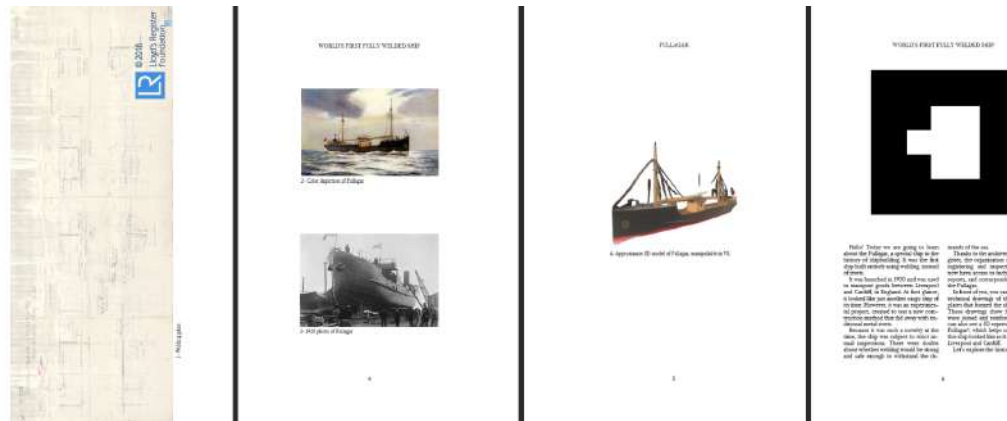


Figure 4.3: First two page spreads presenting fullagar

The ship's 3D model was generated by inserting a 2D representation of Fullagar into Meta's SAM3D image-to-3D-model conversion tool¹, which reconstructed the vessel's geometric shape (Figures 4.4 and 4.5).



Figure 4.4: 3D model of the Fullagar generated using image-to-3D-model software.



Figure 4.5: Historical image source asset used to generate the 3D ship mesh.

On this page is the first audio narration encountered by the user, in this case, the feminine voice. A masculine voice is introduced subsequently on markers containing letters, logs, or other documents requiring transcription.

These vocal tracks were synthesized using the ElevenLabs² platform. To ensure international accessibility, the system utilizes specific pre-made voice profiles for each language. The English narration features "Katherine" as the primary voice, selected for her articulate and authoritative delivery of historical and technical prose, and "Grizzled Man," a raspy masculine profile used to read personal records such as captain logbooks and letters.

The Portuguese narration employs "Daniela" as the primary voice, configured for maximum clarity when conveying complex technical descriptions, while "Vasco"

¹<https://ai.meta.com/research/sam3d/>

²<https://elevenlabs.io/>

provides a grounded, conversational masculine tone for reading personal correspondence and testimonies.

4.2 Fullagar's Life and Final Voyage

The book describes fullagar's life until it's final catastrophic voyage, such as it's initial use: transporting cargo between Liverpool and Cardiff. This is represented with an animated 3D map. This model was built manually in Blender, animating the specific historical route taken by the *Fullagar*, between Liverpool and Cardiff. There are other animated maps showing its transatlantic crossing to Canada, its Pacific operations near Mexico, and its ultimate sinking off Ensenada. The asset were compiled and exported as GLB files (Figure 4.7).

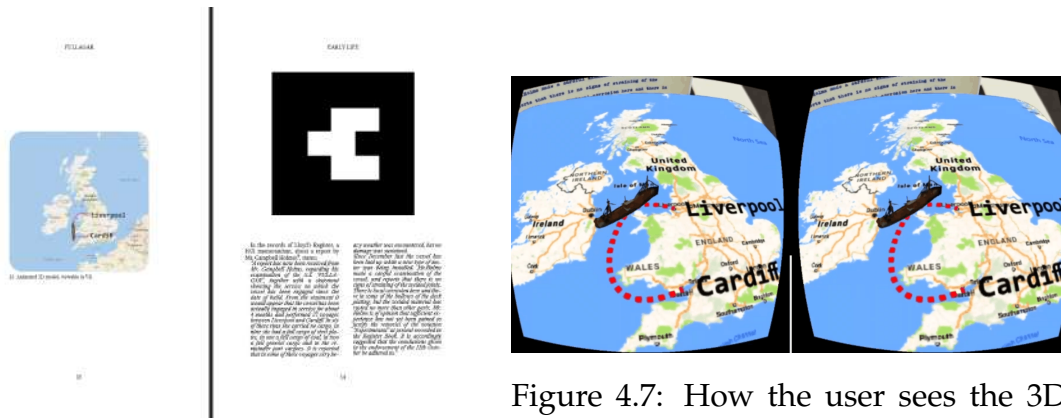


Figure 4.6: Animated 3D map presented in the book



Figure 4.7: How the user sees the 3D map in the immersive experience

Since many documents found about Fullagar mentioned 'Freeboard' in some way, this concept was investigated further at page 24. This was explained with the only video in the book, it was cut and subtitled to Portuguese, from a larger Lloyds Register Foundation video³ about plimsoll line and freeboard.



Figure 4.8: Freeboard section in the book



Figure 4.9: Example frame from the video

³<https://www.youtube.com/watch?v=vuve8DU84Co>

In the book, various concepts are clarified through diagrams designed to simplify complex historical events, such as the structural collision with a sandbank (Figure 4.10). These assets were developed through an iterative AI-assisted workflow, where historical data and technical specifications were synthesized into visual representations, followed by manual refinement.

Figure 4.10: Diagram illustrating the structural impact during the sandbank collision.

Fullagar's life ends with a tragic crash that involved the deaths of 3 sailors, near the coast of Mexico. This is proven by attachments in the 'Report of total loss'.

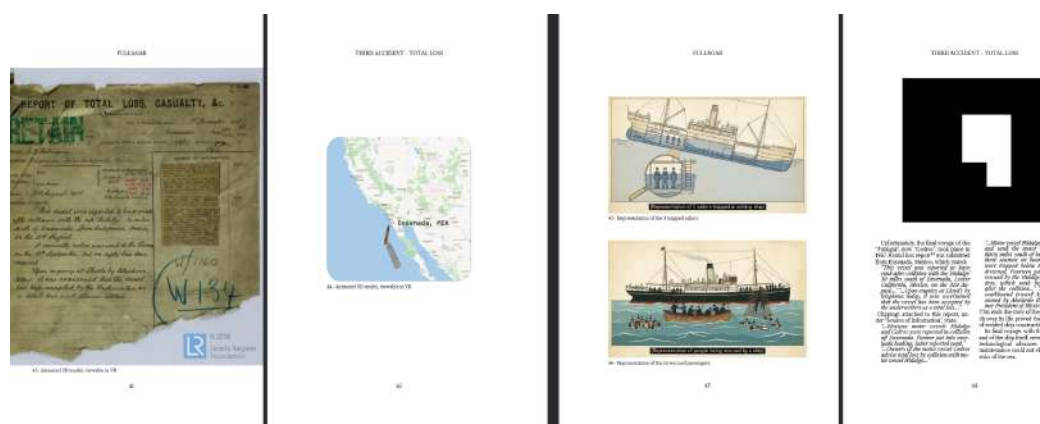


Figure 4.11: Final two book spreads

The following figures demonstrate the integration of visual elements within the book's layout. Figure 4.12 illustrates a spread combining archival documents with contemporary photography, while Figure 4.13 showcases the placement of technical diagrams, navigational markers, and accompanying narrative text.

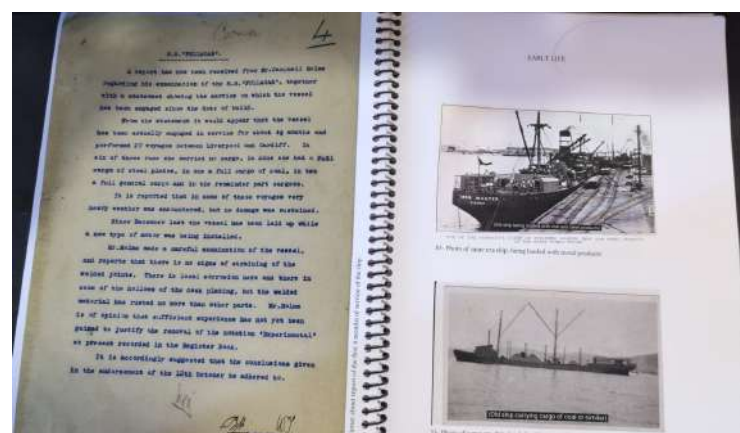


Figure 4.12: Physical book spread showing archival document and two related era photos

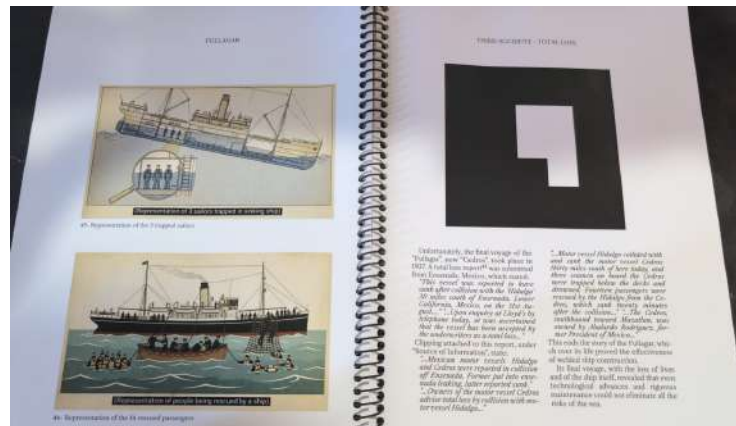


Figure 4.13: Physical book spread showing 2 diagrams, a marker and the related narration

4.2.1 Design and Constraints

The physical book functions as both a traditional archival object and a tangible interface for digital interaction. During the prototyping phase, the format evolved from A5 to A4, ultimately settling on this octavo-inspired dimension to better suit handheld VR interaction. The final trimmed size is 15.3×23.2 cm, based on an original digital layout of 15.6×23.4 cm, bound with a 1.2 cm metal spiral that allows the pages to lie perfectly flat, as shown in Figure 4.14, which is essential for reliable marker tracking.

The visual language draws inspiration from 1920s editorial standards. The text is set in Libre Caslon, with the main body utilizing an 8pt font and 10pt leading, justified with auto-hyphenation and a 3mm first-line indent. The introduction (figure 4.2) section features 3-line high drop caps to echo the period's style. The layout is defined by a grid with 18mm inner, 28mm outer, 22mm top, and 38mm bottom margins, though selected images intentionally exceed these boundaries to maximize visual impact. Page numbering is set at 8pt, centered at the bottom of the page. The cover, featuring a 1931 archival image of the *Fullagar*, utilizes a very dark brown background (#120F0E) with a contrasting yellow-"gold" decorative frame and text in #EDB34D.

The book is designed to be accessible to anyone familiar with standard publishing software such as Affinity or Adobe InDesign, provided the tracking markers are correctly integrated into the layout.

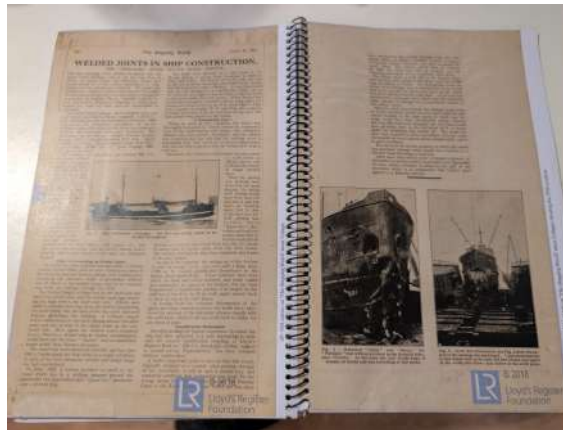


Figure 4.14: Metal spiral binding allowing flat pages

As seen on figures (4.14) and (4.15), light reflection is a factor to take into consideration while printing this book, as glare can cover a portion of the marker's surface. If the glare is uniform rather than sharp and localized, AR.js can more reliably detect the marker.

It should still be possible to use this book anywhere with light, but it might be necessary to pick up the book and manipulate it in an angle that allows the marker to be read, if it has excessive glare.



Figure 4.15: Glare on marker, possibly difficulting tracking

The book uses standard metal spiral binding with regular paper stock of 80 to 100 gram per square metre.

4.2.2 Previous prototypes

Earlier iterations of the book, with A5 format, 3D-printed hardcovers and binding rings, which proved difficult to reproduce and did not allow pages to lie flat reliably.



Figure 4.16: Cover and first page of the 3D-printed hardcover prototype (left and centre), and point-of-view VR view with image and description (right)

The second prototype, with A4 format, introduced metal spiral binding with a transparent plastic cover, which improved page flatness.

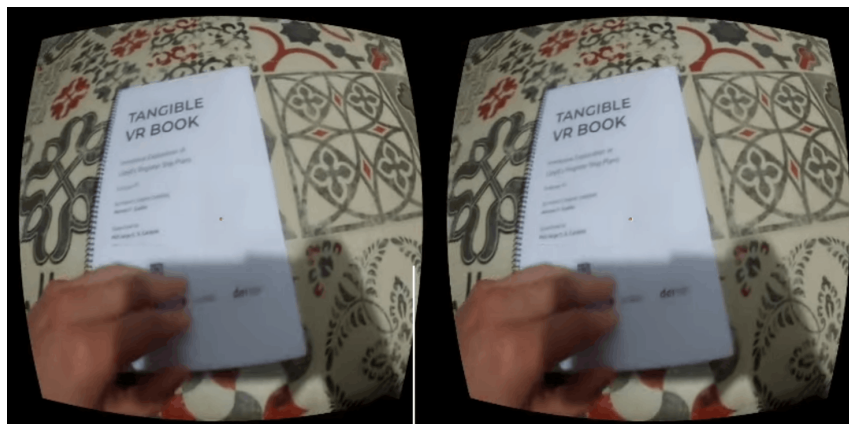


Figure 4.17: VR view of the second prototype cover showing the transparent cover and spiral binding

On larger A4-format markers, light reflection appears as a small, localised spot of glare. Although the spot occupies only a portion of the marker, AR.js interprets the entire affected area as distorted, rendering the marker unrecognisable and causing frequent tracking loss. The octavo format's smaller markers, despite being more extensively affected by reflection, prove more trackable because the reflection is distributed across the entire marker rather than concentrated in a problematic spot.

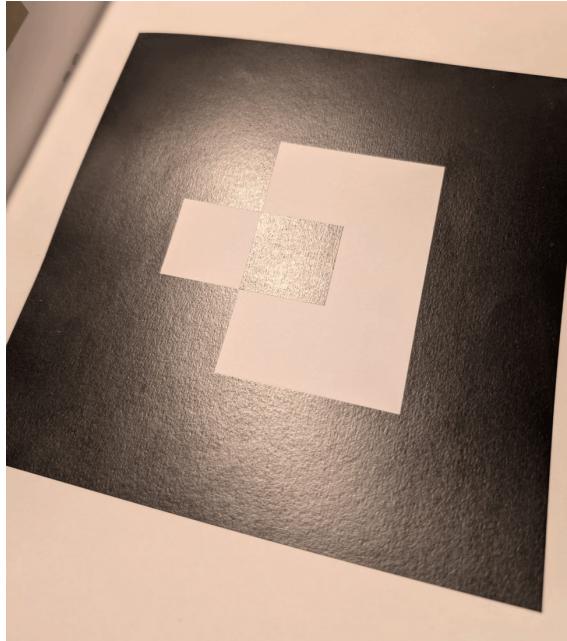


Figure 4.18: VR view of the second prototype cover showing the transparent cover and spiral binding

Chapter 5

Authoring System and Immersive Content Framework

We handle the immersive digital content with a web-based setup using standard web technologies: HTML for structure, CSS for styling, and JavaScript for all application logic and interactivity. We combine A-Frame for 3D scene rendering and AR.js for marker-based tracking, allowing the system to overlay virtual content onto physical markers detected through the device camera.

The experience can be reconfigured for different educational subjects without requiring any programming knowledge, via a companion webUI authoring tool that allows users to create and edit a JSON file.

5.1 Authoring Tool

This web-based interface acts as a user-friendly front-end for the JSON configuration format, eliminating the need for manual code editing and providing an intuitive way to manage the entire content structure of a Tangible VR Book. Users can import an existing JSON configuration, edit it through the graphical interface, or create a new configuration from scratch, then export the JSON for use with the VR application.

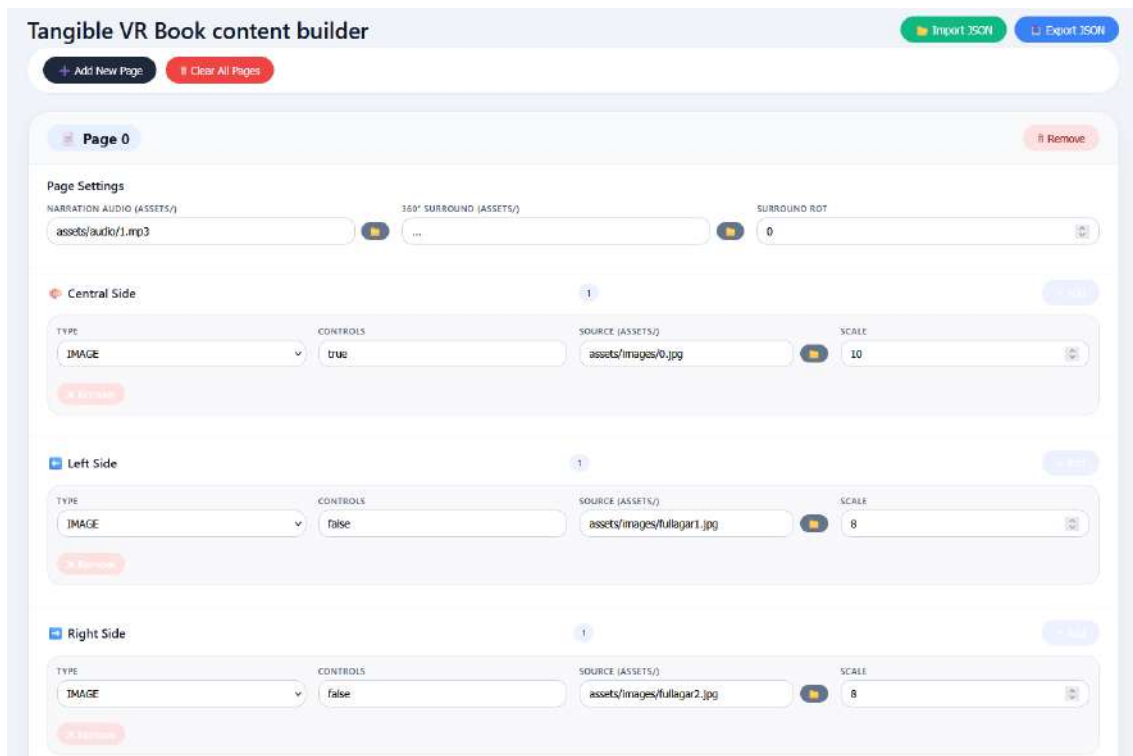


Figure 5.1: The graphical interface of the Content Maker tool, showing the structure of a page with central content and marker-based 3D models.

At startup, the JSON output is empty, and basic functions are visible: Import/Export JSON, or starting a new file from scratch with the "Add new Page" button.

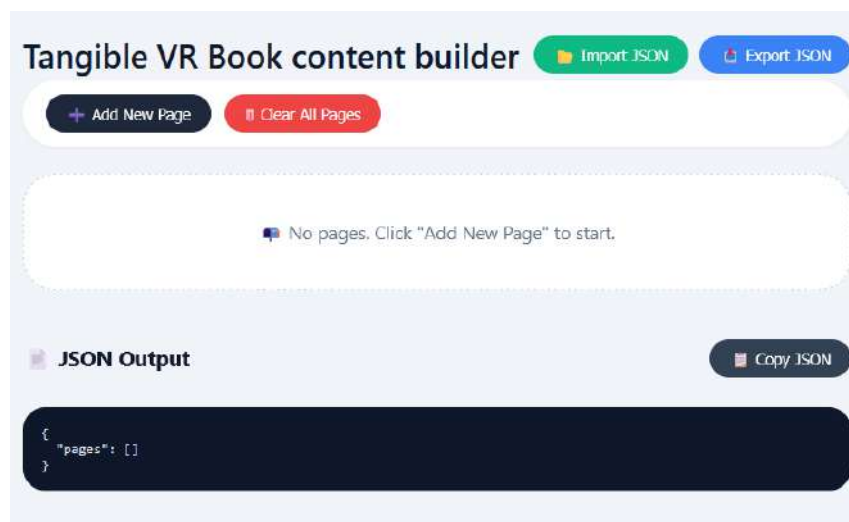


Figure 5.2: Basic functions

If starting a new file from scratch, after adding new page, the narration and surround image/video file source fields are visible, which should be located in the "assets" folder. In figure 5.3, you can see the central, left, right and marker planes in the immersive experience.

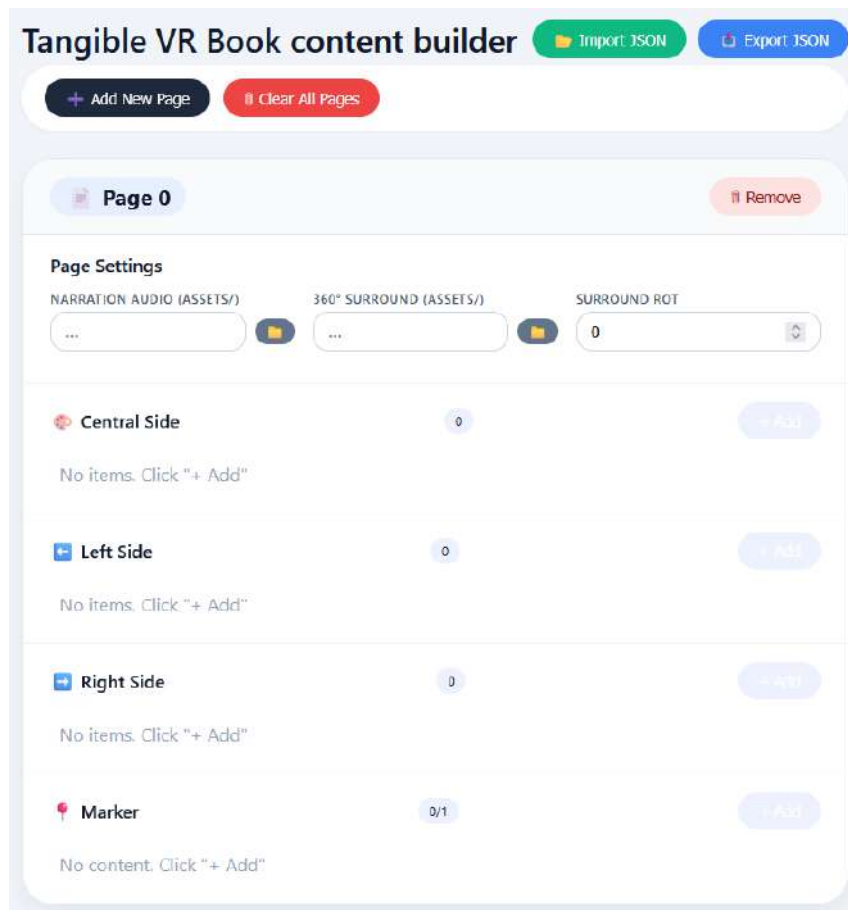


Figure 5.3: New empty page added

Since this is page 0, the content set here would get triggered when marker 0 is detected, which is labeled 0.png in the 3x3 markers folder.

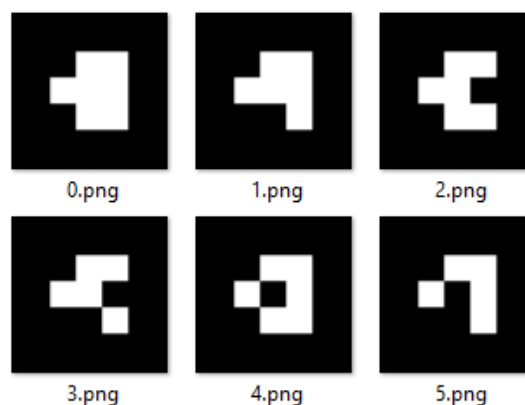


Figure 5.4: First 6 3x3 markers

After importing a premade JSON, the results are visible in figure 5.5. This is an example of what a configured page 0 would look like; this case is from an experience where all content is concentrated in the center, which means there will be a navigation bar above the content, to navigate between each media file.

Page 0 Remove

Page Settings

NARRATION AUDIO (ASSETS/) ... 360° SURROUND (ASSETS/) ... SURROUND ROT

Central Side 4 Add

TYPE	CONTROLS	SOURCE (ASSETS/)	SCALE
IMAGE	true	assets/images	10
IMAGE	false	assets/images	8
IMAGE	false	assets/images	8
3D	true	assets/model:	3

ROT X ROT Y ROT Z AUTO ROTATE

Left Side 0 Add

No items. Click "+ Add"

Figure 5.5: JSON Imported

In the specific page above, there is no 360 surround content, which means the video passthrough is active, so the user can see world around them. For this field there is a "surround rotation" setting, which rotates the 360 content to set which side of it the viewer sees first on startup.

Each image/video/3D model object features settings like: enabling/disabling controls and setting scale. The 3D model objects can also be pre-rotated to change how the user initially sees them. The auto-rotate setting makes the content rotate automatically and infinitely.

This is the resulting JSON after exporting the page above, as well as the example user perspective:

```

1 {
2   "pages": [
3     {
4       "barcode_number": 0,
5       "narration": "assets/audio/1.mp3",
6       "surround": "",
7       "surround_rotation": 0,
8       "central_side": [
9         {
10          "type": "image",
11          "controls": "true",
12          "src": "assets/images/0.jpg",
13          "scale": 10
14        },
15        {
16          "type": "image",
17          "controls": "false",
18          "src": "assets/images/fullagar1.jpg",
19          "scale": 8
20        },
21        {
22          "type": "image",
23          "controls": "false",
24          "src": "assets/images/fullagar2.jpg",
25          "scale": 8
26        },
27        {
28          "type": "3d",
29          "controls": "true",
30          "src": "assets/models/fullagar3d.glb",
31          "scale": 3,
32          "rotation": {
33            "x": 0,
34            "y": 0,
35            "z": 0
36          },
37          "auto_rotate": false
38        }
39      ],
40      "left_side": [],
41      "right_side": [],
42      "marker": []

```

Figure 5.6: Exported JSON of page 0 set above



Figure 5.7: Example user PoV of the JSON set above

As mentioned above, all media files should be placed in the "assets" folder of the general program. This folder encapsulates everything. The general folder structure of a project like this, should be similar to the one visible in figure 5.8, which encapsulates everything. In this figure, the premade 3x3 markers, assets folder, authoring tool (content maker) and main VR experience viewer are marked with green lines. Someone who would like to create their own tangible VR book, would interact most with these 4 elements.

In figure 5.9 is a snippet of code that imports and starts handling the JSON file, which in the present case, has multiple editable options, for testing purposes. In a real-world scenario, there would be only one valid JSON called "configuration.json". This makes it clear that the JSON file resulting from the authoring tool, can just be placed in the general parent folder, making it accessible to the VR experience as long as it has the correct name.

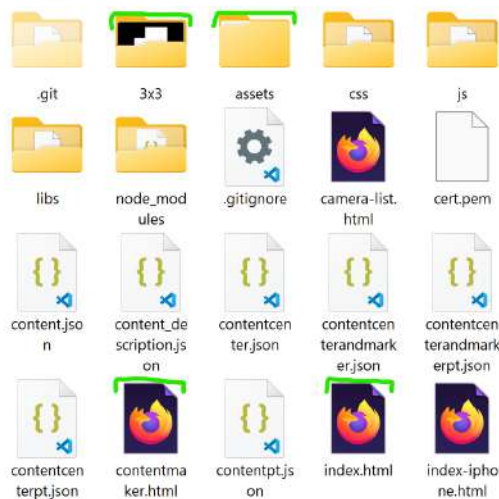


Figure 5.8: General folder structure highlighting most relevant parts

```
3  const AppContent = {
4      data: null,
5
6      //jsonFile: 'content.json',
7      //jsonFile: 'contentcenter.json',
8      jsonFile: 'contentcenterandmarker.json',
9      //jsonFile: 'contentpt.json',
10     //jsonFile: 'contentcenterpt.json',
11     //jsonFile: 'contentcenterandmarkerpt.json',
12
13     // Load JSON content
14     async load(jsonUrl = null) {
15         const url = jsonUrl || this.jsonFile;
```

Figure 5.9: JSON loader with multiple options for development (PT and EN narrated versions)

5.2 Content Display System and Interaction

After the system loads a JSON configuration file, the application creates all the HTML for every marker's content upfront. Everything is prepared in advance so that when a marker is detected, the content is ready to go instantly.

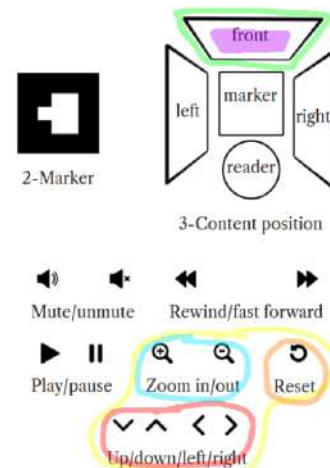


Figure 5.10: HTML structure example of 1 image a center panel of a page 0, color-matched to instructions diagram

When the device camera detects a marker, the application shows only that marker's corresponding content and hides everything else. At the same time, any associated audio begins playing and videos also autoplay.

If the marker is lost from view, the application hides the marker-attached content but leaves the front, left and right panels content visible.

When there are multiple media elements on a panel, a navigation element is au-

tomatically created. It's interactive with look-to-trigger, enabling switch to the desired content.

```

<a-entity id="centerpiece_0" position rotation visible>
  ><a-plane id="centerpiece_0_controls_0" opacity="0" position rotation width="3.6"
    height="0.8" material render-order="2" geometry>...</a-plane> event
  <a-image id="centerpiece_0_image_0" src="assets/images/0.jpg" render-order="1" material
    geometry width="10" height="3.850474530311834"></a-image> event
  <a-image id="centerpiece_0_image_1" src="assets/images/fullagar1.jpg" render-order="1"
    visible material geometry width="8" height="5.066666666666667"></a-image> event
  <a-image id="centerpiece_0_image_2" src="assets/images/fullagar2.jpg" render-order="1"
    visible material geometry width="8" height="5.386666666666667"></a-image> event
  ><a-plane id="centerpiece_0_3dControls_0" opacity="0" position rotation width="3.6"
    height="0.8" material render-order="2" visible geometry>...</a-plane> event
  <a-entity id="centerpiece_0_3d_0" gltf-model animation-mixer data-original-rotation-x="0"
    data-original-rotation-y="0" data-original-rotation-z="0" data-original-scale="3" scale
    rotation render-order="1" visible></a-entity> event
  ><a-entity id="centerpiece_0_navigation" position visible>
    ><a-entity id="centerpiece_0_image_0_navigation_container" position>...</a-entity> event
    ><a-entity id="centerpiece_0_image_1_navigation_container" position>...</a-entity> event
    ><a-entity id="centerpiece_0_image_2_navigation_container" position>...</a-entity> event
    ><a-entity id="centerpiece_0_3d_0_navigation_container" position>...</a-entity> event
  </a-entity>
</a-entity>

```

(a) Resulting HTML structure of the navigation element.



(b) User interface view with navigation options.

Figure 5.11: Integration of digital navigation controls within the AR interface.

As shown in Figure 5.11b, mini-previews provide direct access to specific files.

Navigation was restricted exclusively to static environmental panels (left, right, and center spaces) and omitted from physical marker-tracked coordinates, because informal testing revealed that looking at targets attached directly to the book caused users to tilt their heads, driving the physical marker out of the camera's tracking view and disrupting the experience.

The simple look-to-trigger controls previously mentioned in Figure 5.10 are triggered instantly. They work to move images, rotate 3D or interact with the video player element. As explained above, they can be enabled or disabled for each individual element.



Figure 5.12: Explicit arrow button interface for scrolling, zooming and resetting to initial state

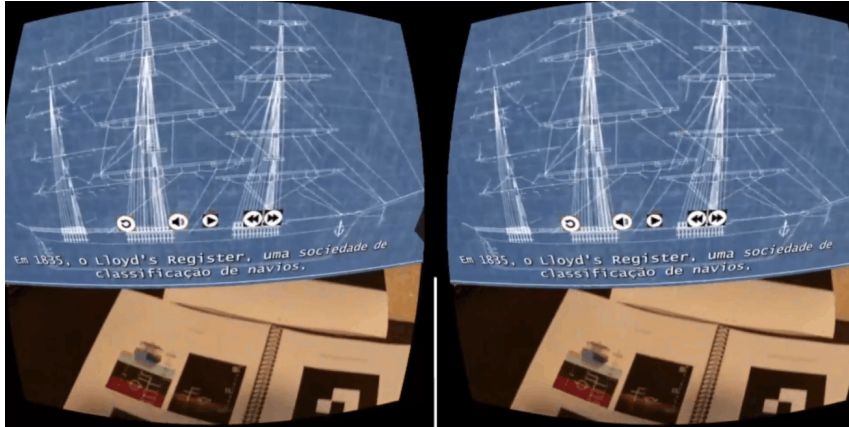


Figure 5.13: Video playback interface with play, pause, restart, fast forward, and rewind controls.

The narration files, seen in 5.5, play whenever the corresponding page marker is detected. To replay a narration from the start, the user must look at another marker to trigger another narration, and to back to the wanted narration's marker.

Marker detection and content persistence

To prevent tracking disruptions from breaking narrative continuity, the system divides digital content into two types.

The first type is marker-bound content. This content is physically attached to the book page. When the camera sees the marker, AR.js automatically shows everything inside it. When the marker is lost, AR.js automatically hides it, and the system pauses any playing videos. This keeps page content anchored to the physical book.

The second type is environment-anchored content. This includes the center, left, and right panels. These panels stay fixed relative to the camera, not on the book. When a new marker is detected, the script manually hides the old panels and shows the new ones. When a marker is lost, these panels remain visible. This lets users lower the book or look away without losing context.

5.3 Interaction Logging System

A dual-redundancy logging system captures all user interactions for behavior analysis and debugging, storing data locally in CSV format while backing up to Discord webhooks. The system records six fields per interaction: timestamp, action type (marker_found, marker_shown, marker_lost, navigation switches, or control button presses), panel location (center, left, right, or marker-bound), media type (image, video, or 3D model), marker ID, and element ID. Element IDs follow a consistent naming convention (e.g., centerpiece_0_image_reset_0), enabling automatic parsing of panel, marker, media type, and action without man-

ual annotation. All entries are stored locally in the `allCSVEntries` array with real-time console logging, while summary reports are sent to Discord on marker transitions. The system automatically exports a CSV file upon reaching the final marker. A representative log excerpt is shown below:

```
"2026-06-19 17:53:28",marker_found,,0,undefined
"2026-06-19 17:53:31",arrow down,center,image,0,centerpiece_0_image_down_0
"2026-06-19 17:53:40",navigation,center,image,0,centerpiece_0_image_1
```

This infrastructure enables usability analysis, session tracking, and ensures data persistence despite client-side failures.

5.4 Implementation challenges

5.4.1 Practical Limitations of Mobile VR

Despite the accessibility and low cost of mobile VR headsets, the platform imposes constraints that are absent from dedicated VR hardware. These limitations stem from the diversity of consumer smartphones and the fact that these devices were not designed primarily for VR use.

Not all smartphones fit all mobile VR headsets. During development, a Google Pixel 8 Pro could not be used with a Zapbox headset because the camera bump prevented the phone from sitting flush against the viewer. This may seem a minor mechanical issue, but it effectively excludes entire device categories from use with certain headsets, complicating the promise of universal accessibility. Passthrough VR relies on the smartphone's rear camera to show the physical environment. However, camera specifications vary widely between devices. Testing on an iPhone revealed a significantly narrower field of view than on Android devices used during development. The reduced peripheral vision altered the experience substantially: the book appeared closer, and the user had to hold it at different distances to keep markers in frame. The system's spatial configuration, carefully designed for a given field of view, cannot be assumed to translate uniformly across devices.

A more disruptive problem emerged when the phone was brought close to the physical book. Some smartphones automatically switch to a macro lens when objects are near the camera. This produces a sudden, jarring change in viewpoint and scale, breaking immersion and disorienting the user. The phone then switches back to the standard wide lens when pulled away. This behaviour is entirely outside the application's control and cannot be disabled through browser APIs.

iOS devices presented additional difficulties. On iPhone, the camera feed intermittently failed to appear in VR mode, showing a black background instead of passthrough. The cause could not be definitively identified but appeared related to WebXR's handling of the camera stream on Safari's rendering engine. This

meant that the same web application, running identical code, behaved differently on Android and iOS, an important consideration for any system that claims device-agnostic accessibility.

A fundamental limitation of smartphone-based mobile VR is that smartphones have only one rear camera (or multiple but spaced closely). Unlike dedicated VR headsets that use dual cameras for stereoscopic passthrough, smartphones present a monoscopic feed to both lenses. This reduces depth perception, making it difficult for users to accurately judge the spatial alignment between physical objects (e.g., the book) and virtual elements overlaid in the VR view. While passthrough remains functional for seeing the environment, this loss of stereopsis affects tasks requiring precise manual alignment with virtual content.

These limitations do not undermine the viability of mobile VR for educational use, but they do qualify the claim of universal access. A practical deployment must account for device diversity not as an afterthought but as a first-order design constraint.

5.4.2 Split-View VR Passthrough

A significant technical challenge was supporting both AR and VR modes within the same application. AR.js displays the camera feed as a background behind the A-Frame scene. This works in AR mode but fails in VR mode because the camera feed sits outside the A-Frame scene and cannot be rendered to the split-screen stereoscopic display.

Our solution captures the camera feed from AR.js and redirects it into the A-Frame scene. AR.js initializes the camera and stores the video stream in a hidden video element. Our script waits for this initialization to complete, then retrieves the live video stream and attaches it to a spherical video element inside the A-Frame scene. This makes the camera feed available as a 360-degree background within the VR environment.

The approach enables seamless switching between AR and VR modes without reloading the camera or restarting the application. The same live feed powers both modes, with the only difference being how it is rendered.

5.4.3 Marker Detection Debouncing

A persistent challenge encountered during development was the occurrence of false positive marker detections. The AR.js tracking system would occasionally trigger `markerFound` events erroneously, typically caused by visual artifacts such as shadows, reflections, or transient patterns in the camera feed that superficially resembled the marker's fiducial design. These false positives resulted in content briefly flashing on screen or media playback being interrupted, creating a frustrating and disjointed user experience.

To address this issue, we implemented a debouncing mechanism that introduces

a 1000-millisecond validation period between initial marker detection and content switching. Rather than responding to the first detection event, the system initiates a countdown. If the marker remains continuously detected throughout this period, the content switch proceeds. If the marker is lost during this window, the timer is cleared and no switch occurs. Additionally, subsequent detection events before the timer expires reset the countdown, effectively extending the validation period until the marker has been consistently detected for a full second. This approach ensures that only sustained, genuine marker detections trigger content changes, while brief artifacts are silently ignored.

The debouncing mechanism also includes immediate detection logging for debugging purposes. The `logMarkerFound()` function is called instantly when any detection event occurs, providing real-time visibility into marker detections without triggering any visual content changes. This separation between logging and content switching allows developers to monitor tracking behavior while maintaining a stable user experience.

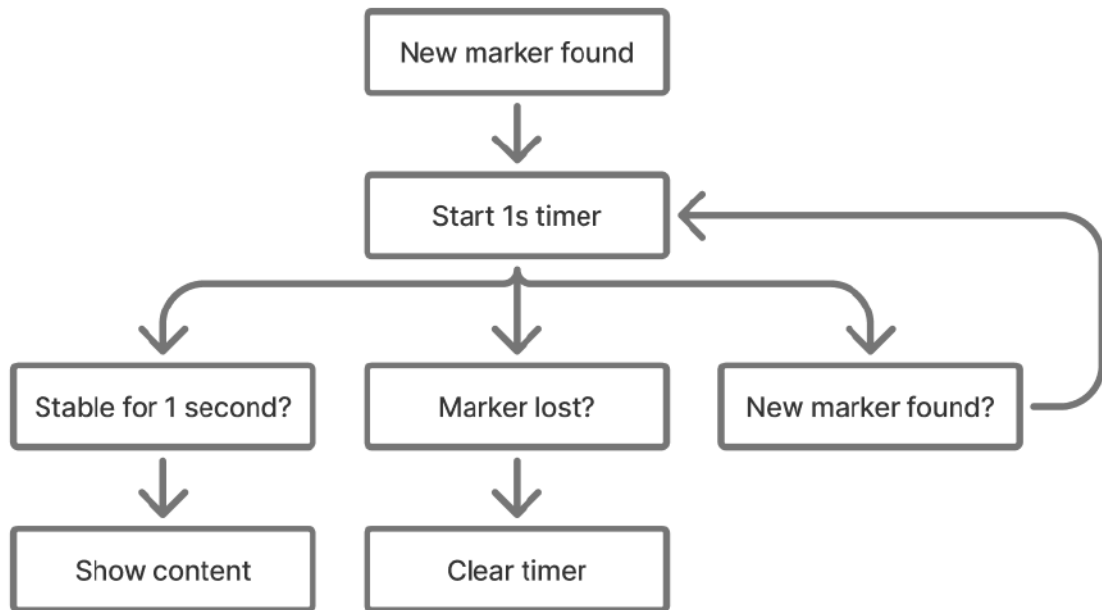


Figure 5.14: Diagram illustrating the marker debouncing validation period. False positives are ignored while sustained detections trigger content display.

5.4.4 Auto-Realignment System for Drift Correction

A significant challenge encountered during development was spatial drift, where accumulated sensor inaccuracies cause virtual content to gradually shift from its intended position. This manifests as content "floating" or slowly moving across the user's view even when the device remains stationary. To address this, we implemented an automatic realignment system that corrects positional errors whenever a user re-acquires a visual marker.

The realignment process retrieves the world-space positions of both the cam-

era and the detected marker, projecting both onto the horizontal plane to eliminate vertical variations. The normalized direction vector from the camera to the marker is computed, and the center panel is positioned at a fixed distance of 5 units along this vector. The target rotation angle is calculated using the arctangent function to orient all panels toward the camera's current viewpoint. Left and right panels are positioned perpendicular to the direction vector with a slight offset toward the camera, creating a subtle wraparound effect that enhances depth perception and visibility. The system uses a 500-millisecond animation with ease-in-out interpolation rather than instant snapping, preserving the marker's actual vertical position to maintain alignment with the physical marker's height.

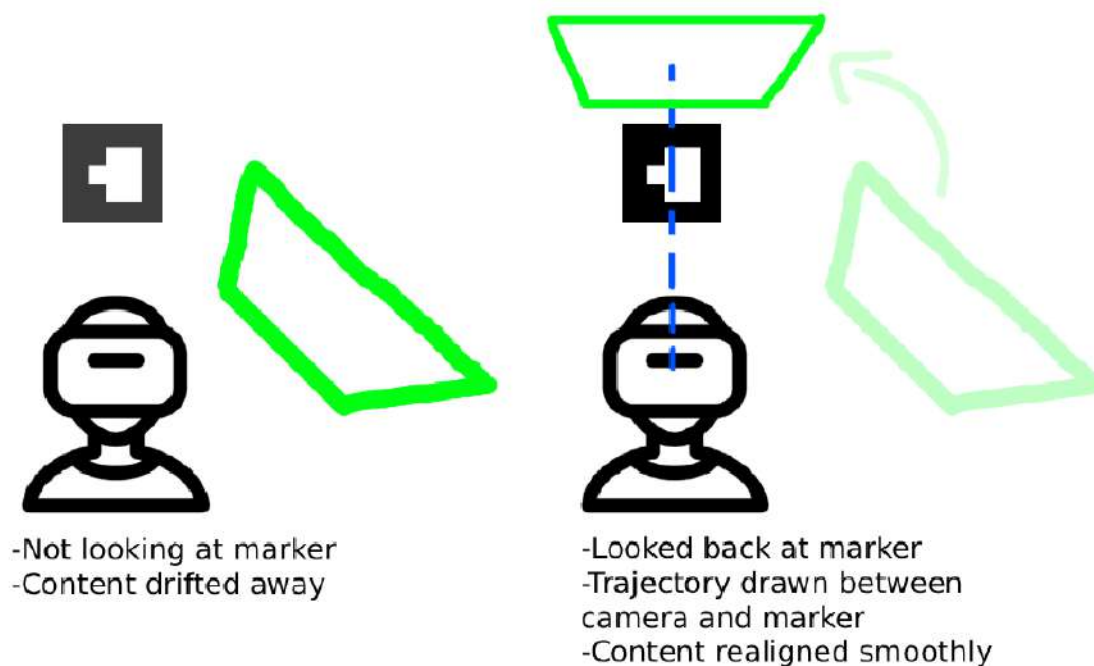


Figure 5.15: Diagram illustrating automatic content alignment toward user when marker is detected.

5.4.5 Old versions

Early implementations of the navigation allowing users to switch between multiple media files in the same marker, worked with look-to-trigger left and right arrows, that had a 2 second fuse. (blue bar)



Figure 5.16: Blue loading bar visual feedback for look-to-trigger interactions.

In the refined design, this loading bar "fuse" mechanism was completely removed, decreasing visual clutter and providing a more responsive experience.

An early implementation of image manipulation introduced gaze-based edge detection for scrolling, mapping invisible hitboxes to image margins (Figure 5.17) alongside directional indicator arrows (Figure 5.18). However, this implicit approach proved unstable, causing frequent accidental triggers whenever users looked near the document borders.

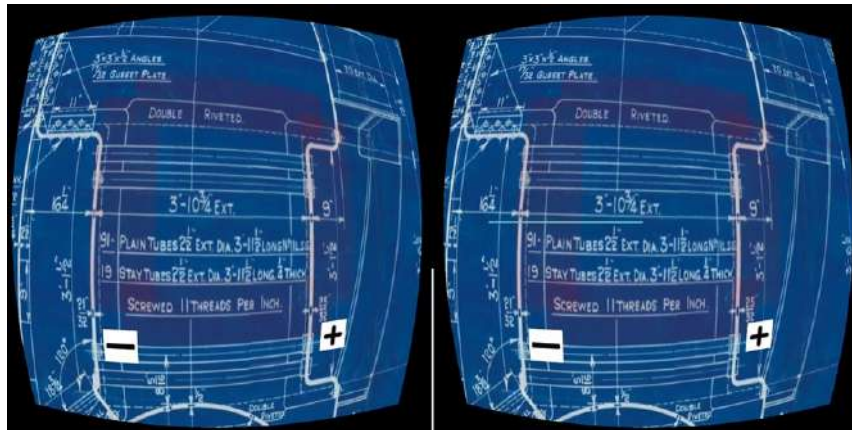


Figure 5.17: Red hitboxes showing gaze-based edge scrolling regions for zoomed documents.

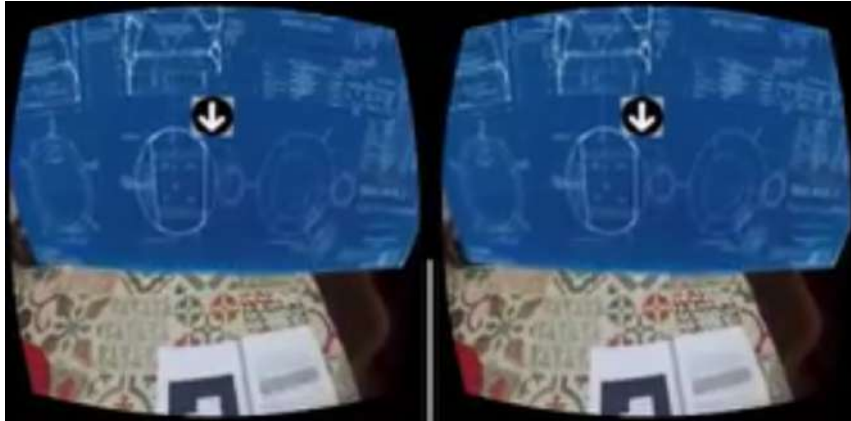


Figure 5.18: Visual feedback arrow indicating scroll direction during zoomed document navigation.

Chapter 6

Evaluation

This chapter presents evaluations and user study designed to assess the Tangible VR Book system. The study investigates how different spatial arrangements of digital content affect user experience, workload, and learning outcomes.

6.1 Preliminary evaluations

A first informal evaluation was conducted during the European Researchers' Night on 26 September 2025, where we presented the initial prototype to the public. This demonstration served as a proof of concept, featuring a selection of Lloyd's Register documents and narrative content centered on the *Fullagar*, the world's first all-welded ship. This version, as described in section 4.2.2, was a very early and basic version of the core display mechanism.

This public trial provided critical insights that shaped subsequent development. First, the evaluation revealed that image-based tracking for mobile Augmented Reality is insufficient in open-air environments, as uncontrolled ambient lighting frequently caused tracking failures. Second, the study highlighted a significant visibility gap: once the user put on the headset, it was impossible to monitor the application state or verify the user's point of view. These findings prompted the setup of a real-time screen-sharing system to stream the mobile output to a PC, facilitating robust monitoring for formal studies. Despite these technical challenges, the qualitative feedback was highly positive, demonstrating significant public interest in the concept of bridging historical archival documents with immersive narrative experiences.



Figure 6.1: First prototype public demonstration

After that public trial, a practical evaluation was conducted to select the most suitable marker tracking approach. Initial research into commercial SDKs like Vuforia ruled them out due to licensing costs and poor web compatibility, narrowing the focus to two open-source, web-based solutions: MindAR (image-based tracking) and AR.js (using Hiro barcode markers). The testing methodology prioritized detection reliability, speed, and performance. Tests were done with a phone on a fixed tripod, at a top-down near vertical angle and also at a low angle.

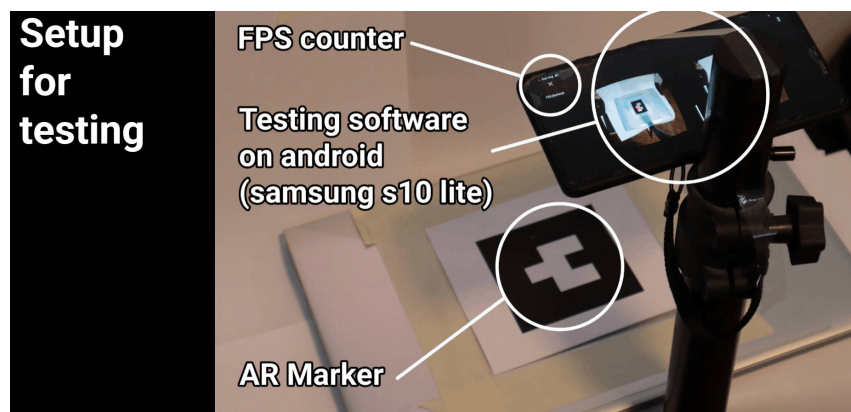


Figure 6.2: Setup For Testing

A video of the testing can be found here: https://youtu.be/8o9CQ_41HI8

6.1.1 MindAR

MindAR's promise was to turn the beautiful historical documents themselves into invisible triggers. No ugly markers, just pure archival aesthetics. But this

elegant theory met a messy reality. To make it work, we had to blow images up until they swallowed the page.

Even then, performance was shaky. Detection took a noticeable pause, frame rates stuttered, and the book had to be held perfectly flat and viewed from above, like a museum exhibit. This didn't match the spirit of interactive reading. While it could follow basic movement, 3D models wobbled unsteadily, never quite locking into place.



Figure 6.3: MindAR struggling: images had to be huge to work

6.1.2 AR.js

Switching to AR.js's classic barcode markers, the difference was instant.

The blocky Hiro markers were detected instantly and tracked nearly flawlessly. Performance stayed locked at a smooth 61 FPS, critical for comfortable VR. Best of all, it worked how a real book works, the tracking held firm through natural movement, and 3D models anchored to the page with satisfying stability.

The cost was visual. We traded invisible elegance for a functional, intrusive, pattern on our pages. But this reliable engine gave us exactly what we needed.

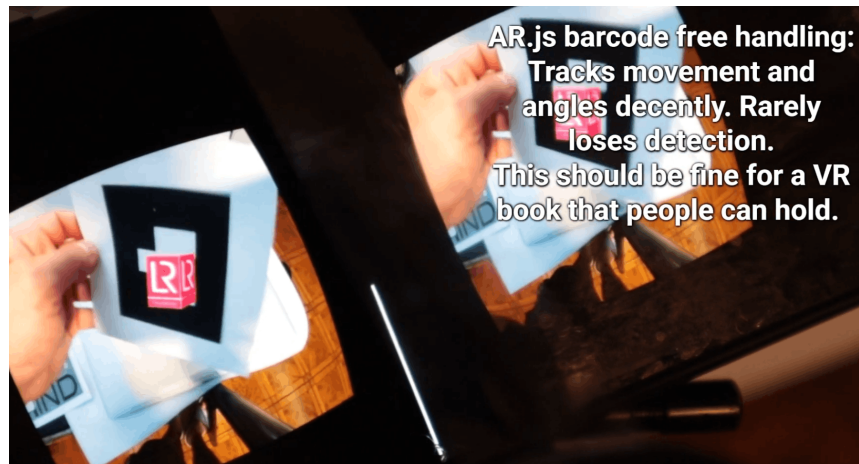


Figure 6.4: AR.js in action: robust tracking for natural handling

6.1.3 Comparative Summary of Results

The following table summarizes the key findings from the comparative evaluation, highlighting the trade-offs between aesthetics and performance.

Evaluation Metric	MindAR (Image)	AR.js (Barcode)
Detection Speed	Slower (0.3s)	Fast (<0.2s)
Frame Rate Stability	Unstable (40-61 FPS)	Stable (61 FPS)
Low-Angle Detection	Fails	Robust
Free-Handling Support	Poor (requires fixed position)	Excellent
Marker Aesthetics	Good (uses content images)	Poor (visually intrusive)
3D Anchor Stability	Unstable (jittery rotation)	Stable

Table 6.1: Comparative evaluation of marker tracking technologies

6.1.4 Conclusions and Decision

The experimental data led to a clear technical decision: AR.js barcode markers were selected as the primary tracking technology.

While MindAR offered a more aesthetically pleasing solution by hiding the tracking mechanism, its fundamental technical flaws, particularly its failure at low angles would have broken the core promise of a tangible book. In contrast, the barcode markers provided the rock-solid performance tracking necessary for a smooth, comfortable, and immersive VR experience.

6.2 Study: Layout alternatives and content anchoring

6.2.1 Objectives and Setup

One of the fundamental questions when designing a tangible augmented reality system is where to place the digital content relative to the physical book. Content can be anchored to the marker itself, appearing directly on the page, or positioned in fixed locations around the reader, left, centre, or right. Each approach presents trade-offs: marker-attached content feels intrinsically linked to the physical object, reinforcing the connection between print and digital media, but may obscure the page. Fixed-position content offers greater visual stability and readability, yet risks feeling disconnected from the physical book. Furthermore, the movement required to view content in different positions, turning head or shifting gaze across multiple locations, introduces a risk of cybersickness, a known issue in head-mounted displays where frequent head movements can cause discomfort or disorientation. Understanding these trade-offs was central to the study's motivation.

The primary objective was to compare three spatial configurations of digital content within the same physical book. In Condition A (Distributed), content appeared on the left side, centre, right side, and anchored to the marker itself. Condition B (Hybrid) restricted content to the centre and the marker, with the latter reserved exclusively for 3D models and maps. Condition C (Centralised) placed all content in the centre position.

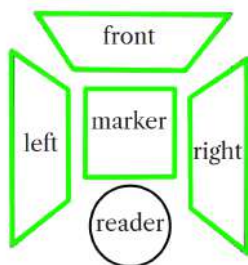


Figure 6.5: Distributed

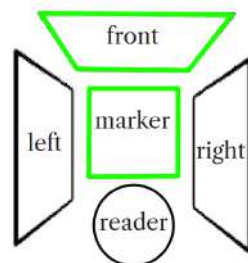


Figure 6.6: Hybrid

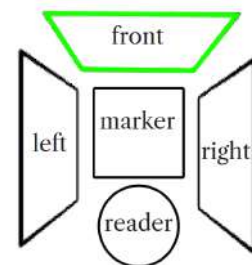


Figure 6.7: Centralised

The study sought to answer four research questions: which spatial configuration minimises perceived workload, which maximises enjoyment and engagement, whether spatial distribution affects comprehension and recall, and what qualitative preferences users express regarding content placement.

The study was conducted in a quiet indoor environment with consistent lighting conditions. Participants used the same physical Tangible VR Book and a smartphone inserted into a mobile VR headset running the AR application. The researcher monitored each session to assist with headset adjustments.

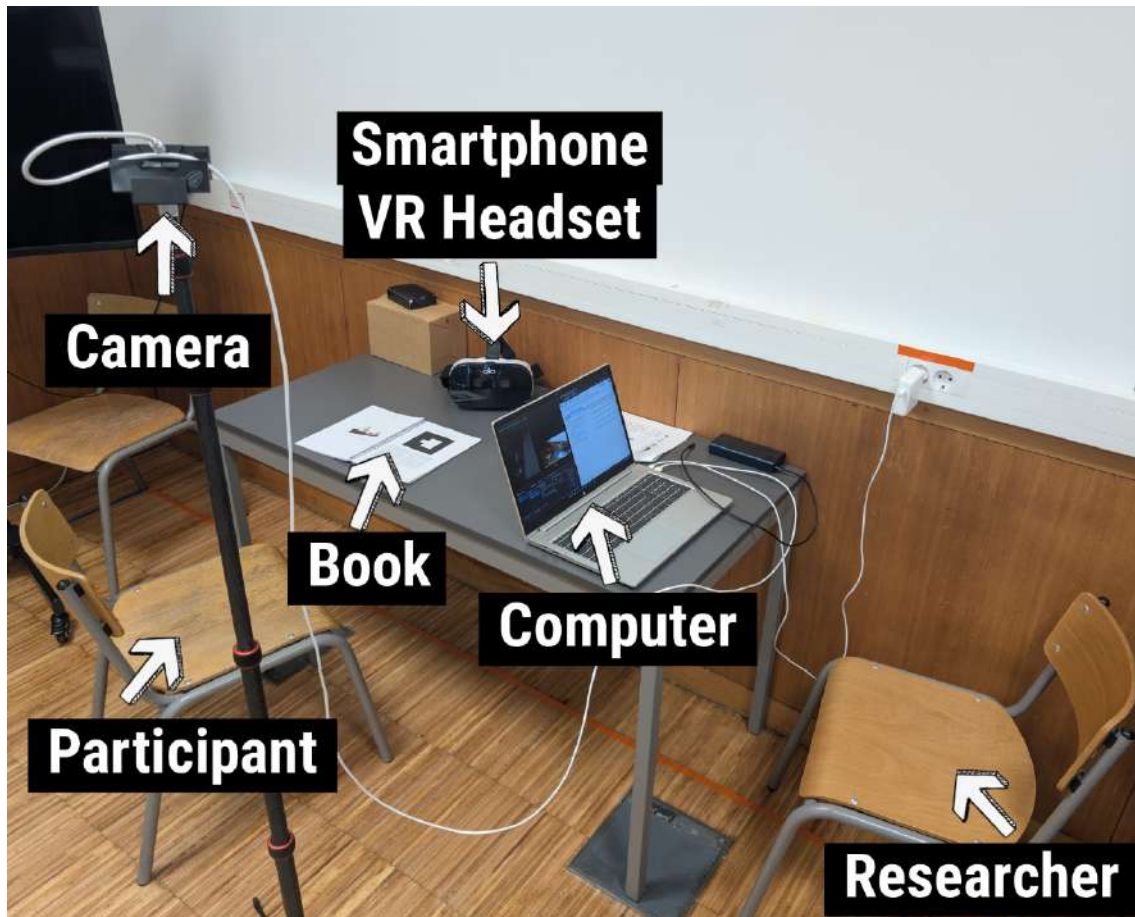


Figure 6.8: Experiment setup

A camera placed behind the participants captured their interactions with the book. The smartphone VR view was captured by the laptop via screen share using `scrcpy`¹. The researcher monitored and recorded the participant's point of view and camera feed with `OBS`². The resulting setup produced 72 videos and logs.

¹<https://scrcpy.org/>

²<https://obsproject.com/>

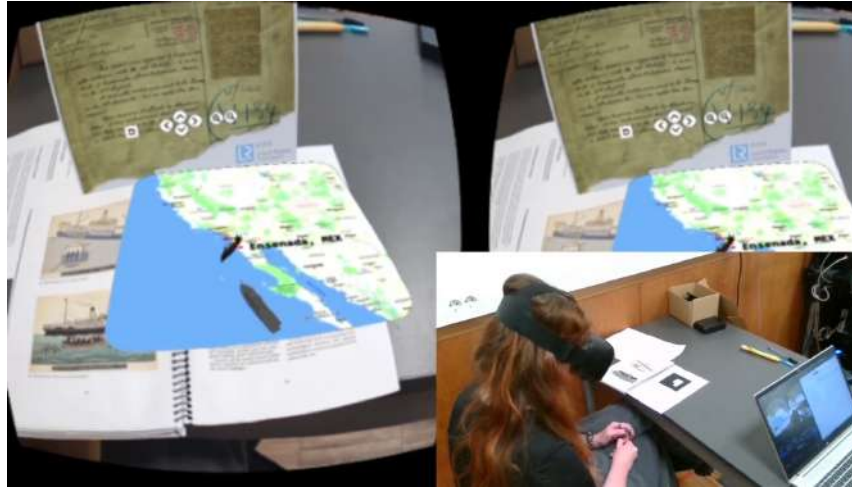


Figure 6.9: Example frame from experiment video

Each participant experienced all three spatial configurations. To counterbalance order effects, a Balanced Latin Square design was employed with six sequences. With 24 participants, the six sequences were assigned in three complete rotations.

Sequence	First	Second	Third
1	Distributed	Hybrid	Centralised
2	Distributed	Centralised	Hybrid
3	Centralised	Distributed	Hybrid
4	Centralised	Hybrid	Distributed
5	Hybrid	Centralised	Distributed
6	Hybrid	Distributed	Centralised

Table 6.2: Balanced Latin square counterbalancing for three conditions across six sequences

The same physical Tangible VR Book was used for all conditions. Only the JSON configuration file changed to reposition content according to each condition. The application logged all user interactions, and sessions were video-recorded for behavioural analysis.

Each session lasted approximately 60 minutes. The procedure began with a welcome and system explanation, followed by informed consent and a demographic questionnaire. Participants then completed a brief VR familiarisation tutorial on the look-to-trigger interaction mechanism. Each of the three conditions followed the same structure: participants explored the content freely, completed a comprehension quiz and questionnaires, followed by open-ended feedback. After all three conditions, a final interview captured overall preference rankings and additional comments.

Demographic variables included gender, age group, occupation, use of corrective lenses, VR/AR familiarity, video game frequency, archival familiarity, prior immersive learning experience, and self-rated digital comfort.

Learning outcomes were measured with a 7-question multiple-choice quiz testing recall of key facts about the *Fullagar*, including its launch year, route, construction method, and other historical details. The same quiz was used across all conditions with randomised answer order to prevent memorisation effects.

Perceived workload was measured using the NASA-TLX, consisting of six 7-point scales measuring mental demand, physical demand, temporal demand, performance, effort, and frustration.

Enjoyment and engagement were measured with a 7-item scale adapted from Makransky and Lilleholt [2018] using 7-point Likert responses.

Spatial experience was measured with a 5-item scale assessing spatial coherence, virtual connectedness, guidance, encouragement of exploration, and immersiveness, also using 7-point Likert responses. Qualitative feedback was collected through open-ended questions for each condition asking participants what they liked most and what could be improved, followed by a final preference ranking of the three configurations.

A total of 24 participants were recruited from the university student body and general public. No specific prior VR experience was required. Participants provided written informed consent after receiving a full explanation of the study purpose, procedures, voluntary nature of participation, and their right to withdraw at any time without penalty. Participants were informed about potential VR-related discomforts (including dizziness, eye strain, and nausea) and were encouraged to take breaks as needed, with the researcher monitoring for signs of discomfort throughout each session.

6.3 Results

6.3.1 Participant Profile

A total of 24 participants completed the study, comprising 13 females and 11 males. All participants were university students, with the majority aged 18–24 and the remainder aged 25–34.

Just over half of the participants reported using corrective lenses. VR/AR usage was generally low, with most participants using it "Rarely" or "Never," and only one participant reporting frequent use. Video game habits were more evenly distributed, with "Regularly" being the most common response, followed equally by "Rarely" and "Occasionally." Familiarity with historical and archival materials was predominantly moderate to slight, with only a small minority reporting being "Very familiar." Exactly half of the participants had previously used immersive technologies for learning purposes. Self-rated digital technology comfort was generally high, with the vast majority rating it as "High" or "Very high," and only a few reporting a "Medium" comfort level.

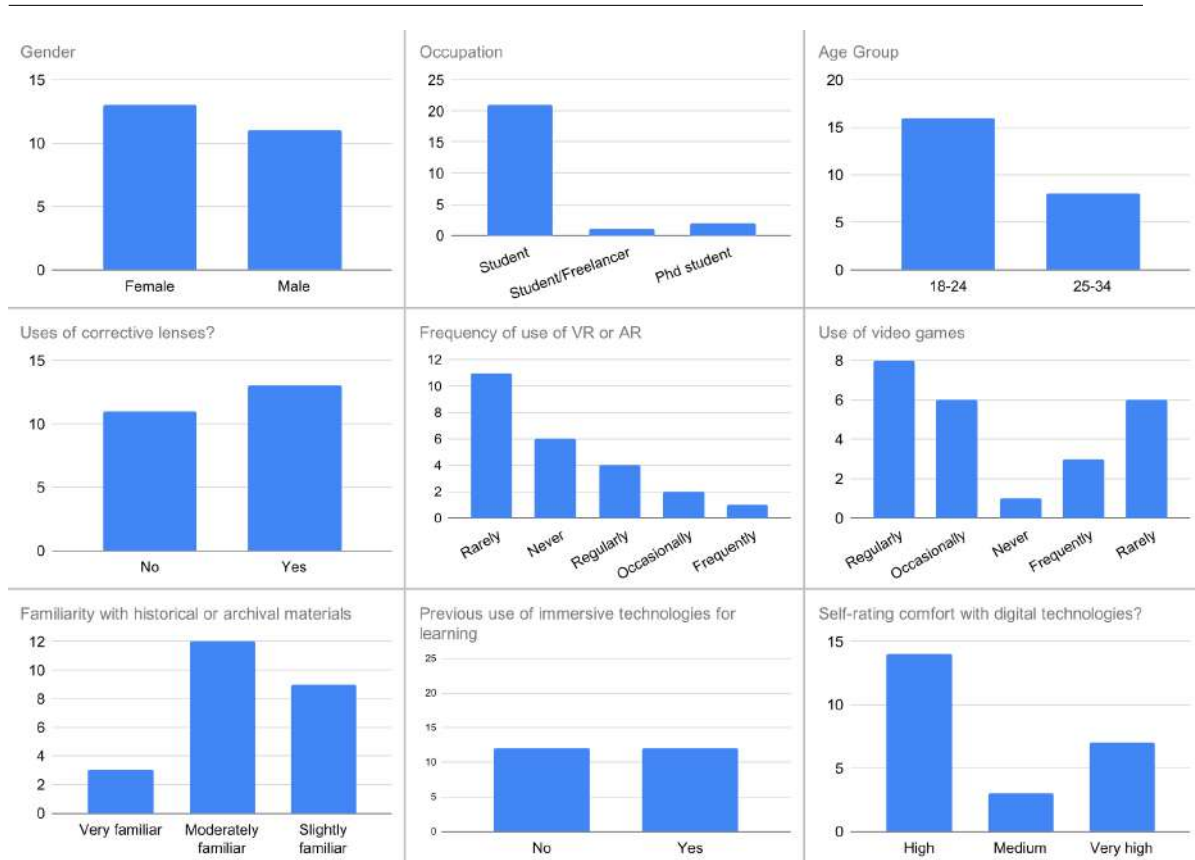


Figure 6.10: Participant Profile Results Charts. (Horizontal: Answers; Vertical: Count)

6.3.2 Learning Outcomes

Participants completed a 7-question multiple-choice quiz of key facts about the Fullagar. Overall performance was high, with most participants answering the majority of questions correctly.

In the questions regarding Fullagar's claim to fame (first fully welded ship), its launch year (1920), original operating route (Liverpool–Cardiff), construction method (welding), and the circumstances of its loss (collision with another vessel), the vast majority of participants selected the correct answers.

Moderate performance was seen for the question about the ship's 1924 disposition, where most participants correctly identified that the ship was sold after an accident, though a few mistakenly believed it had sunk or been converted.

The weakest performance was for the question regarding the ship's first renaming, where approximately half of the participants incorrectly identified the name as "Cedros" or "Hidalgo" instead of the correct answer, "Caria." This suggests that the vessel's name change history was less effectively retained compared to other factual content.

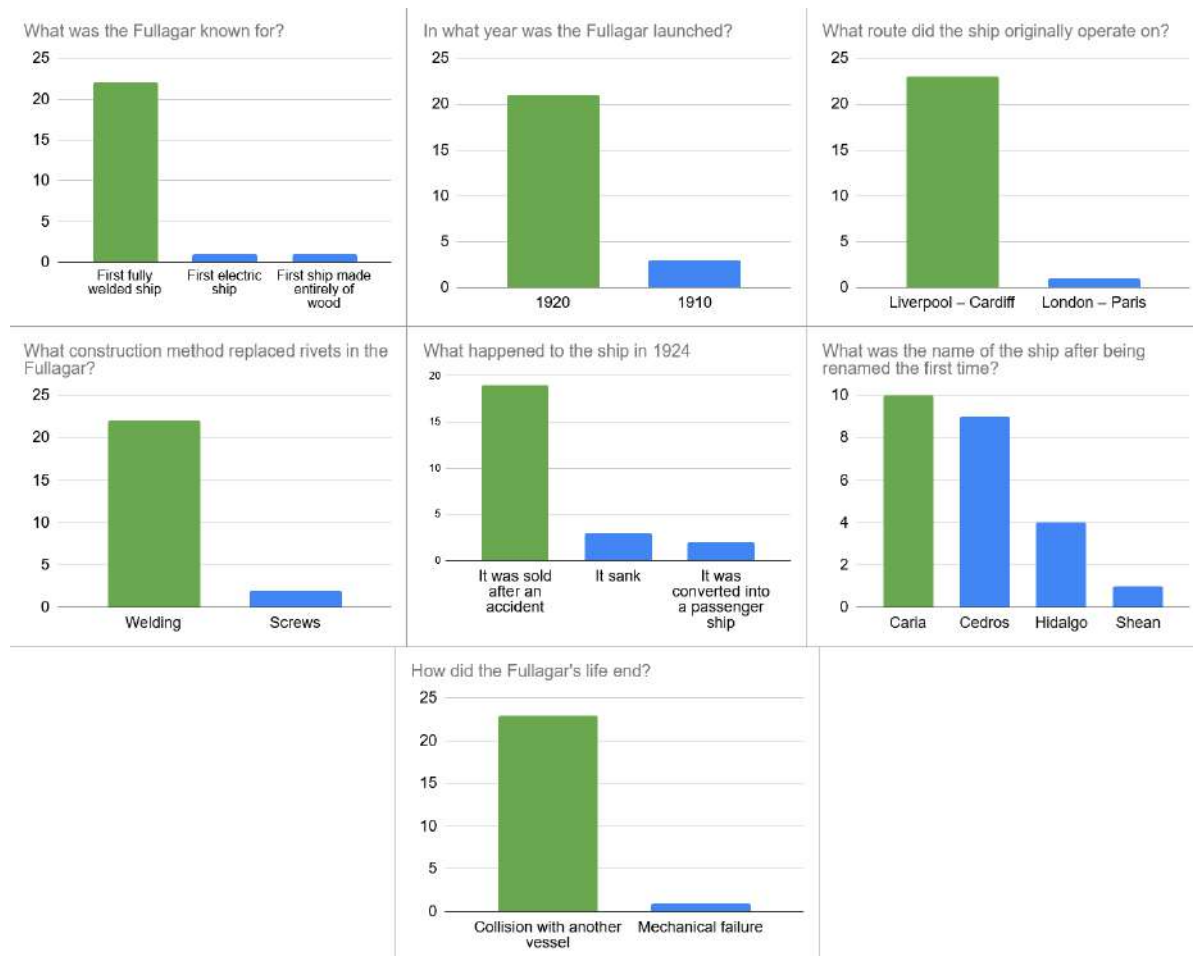


Figure 6.11: Learning outcomes Results Charts (Horizontal: Answers; Vertical: Count)

6.3.3 Perceived Workload

Mean NASA-TLX scores across the six dimensions are reported in Table 6.3, with standard deviations in parentheses. Lower scores indicate lower perceived workload. Standard deviations indicate response variability, smaller values suggest participants were more consistent in their ratings, while larger values reflect greater individual differences.

Measure	Distributed	Center only	Center +marker
Mental Demand	3.21 (1.82)	2.33 (1.13)	2.67 (1.58)
Physical Demand	3.25 (1.98)	2.21 (1.25)	2.50 (1.67)
Temporal Demand	2.29 (1.49)	2.21 (1.28)	2.42 (1.56)
Performance	5.75 (1.07)	5.92 (1.06)	5.71 (1.40)
Effort	3.04 (1.83)	2.38 (1.28)	2.79 (1.67)
Frustration	2.08 (1.72)	1.67 (1.13)	1.83 (1.34)
Overall TLX	3.27 (1.04)	2.78 (0.64)	2.99 (1.05)

Table 6.3: Mean NASA-TLX scores by condition with standard deviations in parentheses (scale 1-7; lower = less workload)

The Centralised configuration produced the lowest overall workload ($M = 2.78$, $SD = 0.64$), followed by Center+marker ($M = 2.99$, $SD = 1.05$), while Distributed had the highest ($M = 3.27$, $SD = 1.04$). Performance scores were consistently high across all conditions (5.71–5.92), indicating participants felt successful regardless of configuration. Frustration remained low across all conditions (1.67–2.08), suggesting the experience was not particularly stressful. The Distributed configuration showed the highest scores in Physical Demand ($M = 3.25$, $SD = 1.98$) and Effort ($M = 3.04$, $SD = 1.83$), suggesting that spreading content across multiple locations required greater physical and cognitive resources compared to the other layouts.

6.3.4 Enjoyment and Engagement

Mean enjoyment scores across the seven items are reported in Table 6.4, with standard deviations in parentheses. Higher scores indicate greater enjoyment and engagement. Note that the items “Boring” and “Didn’t hold my attention” were reverse-coded, so higher scores indicate greater enjoyment.

Measure	Distributed	Center only	Center +marker
Enjoyed doing this activity	5.88 (1.33)	5.54 (1.06)	6.00 (0.83)
Activity was fun to do	5.71 (1.23)	5.71 (1.00)	5.92 (1.02)
Boring (reversed)	6.33 (0.87)	5.83 (1.49)	6.13 (1.36)
Didn’t hold my attention (reversed)	6.21 (1.22)	6.00 (1.35)	6.00 (1.41)
Very interesting	6.00 (0.93)	5.83 (1.01)	5.92 (1.10)
Quite enjoyable	5.58 (1.25)	5.58 (0.97)	5.79 (1.18)
Thought about how much I enjoyed it	4.83 (1.90)	4.46 (1.82)	5.04 (1.94)
Overall Enjoyment	5.79 (0.92)	5.57 (0.83)	5.83 (0.91)

Table 6.4: Mean enjoyment scores by condition with standard deviations in parentheses (scale 1-7; higher = more enjoyment)

Center+marker produced the highest overall enjoyment ($M = 5.83$, $SD = 0.91$),

followed closely by Distributed ($M = 5.79$, $SD = 0.92$), with Center only slightly lower ($M = 5.57$, $SD = 0.83$). Participants consistently found the experience engaging and not boring across all conditions, as reflected in the high scores for attention and boredom (5.83–6.33). The lowest scores were for the item measuring self-reflection about enjoyment (4.46–5.04), with relatively large standard deviations (1.82–1.94), suggesting participants varied considerably in how much they thought about their enjoyment during the task. This may indicate that most participants were more focused on the task itself than on evaluating their experience during the activity.

Spatial Experience

Mean spatial experience scores across the five dimensions are reported in Table 6.5, with standard deviations in parentheses. Higher scores indicate stronger spatial presence and coherence.

Measure	Distributed	Center only	Center +marker
Spatial organization felt coherent	5.08 (1.56)	5.38 (1.35)	5.46 (1.32)
Virtual content connected to physical book	6.00 (1.14)	5.58 (1.25)	6.21 (0.83)
Always knew where to look next	5.00 (1.69)	5.54 (1.38)	5.42 (1.32)
Layout encouraged exploration	5.92 (1.35)	5.58 (1.25)	5.50 (1.32)
Placement enhanced immersive experience	5.63 (1.44)	5.38 (1.47)	5.71 (1.30)
Overall Spatial Experience	5.53 (1.20)	5.49 (1.14)	5.66 (1.06)

Table 6.5: Mean spatial experience scores by condition with standard deviations in parentheses (scale 1-7; higher = stronger spatial presence)

Center+marker achieved the highest overall spatial experience ($M = 5.66$, $SD = 1.06$), with Distributed ($M = 5.53$, $SD = 1.20$) and Center only ($M = 5.49$, $SD = 1.14$) scoring similarly. Across all conditions, participants strongly felt that virtual content was meaningfully connected to the physical book (5.58–6.21), with Center+marker showing the lowest variability ($SD = 0.83$), indicating strong agreement among participants. Knowing where to look next received the lowest scores (5.00–5.54), with Distributed showing the largest variability ($SD = 1.69$), suggesting that some participants navigated more easily than others. Distributed stood out for encouraging exploration ($M = 5.92$, $SD = 1.35$), suggesting that spreading content around the page promoted curiosity and discovery, though this came at the cost of navigational clarity.

VR Sickness

VR sickness scores were recorded on a 0–20 scale at three timepoints (Start, Mid, End) for each condition, with a Baseline measurement taken prior to any VR exposure. Mean sickness scores are reported in Table 6.6, with standard deviations in parentheses.

Metric	Distributed	Central Only	Center + Marker
Average Sickness	1.42 (3.14)	0.82 (1.72)	1.06 (2.43)
Start	0.79 (1.91)	0.63 (1.38)	1.00 (2.62)
Mid	1.83 (3.82)	0.92 (1.82)	1.17 (2.41)
End	1.63 (3.40)	0.92 (1.89)	1.00 (2.34)
Change (End - Start)	+0.83	+0.29	0.00
% with Sickness (>0)	25%	25%	26%

Table 6.6: Mean VR sickness scores by condition with standard deviations in parentheses (scale 0-20; higher = more sickness)

Baseline sickness was minimal ($M = 0.29$, $SD = 1.08$). The Distributed configuration produced the highest overall sickness ($M = 1.42$, $SD = 3.14$) and the largest increase over time (+0.83), peaking at the Mid timepoint ($M = 1.83$, $SD = 3.82$). The large standard deviations reflect the bimodal nature of the data: 75% of participants reported zero sickness, while a small subset experienced notable discomfort. Central Only was the most comfortable overall ($M = 0.82$, $SD = 1.72$), while Center + Marker showed no increase over time (0.00 change) and remained stable throughout ($1.00 \rightarrow 1.17 \rightarrow 1.00$).

Overall, all configurations remained within acceptable comfort levels, with 75% reporting no sickness. The large standard deviations suggest considerable individual variability. Center + Marker emerged as the optimal balance, offering spatial richness without the discomfort penalty of Distributed.

6.3.5 Preference Rankings

Participants ranked the three configurations from 1 (most preferred) to 3 (least preferred). Figure 6.12 presents the same data in two complementary visual formats: the bottom chart shows the distribution of ranks across configurations, while the top chart displays the same data with configurations as rows for clarity.

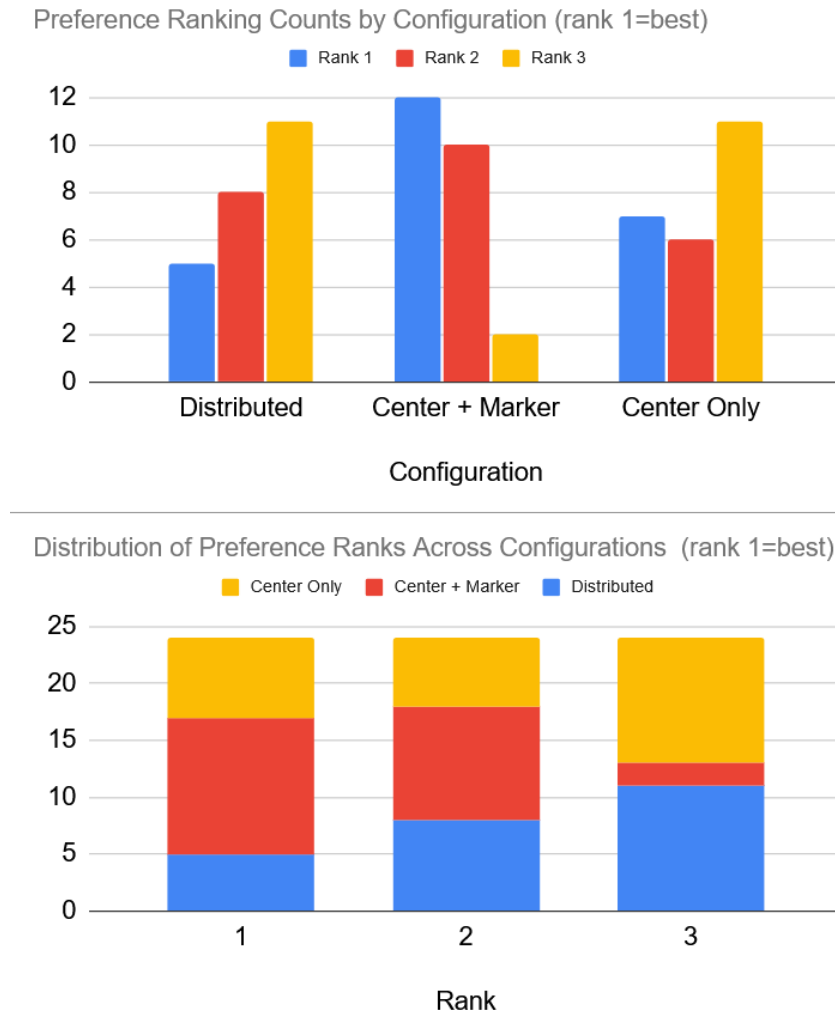


Figure 6.12: Participant preference rankings by configuration

The Center + Marker configuration received the highest number of Rank 1 votes (12) and the fewest Rank 3 votes (2), indicating it was the most preferred configuration overall. In contrast, Distributed and Center Only received similar numbers of Rank 3 votes (11 each), suggesting they were equally unpopular among participants.

6.3.6 Behavioural Analysis

Observing the participants during testing, as well as reviewing testing footage revealed several notable interaction patterns. Most participants avoided holding the Tangible VR Book, instead leaving it resting on the table throughout the experience, suggesting they perceived it as a static display rather than an interactive tool.

Despite being informed that documents could be zoomed in to examine fine details, including individual letters within 8K scans, almost no participants fully utilised this feature. Most would zoom in approximately five increments and

stop, even when explicitly instructed that greater zoom was possible. This reluctance suggests participants either found the default view sufficient or were hesitant to fully explore the capability.

Several participants instinctively attempted hand gestures to control the virtual content, but the system relied solely on gaze-based "look-to-trigger" interactions, meaning these gestures were not recognised. This indicates a natural inclination toward tangible interaction even within a VR setting.

The look-to-trigger interaction proved relatively intuitive, requiring only brief explanation for most users. However, the reluctance to hold the book and fully explore zoom functionality suggests participants may have been cautious due to unfamiliarity with the technology, concern about damaging equipment, or simply satisfaction with the default experience.

6.3.7 Interview and Open-Ended Questions

The qualitative data was collected through open-ended questions and oral interviews, capturing participants' overall impressions of the Tangible VR Book experience. Comments were analysed thematically, revealing several recurring patterns across participants.

Immersion and Presence

Participants consistently highlighted the immersive quality of the experience, particularly through the 3D models and the combination of audio with visual elements.

Como se tivéssemos dentro de uma sala de aula." (P2)

It felt like we were inside a classroom."

Adorei os conteúdos 3D, acrescentam imenso à experiência." (P5)

I loved the 3D content, it adds immensely to the experience."

"The placement of content around me enhanced the immersive experience." (P24)

However, several participants noted that the AI-generated narration broke immersion due to unnatural intonation and accent:

A narração ser feita por pessoas reais, porque, por vezes, a voz começa a falar com o sotaque diferente e perdia-se a atenção do que estava a dizer." (P14)

The narration should be done by real people, because sometimes the voice starts speaking with a different accent and you lose attention to what is being said."

A narração era um pouco estranha - entoação de algumas palavras é estranha e quebra a imersão." (P9)

The narration was a bit strange - the intonation of some words is odd and breaks immersion."

Cognitive Load and Distraction

The Distributed configuration created a tension between exploration and cognitive overload. While some participants appreciated the freedom to explore, others found it overwhelming.

Para pessoas que se distraem facilmente, como eu, a primeira experiência não funciona porque não sabia para onde olhar e só queria explorar." (P2)

For people who get easily distracted, like me, the first experience (distributed) doesn't work because I didn't know where to look and just wanted to explore."

"Too much information and all over the place. I felt a bit overwhelmed." (P6)

A distribuição do primeiro contribui a exploração dos materiais de forma mais imersiva, mas pode afetar os mais sensíveis ao movimento." (P8)

The distribution of the first (distributed) contributes to exploring materials in a more immersive way, but it can affect those sensitive to movement."

Physical Discomfort and VR Sickness

Physical discomfort was consistently associated with the Distributed configuration, requiring excessive head movement and causing nausea for some participants.

O distribuído pelos lados é muito desconfortável e enjoativo." (P16)
The distributed layout is very uncomfortable and nauseating."

O layout no centro, esquerda e direita, foi o que gostei menos, pois exige mais algum esforço físico e sinto 'clutter' de informação." (P5)
The center, left, and right layout was what I liked least, as it requires more physical effort and I feel information clutter."

Senti que dificultava um bocado a manipulação dos controlos. Também foi o layout que, apesar de reduzido, me deixou mais mal-disposta." (P22)
(distributed layout) ...made it a bit difficult to manipulate the controls. It was also the layout that made me feel more queasy."

Real-World Application Potential

Participants overwhelmingly saw potential for this technology in museums, schools, and libraries, though they emphasised it should complement rather than replace traditional methods.

Consegue imaginar este formato a ser aplicado no mundo real - visualização virtual pode ser muito custoso - este formato pode ser mais fácil e acessível." (P4)

You can imagine this format being applied in the real world - virtual visualization can be very costly - this format can be easier and more accessible."

Pode ser aplicado em escolas, museus, universidades, em todo o lado que tenha o livro." (P3)

It can be applied in schools, museums, universities, everywhere that has the book."

Não devia ser usado 100% das aulas mas apenas como complemento." (P9)

It shouldn't be used 100% of classes but only as a complement."

Summary of Key Themes

The qualitative feedback reinforces the quantitative findings: the Center + Marker configuration strikes the best balance between immersion and comfort, while the Distributed configuration offers greater exploration potential at the cost of cognitive and physical strain. Participants consistently valued the 3D models and animations as the most impactful elements, and identified audio narration quality and image resolution as key areas for improvement. The system was perceived as having strong potential for real-world educational applications, particularly in museums and schools.

6.3.8 Discussion

The results reveal a consistent pattern across all measures: the Center + Marker configuration consistently outperformed or matched the other configurations, while the Distributed configuration introduced trade-offs between engagement and comfort.

The Centralised configuration produced the lowest overall workload ($M = 2.78$), followed by Center + Marker ($M = 2.99$), with Distributed scoring highest ($M = 3.27$). The Distributed configuration's elevated Physical Demand ($M = 3.25$) and Effort ($M = 3.04$) scores suggest that spreading content across multiple locations imposed a measurable cognitive and physical cost. This aligns with cognitive load theory [Hollender et al., 2010; Paas et al., 2003; Sweller et al., 1998], which posits that extraneous load increases when users must integrate information from disparate sources. However, all workload scores remained relatively low (below 4 on a 7-point scale), indicating that even the most demanding configuration was tolerable.

Center + Marker achieved the highest enjoyment ($M = 5.84$), with Distributed ($M = 5.79$) and Centralised ($M = 5.57$) following closely. The high scores across all conditions suggest that participants found the Tangible VR Book experience engaging regardless of layout. The lowest scores were consistently for self-reflection

on enjoyment (4.46–5.04), indicating participants were immersed in the task rather than evaluating their experience, a positive sign for engagement.

Center + Marker scored highest for spatial presence ($M = 5.66$), while Distributed ($M = 5.53$) and Centralised ($M = 5.49$) were similar. The strongest dimension across all conditions was the perceived connection between virtual content and the physical book (5.58–6.21), validating the core premise of tangible VR: that anchoring digital content to physical pages enhances coherence. The weakest dimension was navigational clarity (5.00–5.54), suggesting users occasionally felt uncertain about where to direct their attention. Distributed excelled at encouraging exploration ($M = 5.92$), confirming that spatial distribution promotes curiosity and discovery.

All configurations remained well within acceptable comfort levels, with 75% of participants reporting zero sickness. Distributed caused the most discomfort ($M = 1.42$), while Centralised was the most comfortable ($M = 0.82$). Center + Marker showed no increase over time (0.00 change), demonstrating that it offers spatial richness without the sickness penalty of Distributed. Large standard deviations across all conditions indicate considerable individual variability in susceptibility.

Participants performed well across all conditions, with the strongest performance on factual recall and the weakest on the ship's renaming history. The absence of significant differences between conditions suggests that spatial configuration does not substantially affect immediate recall, though the quiz may not have been sensitive enough to detect subtle differences.

Center + Marker was the clear favourite, receiving 12 of 24 first-place votes and the lowest average rank (1.58). Distributed and Centralised were roughly equally unpopular, with 11 third-place votes each.

Participants were reluctant to hold the book, leaving it on the table, and rarely fully utilised the zoom functionality despite explicit instruction. Some instinctively attempted hand gestures, revealing a natural inclination toward tangible interaction that the gaze-based system could not accommodate.

The Center + Marker configuration consistently emerges as the optimal choice: it minimises workload, maximises enjoyment, provides the strongest spatial presence, causes no increase in VR sickness, and is the clear user favourite. Distributed offers greater exploration potential but at the cost of physical effort, navigational uncertainty, and mild discomfort. The trade-off between exploration and comfort is clear, Distributed excites but fatigues, while Centralised comforts but constrains. Center + Marker strikes the balance, providing spatial richness without overwhelming the user. These findings support the use of hybrid layouts that combine centralised content with marker-anchored 3D models as the most effective design for tangible VR applications.

The sample size of 24 participants may limit generalizability of the results and the study measured immediate recall rather than long-term retention, potentially limiting insights into sustained learning outcomes. While two mobile VR headsets were used, a transition occurred: participants 1–5 used a VRG model, which was replaced by a more durable Ollo+ model for participants 6–24 after the for-

mer's padding started peeling. Both devices utilized identical smartphone insertion mechanisms and offered comparable fields of view, maintaining consistency in the immersive experience.

Chapter 7

Conclusion

This dissertation explored how tangible and immersive technologies can bridge the gap between physical archives and digital learning. By developing a Tangible VR Book, this project created a space where physical pages and virtual content coexist, allowing users to interact with 3D models, animations, and narrative audio in a way that feels both natural and discovery-driven. Through the creation of a custom web-based editor and the implementation of marker tracking, this work provided a flexible, accessible framework for presenting complex materials in ways that traditional media cannot match.

The core of this research involved a detailed study of how different spatial layouts influence the user experience. The results clearly pointed to the Center + Marker configuration as the most effective design. By anchoring digital content to the physical book while keeping the focus centralized, this approach strikes a meaningful balance: it provides the spatial depth needed for immersion without overwhelming the user. While the Distributed layout offered exciting opportunities for exploration, it also highlighted a clear trade-off, showing that pushing the limits of the virtual environment can sometimes lead to physical fatigue and unnecessary cognitive strain.

Beyond the numbers, this study revealed a great deal about how people interact with new technology. Participants showed an instinctive desire to touch and gesture with the virtual objects, a finding that points to a bright future for more tactile and intuitive VR designs. Most importantly, the feedback suggests that this technology is not meant to replace traditional education, but rather to enrich it. Whether in museums, classrooms, or libraries, there is a clear appetite for tools that make learning more tactile and engaging. This research offers a foundational roadmap for designers and educators, proving that when we thoughtfully combine the physical and the digital, we can create experiences that are not only technologically sound but also deeply rewarding for the learner.

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Appendices

Appendix A

Submission for ICEC 2026

A.1 The Lloyd's Register Tangible VR Book: A Playful Mixed-Reality Interface for Exploring Maritime Heritage

The Lloyd's Register Tangible VR Book: A Playful Mixed-Reality Interface for Exploring Maritime Heritage

Marcelo F. Coelho¹[0009-0000-7237-6865] and
Jorge C. S. Cardoso²[0000-0002-0196-2821]

¹ University of Coimbra, DEI, Coimbra 3030-290, Portugal

² University of Coimbra, CISUC/LASI, DEI, Coimbra 3030-290, Portugal.
mfcoelho@student.dei.uc.pt, jorgecardoso@dei.uc.pt

Abstract. This paper presents the Lloyd's Register Tangible VR Book, a playful mixed-reality interface that combines a physical book with immersive virtual content to support interactive storytelling. Using a smartphone-based VR setup, users interact with printed pages augmented with markers that trigger spatially distributed digital media, including 3D models, archival images, narration, and 360° environments. The system allows content to be arranged across multiple spatial planes around the user, encouraging exploration and comparison of materials within an immersive setting. We demonstrate the system through the case study of the Fullagar, the world's first fully welded ship. The resulting experience transforms archival materials into an interactive narrative that users can physically navigate and explore. This work shows the potential of low-cost tangible mixed-reality systems for playful, physically grounded exploration of complex content in public and educational settings.

Keywords: Tangible interaction · Virtual reality · Interactive storytelling · User experience

1 Introduction

The Lloyd's Register Foundation Heritage Centre³ is rich with historical and technical insights into ship design, construction, and maritime safety, dating back to the 1760s. Despite their value, these materials are difficult to explore in engaging and interactive ways due to their complexity and format, which are not well-suited for modern educational environments: material consists of static, sometimes difficult to read, digitized records. Research indicates that static presentations of complex documents can lead to disengagement, particularly when these materials require specialized knowledge to understand [5]. This highlights the need for more intuitive, interactive formats to make such resources accessible. Studies show that hands-on, immersive learning environments, such as those incorporating Virtual Reality (VR) or Mixed Reality (MR), significantly improve engagement and retention of complex subjects [3].

³ <https://heritage.lrfoundation.org.uk/>

Based on prior work [4] that outlined a design space for marker-based Tangible User Interfaces (TUIs) for VR, we built a smartphone-based tangible VR book system. A physical book with 2D barcodes is enhanced with digital immersive content using a smartphone VR enclosure. While the book serves as the main interaction method to explore the story contents, the system supports different spatial layouts for the immersive content: anchored on the marker/page; in front of the user; to the sides of the user; around the user as 360° images or video. The system also allows MR mode by using the smartphone's camera.

Using data from Lloyd's Register as a case study, we created the VR Book⁴ with the story of Fullagar - the world's first fully welded ship.

Our contribution is threefold: (1) a tangible mixed-reality book interface for interactive storytelling, (2) a flexible system for spatially placing immersive content around the user, and (3) a replicable, low-cost platform suited for public exhibitions and educational contexts.

The system potentially enables a playful form of exploration, where users actively navigate and build the narrative by physically interacting with the book and spatially distributed virtual content. With this project we aim to understand if content shown in Extended Reality (XR) is seen as engaging and whether it affects learning. We also want to understand the impact of content layout on user experience.

2 The Tangible VR Book System

The system combines a physical book with a smartphone and mobile VR headset (Fig. 1). By scanning a QR Code to load a WebXR mobile application and placing the smartphone on an MR enclosure (Fig. 1b), users get access to an interactive environment through a look-to-trigger interaction mechanism. The experience can include images, audio (including narration), video, static and animated 3D models, and 360° images or video.

Content can be distributed across four spatial interaction planes (Fig. 1c): on the marker, in front of the user, to the left, and to the right. When multiple elements exist on a plane, a navigation bar (Fig. 1e) allows switching between content.

Users can interact with content in multiple ways (Fig. 1d). Documents (images) can be zoomed into for detailed inspection and repositioned within the scene. 3D models support scaling, rotation, and translation, allowing users to examine them from different perspectives. Video content includes standard playback controls (Fig. 1e). These interactions support exploration, potentially leading to higher engagement with the material.

A web-based authoring tool can be used to structure the book's content, defined using a JavaScript Object Notation (JSON) structure, enabling flexible creation of new narratives by associating media files with specific barcode markers and defining the layout of the content.

⁴ Demonstration video available at: <https://vrlab.dei.uc.pt/lrvrbook/>



Fig. 1: Lloyd's Register Tangible VR Book

2.1 Lloyd's Register Tangible VR Book

We instantiated a tangible VR book with Lloyd's Register material to present the story of "Fullagar". Users learn about Fullagar (1920–1937) story through the following timeline: 1920 launched as first welded ship → 1924 sandbank accident → 1924–1925 renamed *Caria*, sold to Vancouver, later renamed *Shean* → 1930 rock cliff accident → 1935 renamed *Cedros*, sold to Mexico → 1937 collision off Ensenada: total loss.

The book has 42 pages of content and 10 barcode markers. Content was mostly taken from Lloyd's Register archive images. A few 3D models were created and animated manually in Blender. An approximate 3D model of Fullagar was created with an image-to-model Artificial Intelligence (AI). Narration was generated via Text-to-Speech (TTS) AI.

4 Coelho, M. F. and Cardoso J. C. S.

3 Lessons Learned

Although no formal user studies have yet been conducted, the system's development and public demonstration yielded several practical insights that have been incorporated into the final design.

Robustness vs. aesthetics. We initially used MindAR image tracking library[1] which allows for natural image tracking. Although this allowed for more a visually pleasing physical book where images directly related to the content could be used for page identification and tracking, it proved unreliable under variable lighting during a public deployment. We thus switched to AR.js barcode markers[2]. This improved robustness at the cost of visual aesthetics of the pages.

Reproducibility of the physical artifact. The book evolved from an A5 format with 3D-printed components to a simpler spiral-bound design with standard printed pages, reducing production complexity and improving replicability.

Preloading over dynamic updates. Dynamic loading of 3D content introduced latency. Pre-generating the full A-Frame scene and toggling visibility improved responsiveness and simplified state management. Although with a higher initial loading time, this improves the user experience during the actual use of the VR Book.

Explicit vs. implicit interaction. For large images, an initial gaze-based edge scrolling caused unintended activations due to overlap with other elements. Replacing it with explicit on-screen buttons improved interaction reliability at the cost of naturalness.

4 Conclusion

This paper presented a tangible VR system that combines a physical book with an immersive virtual environment. The current implementation demonstrates a flexible approach for linking physical artifacts with spatially organized VR content. The system is intended as a platform for interactive storytelling and educational exploration, and future work will focus on evaluating interaction layouts and expanding the content creation tools. Future user studies will compare different content distributions, including four-sided spatial layouts versus simplified centered layouts, in order to evaluate usability, engagement, and learning effectiveness.

Acknowledgments. This work was supported by Lloyd's Register Foundation under grant Sg10/100005, "Tangible VR Book: Immersive Exploration of Lloyd's Register Ship Plans." This work is further funded by national funds through FCT – Foundation for Science and Technology, I.P., within the scope of the research unit UID/00326 - Centre for Informatics and Systems of the University of Coimbra, <https://doi.org/10.54499/UID/00326/2025>.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

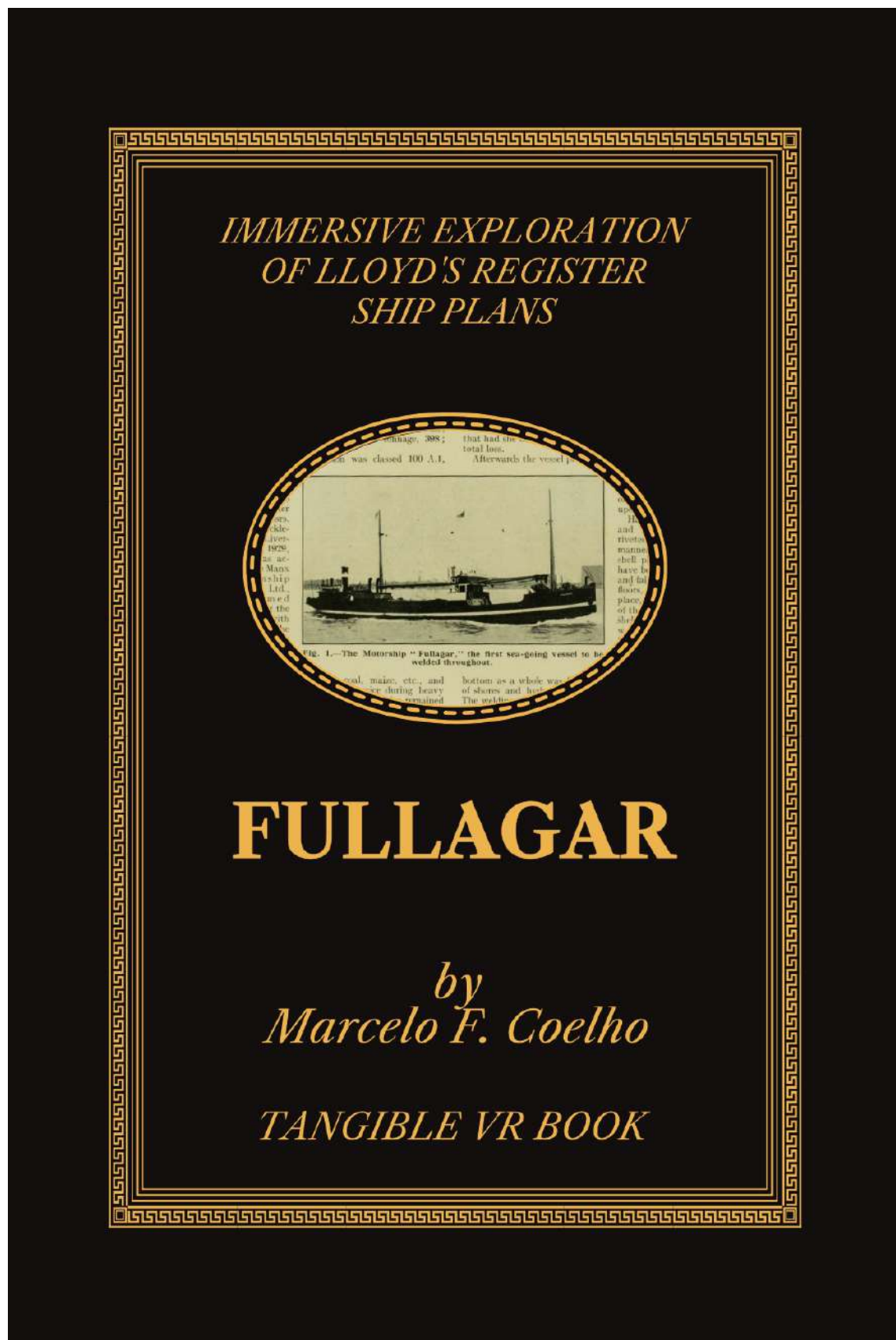
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Appendix B

Lloyd's Tangible VR Book

B.1 Fullagar: The World's First Fully Welded Ship



FULLAGAR

by

Marcelo F. Coelho

Master of Design and Multimedia, Candidate
University of Coimbra, 2026

Tangible VR Book

Immersive Exploration of Lloyd's Register Ship Plans

Thesis supervisors

Jorge C. S. Cardoso, PhD

Paul David Hardman, PhD



FACULDADE DE
CIÊNCIAS E TECNOLOGIA
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dei departamento
de engenharia
informática



FULLAGAR

INSTRUCTIONS

Visit the URL noted below using your smartphone and enter "VR" mode. Then, place the smartphone in a compatible mobile headset¹.

URL:

When looking at a marker² through the headset, you should see and/or hear augmented reality content.

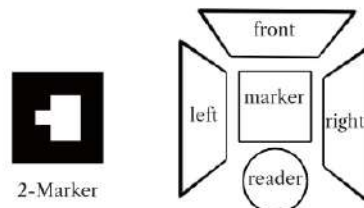
Content can be displayed in 4 places: on the marker, to your left, front, or right³.

You can interact with some images, videos and 3D models by aiming the red cursor at the button you wish to activate⁴.

Some elements might have small thumbnail images above; aim with the red cursor to make them larger.

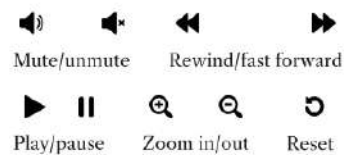


1-Smartphone in mobile headset looking at the book



2-Marker

3-Content position



Mute/unmute

Rewind/fast forward

Play/pause

Zoom in/out

Reset

Up/down/left/right

4-Controls

FULLAGAR

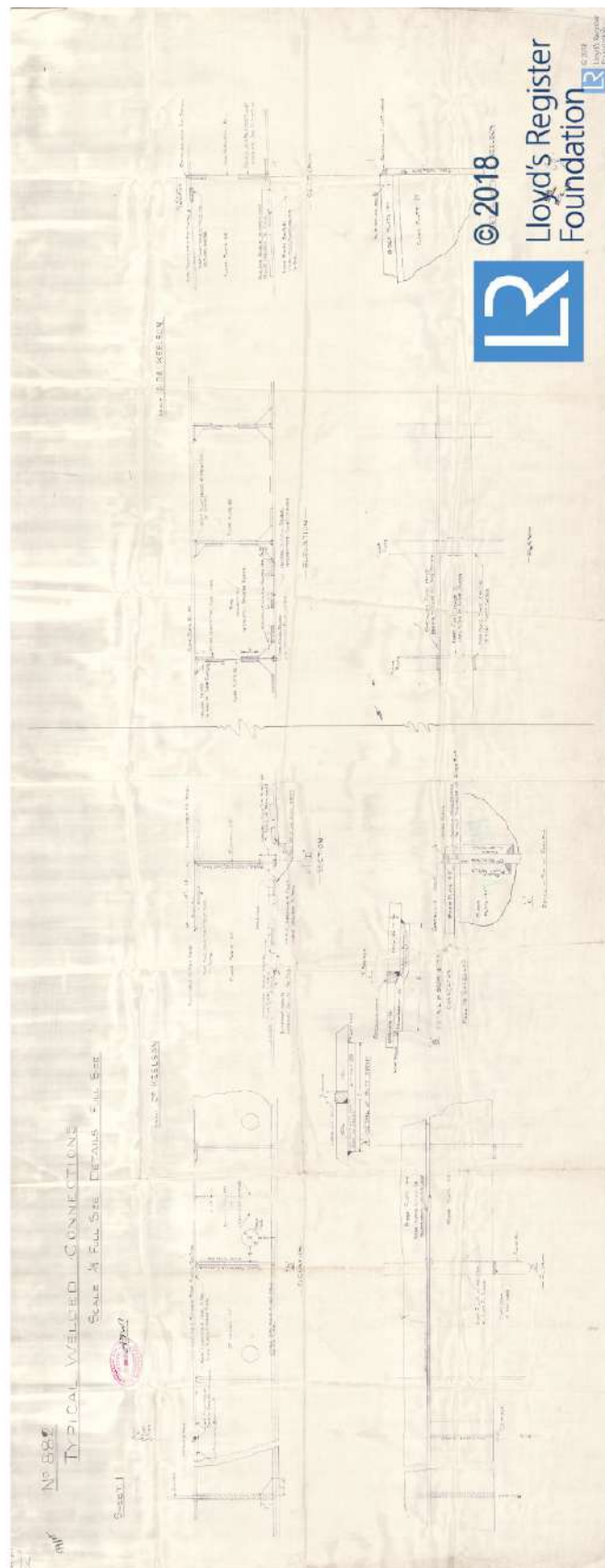
INTRODUCTION

THIS book accompanies the master's thesis *Tangible VR Book: Immersive Exploration of Lloyd's Register Ship Plans* and the associated research project, funded by the *Lloyd's Register Foundation*, aligned with their mission to promote maritime safety education.

The developed tangible VR book framework results in a physical book augmented with digital elements, displayed via a smartphone by scanning the barcodes present in the pages. Readers can thus explore additional multimedia content in augmented reality, enhancing the traditional reading experience.

This particular case focuses on the story of *Fullagar*, the world's first fully welded ship.

The documents and plans in this book are sourced from the *Lloyd's Register Foundation Heritage Education Centre* archive.



1-Welding plans

WORLD'S FIRST FULLY WELDED SHIP



2- Color depiction of Fullagar



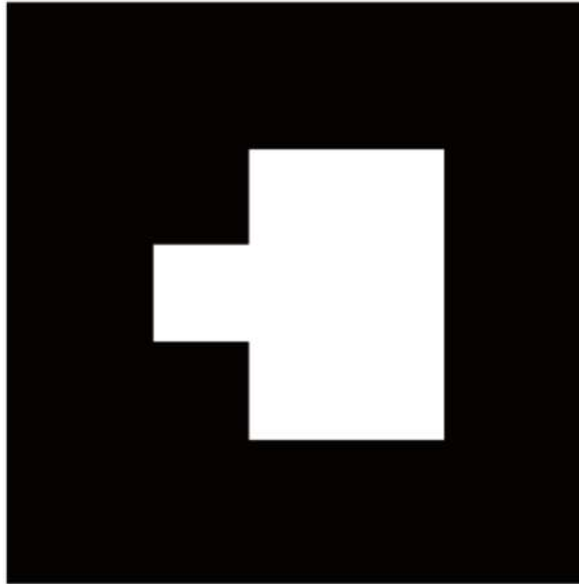
3- 1920 photo of Fullagar

FULLAGAR



4- Approximate 3D model of Fullagar, manipulable in VR

WORLD'S FIRST FULLY WELDED SHIP



Hello! Today we are going to learn about the Fullagar, a special ship in the history of shipbuilding. It was the first ship built entirely using welding, instead of rivets.

It was launched in 1920 and was used to transport goods between Liverpool and Cardiff, in England. At first glance, it looked like just another cargo ship of its time. However, it was an experimental project, created to test a new construction method that did away with traditional metal rivets.

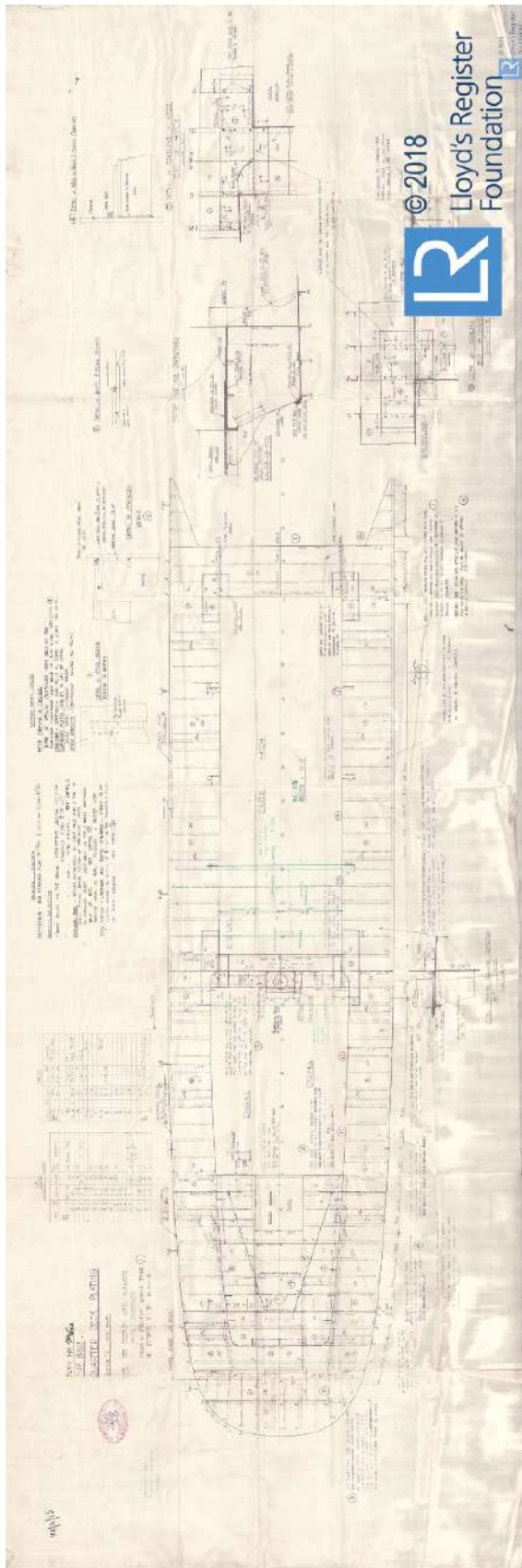
Because it was such a novelty at the time, the ship was subject to strict annual inspections. There were doubts about whether welding would be strong and safe enough to withstand the de-

mands of the sea.

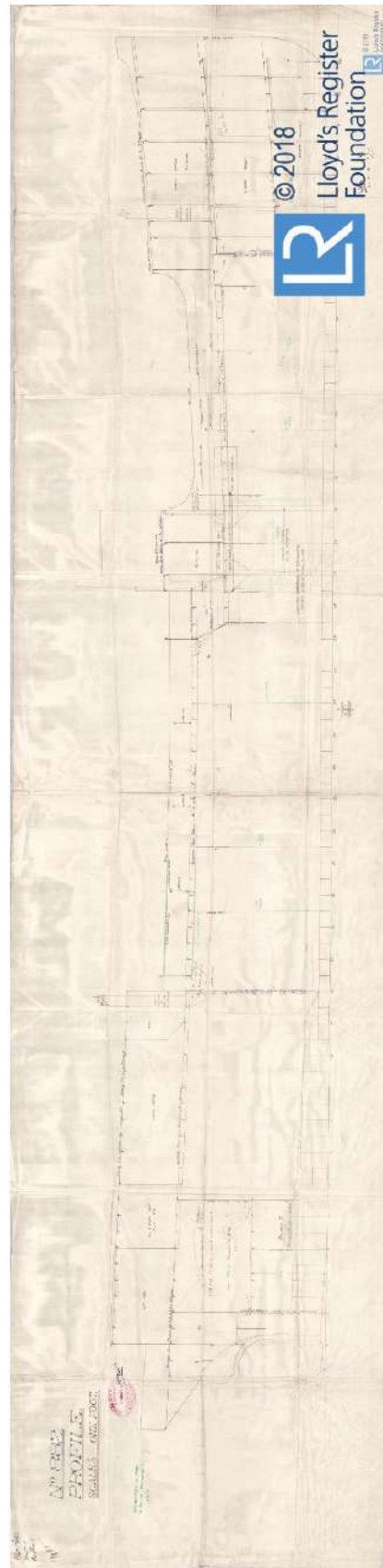
Thanks to the archives of Lloyd's Register, the organization responsible for registering and inspecting ships, we now have access to technical drawings, reports, and correspondence related to the Fullagar.

In front of you, you can see one of the technical drawings of the welded iron plates that formed the ship's structure¹. These drawings show how the plates were joined and reinforced. Here, you can also see a 3D representation of the Fullagar⁴, which helps us imagine what this ship looked like as it sailed between Liverpool and Cardiff.

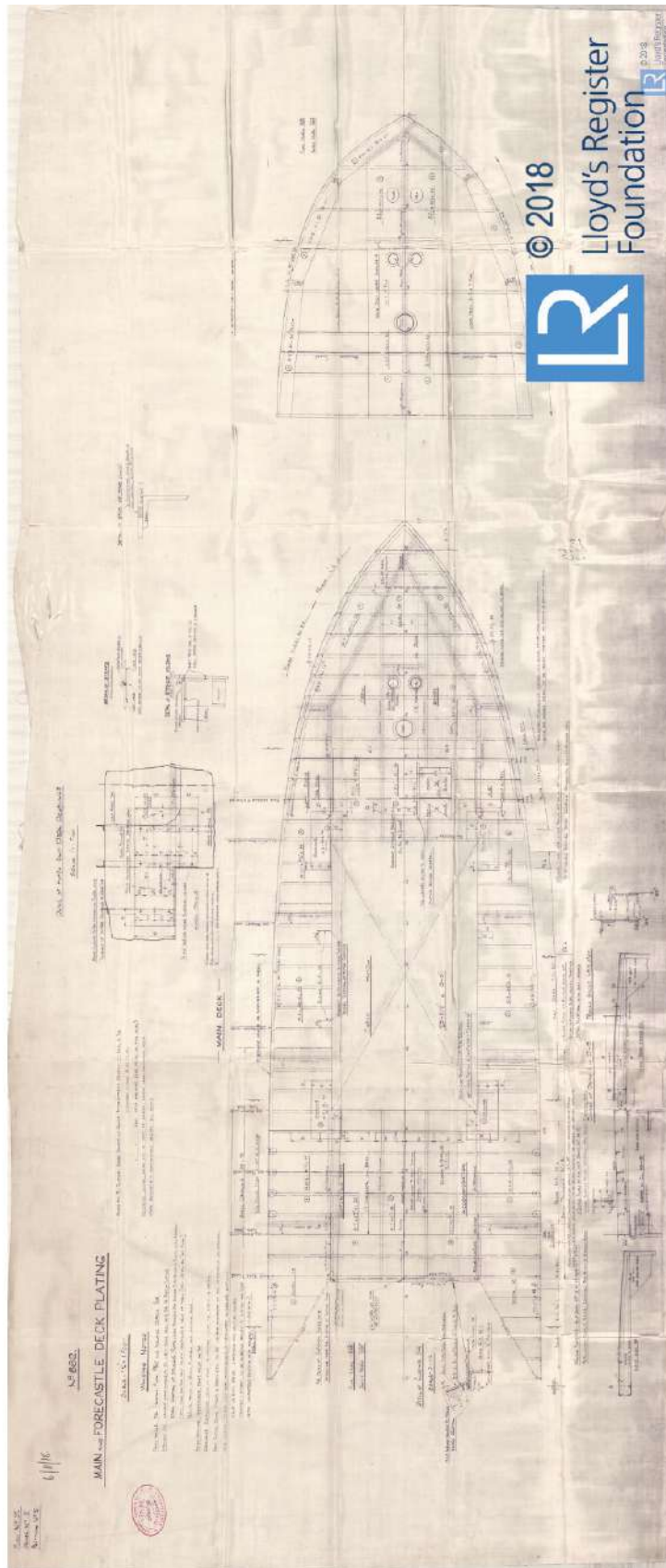
Let's explore the history of this ship.



5- Rear deck plans

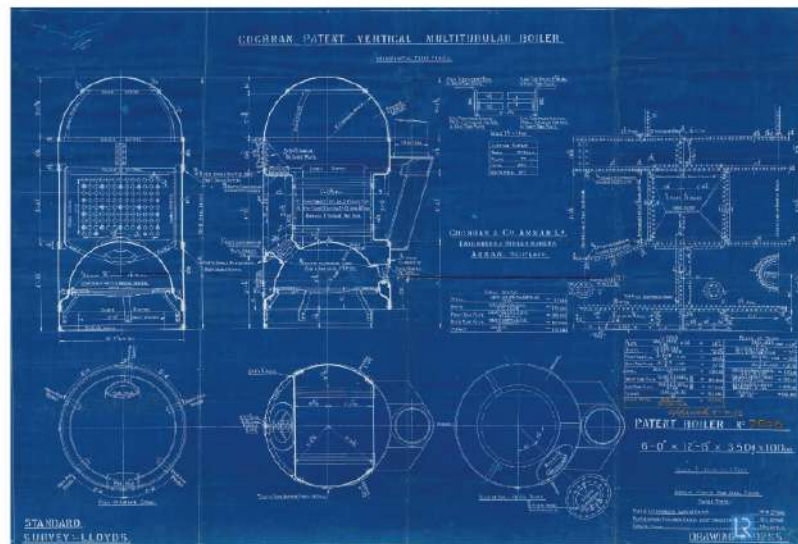


6- Side profile plans



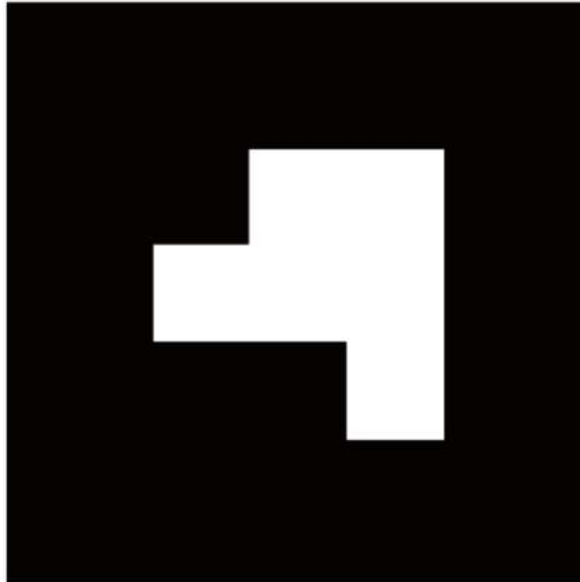
7- Front deck plans

FULLAGAR



8- Boiler plans

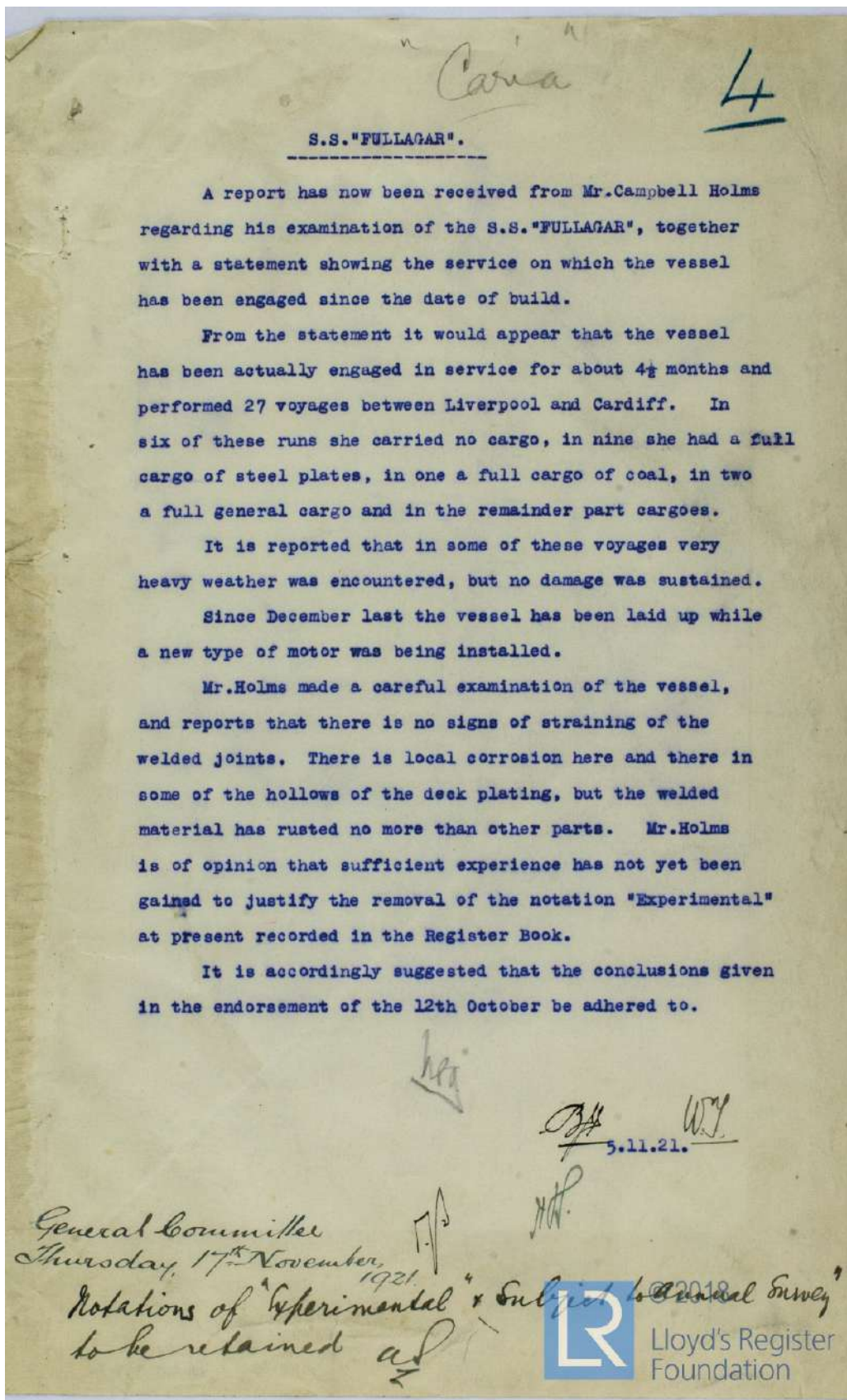
SHIPBUILDING PLANS



On this page, you can see more technical drawings of the Fullagar, like a boiler diagram⁸, showing how steam was produced to power steam-driven equipment. You can also see the ship's profile drawing⁶, where you can observe its shape, and a plan detailing the location of the engine, as well as other important areas on board⁷.

All these drawings contain very inte-

resting details. You can zoom in on the images to read the text more carefully and closely observe these shipbuilding documents, created between 1918 and 1919. These records help us better understand how the Fullagar was designed, structured, and built.



9- 1921 letter about report of the first 4 months of service of the ship

EARLY LIFE



ONE OF THE COMPANY'S FLEET OF STEAMERS LOADING IRON AND STEEL PRODUCTS
AT THE STEEL WORKS WHARF.

10- Photo of same era ship, being loaded with metal products



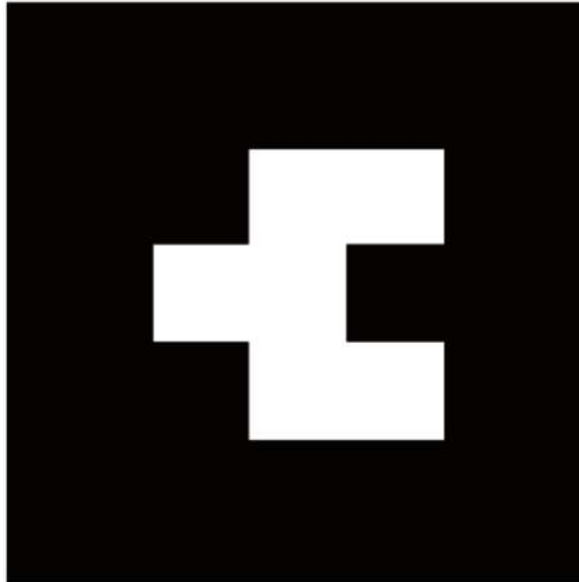
11- Photo of same era ship, loaded with cargo of coal, or similar

FULLAGAR



12- Animated 3D model, viewable in VR

EARLY LIFE



In the records of Lloyd's Register, a 1921 memorandum, about a report by Mr. Campbell Holmes⁹, states:

"A report has now been received from Mr. Campbell Holmes, regarding his examination of the S.S. 'FULLA-GAR', together with a statement showing the service on which the vessel has been engaged since the date of build. From the statement it would appear that the vessel has been actually engaged in service for about 4 months and performed 27 voyages between Liverpool and Cardiff. In six of these runs she carried no cargo, in nine she had a full cargo of steel plates, in one a full cargo of coal, in two a full general cargo and in the remainder part cargoes. It is reported that in some of these voyages very he-

avy weather was encountered, but no damage was sustained.

Since December last the vessel has been laid up while a new type of motor was being installed. Mr. Holmes made a careful examination of the vessel, and reports that there is no signs of straining of the welded joints. There is local corrosion here and there in some of the hollows of the deck plating, but the welded material has rusted no more than other parts. Mr. Holmes is of opinion that sufficient experience has not yet been gained to justify the removal of the notation 'Experimental' at present recorded in the Register Book. It is accordingly suggested that the conclusions given in the endorsement of the 12th October be adhered to."

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FIRST ACCIDENT & RENAME



14- 1920 photo of the Liverpool docks



15- 1920 photo of the Liverpool docks

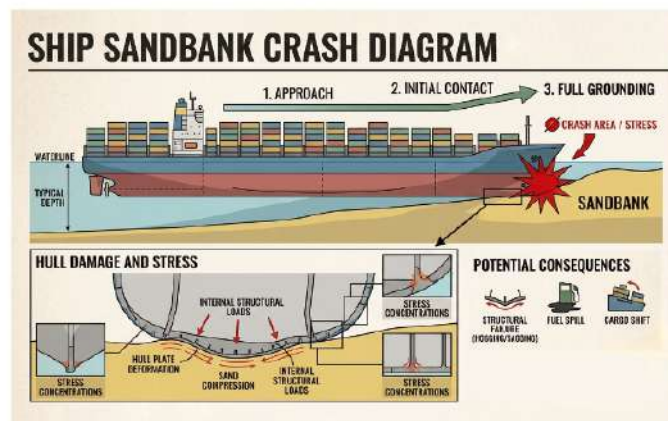
FULLAGAR

In June, 1924, a serious accident occurred to the vessel which has in a striking manner proved the superiority of a ship welded with "Quasi-Arc" electrodes over a riveted ship.

The vessel went aground on a sand bank in the Mersey during a voyage from Liverpool to Belfast, when fully laden. She floated off on the next tide and as she was perfectly watertight proceeded on her voyage and discharged her cargo at Belfast. It was then found that she was damaged to a considerable extent, but as the shell was watertight it was decided to take her back to Liverpool under her own power. When docked the vessel was thoroughly examined and by using sights the bottom was found to be set up 11 in. from bilge to bilge over a length of roughly 70 ft. and from the evidence of inside structural work she had been set up more but had settled when placed on the blocks.

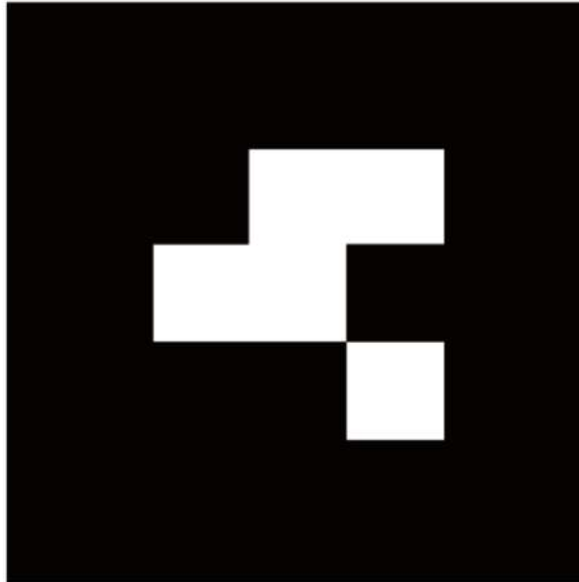
"A Remarkable Test."

16- Clippings confirming 1924 accident



17- Diagram representing a ship sandbank crash

FIRST ACCIDENT & RENAME



But in 1924 something unexpected happened: the Fullagar suffered an accident, clippings¹⁶ state:

"In June, 1924, a serious accident occurred to the vessel which has in a striking manner proved the superiority of a ship welded with "Quasi-Arc" electrodes over a riveted ship.

The vessel went aground on a sand bank in the Mersey during a voyage from Liverpool to Belfast, when fully laden. She floated off on the next tide and as she was perfectly watertight proceeded on her voyage and discharged her cargo at Belfast. It was then found that she was damaged to a considerable extent, but as the shell was watertight it was decided to take her back to Liverpool under her own power. When docked the vessel was thoroughly examined and by using

sights the bottom was found to be set up 11 in. from bilge to bilge over a length of roughly 70 ft. and from the evidence of inside structural work she had been set up more but had settled when placed on the blocks.

"A Remarkable Test."

According to correspondence from Lloyd's Register, the ship was renamed "Caria" and put up for sale. The document¹³ states:

"Dear Sir, I have the honor to return herewith report of survey as below, recently forwarded to us for guidance in the survey of the vessel.

Vessel: Caria. ex Fullagar. Vessel laid up for sale in damaged condition."

Soon, the ship would be about to begin a long journey to its next owners.



HLOYD'S REGISTER
 Recd. 3 DEC. 1924
 And
 LONDON

Maritime Buildings, East Dock Street,

Dundee, 2nd December, 1924.

The Secretary,
London.

I have to inform you that the Freeboard Marking on the oil engine vessel "GARIA", have been verified and found in accordance with the Freeboard Certificates issued when the vessel was named "FULLIGAR".

The vessel is now Under survey for damage and S.S.No.1 and on completion it is understood will be purchased by Messrs The British Columbia Cement Co. Ltd., but that the name of the vessel and Port of Registry are to remain unaltered.

New Certificates have been requested and I shall be obliged if you will kindly let me know if any fee is to be charged for these.

The original certificates are enclosed.

I am, Dear Sir,

Yours faithfully,

© 2018

Lloyd's Register
Foundation

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COPY.

21st November, 1924.

Dear Webster,

I am in receipt of your letter of yesterday's date regarding the case of the S.S. "CARIA" ex "FULLAGAR". As this vessel is not classed for any restricted trading, I see no reason why she should not make the trip to Vancouver.

As Sir Westcott and our old friend Thomson have been interested in this particular case, I referred the matter to them and they also see no reason why the vessel should not be permitted to make the trip. Sir Westcott suggests, however, that in forwarding your report on the case you should state the fact that the vessel is going to Vancouver.

As the present freeboard certificate was issued in the name of "FULLAGAR", it will be necessary for you to verify the freeboards and forward the usual verification of marking form, in order that certificates in the new name of the vessel may be issued.

With kind regards,

Yours faithfully,

Geo. Webster, Esq., D.Sc.,

G L A S G O W.



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Foundation

19- 1924 letter indicating the vessel should be able to make the trip to Vancouver

FULLAGAR



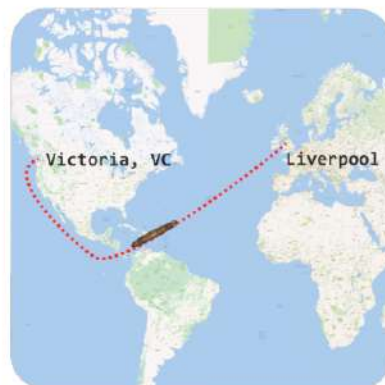
(British Columbia Cement Company)

20- Old photo of The British Columbia Cement Co.



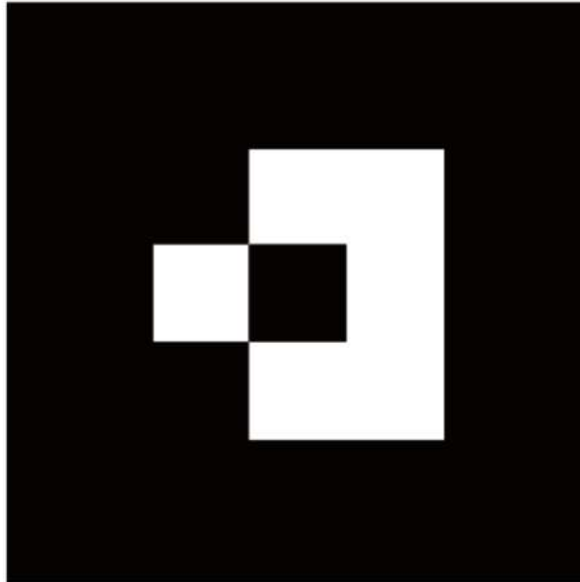
(British Columbia Cement Company Sign)

21- Photo of a sign from the cement company



22- Animated 3D model, viewable in VR

VOYAGE TO CANADA



In 1924, the same year as its first accident, the Fullagar would be sold to a cement company in Vancouver, Canada. A Lloyd's Register letter¹⁹ confirms:

"...As this vessel is not classed for any restricted trading, I see no reason why she should not make the trip to Vancouver."

However, before making this long journey, the ship had to be inspected and pass the freeboard test. Freeboard is a technical term, and we will discover its meaning later.

This Lloyd's Register letter regarding the inspection¹⁸ is a vital instrument for ship safety and registration and states:

"Dear Sir, I have to inform you that the freeboard marking of the oil engi-

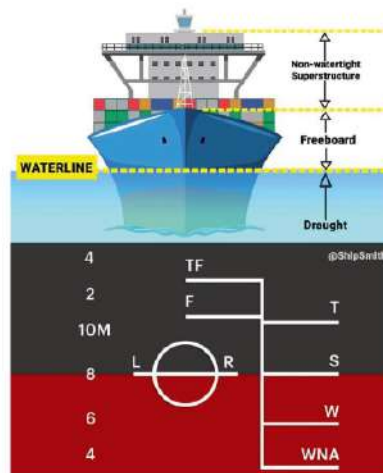
ne vessel "CARLA" has been verified and found in accordance with the Freeboard Certificates issued when the vessel was named FULLAGAR.

The vessel is now under survey for damage, and on completion it is understood will be purchased by The British Columbia Cement Co., but that the name of the vessel and port of registry are to remain unaltered.

New certificates have been requested, and I shall be obliged if you will kindly let me know if any fee is to be charged for these. The original certificates are enclosed."

This confirms the ship would be purchased by a Canadian cement company, likely making the long voyage via the Panama Canal.

FULLAGAR



23- Freeboard and plimsoll line diagram

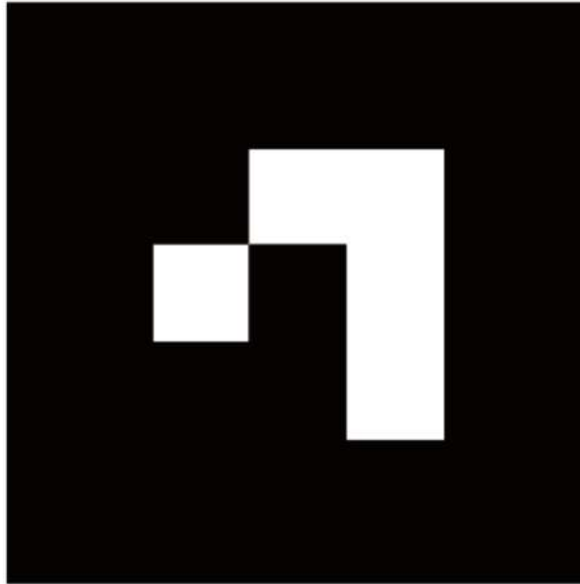


24- Animated 3D model, viewable in VR



25- Video about freeboard and the plimsoll line, viewable in VR

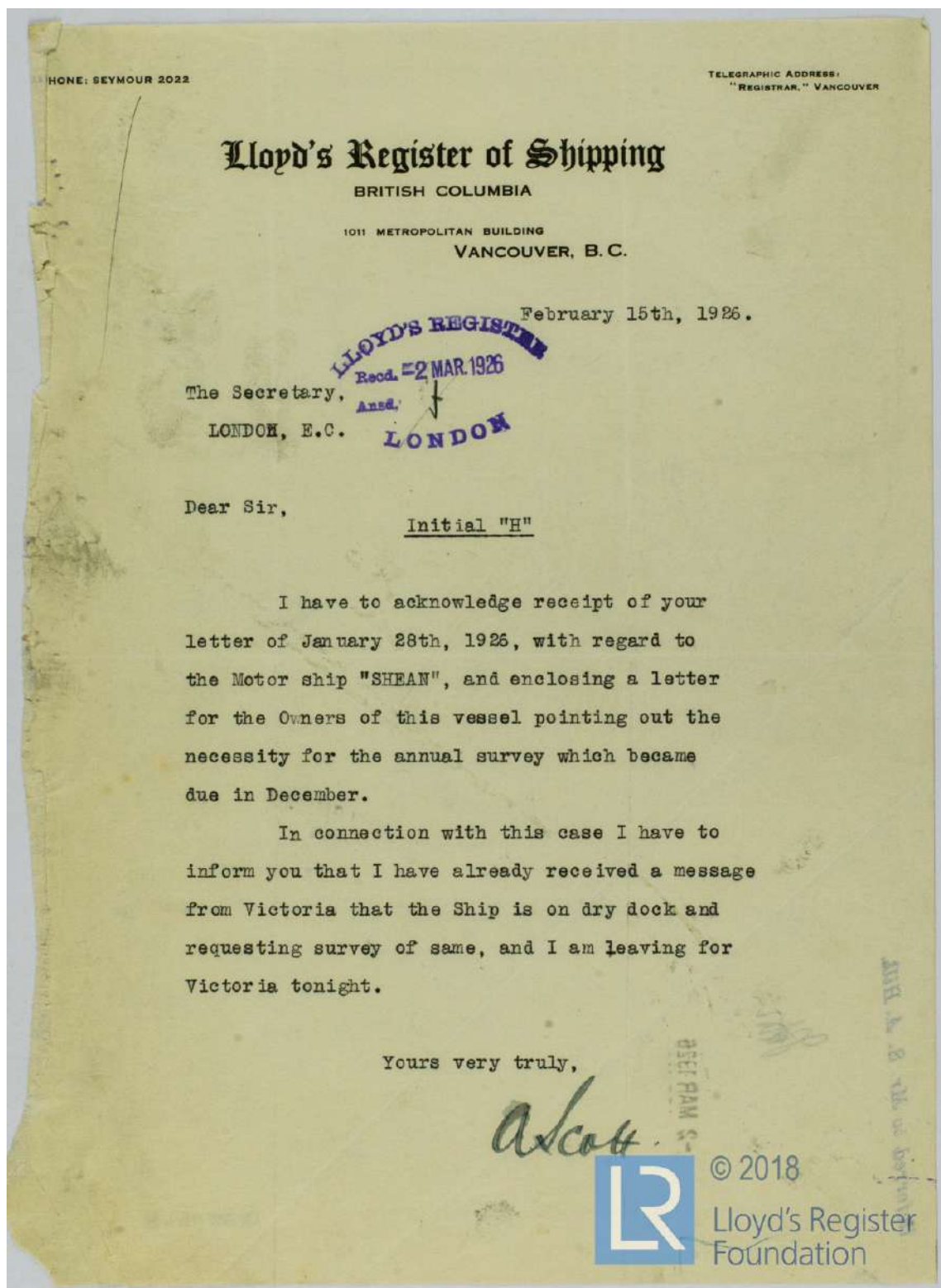
FREEBOARD AND PLIMSOLL LINE



Freeboard is the vertical distance between the waterline and the deck level on a ship, used to ensure buoyancy margin and stability.

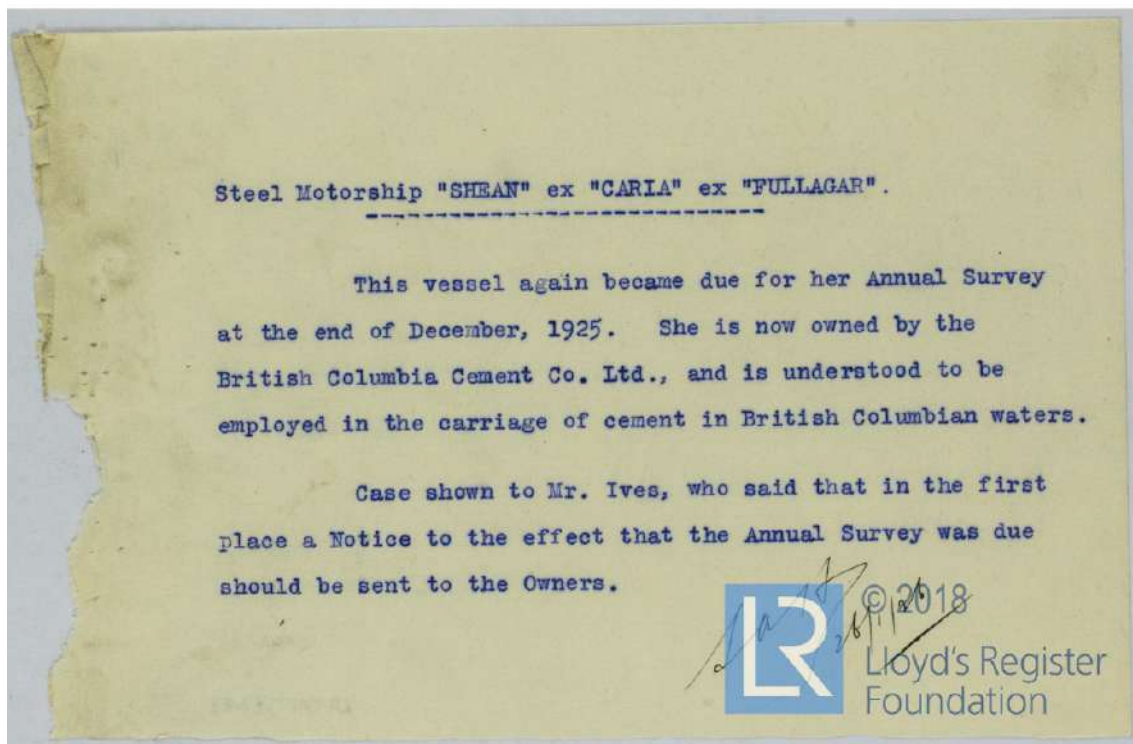
The Fullagar was sold to the British Columbia Cement Company in Van-

couver and was to make the journey from the United Kingdom to Canada. It therefore had to be tested to calculate freeboard and stability for the entire voyage, including crossing the Panama Canal and the Atlantic.



26- 1926 document indicating the inspector is traveling to Victoria to inspect the ship

NEW OWNER INSPECTION & RENAME



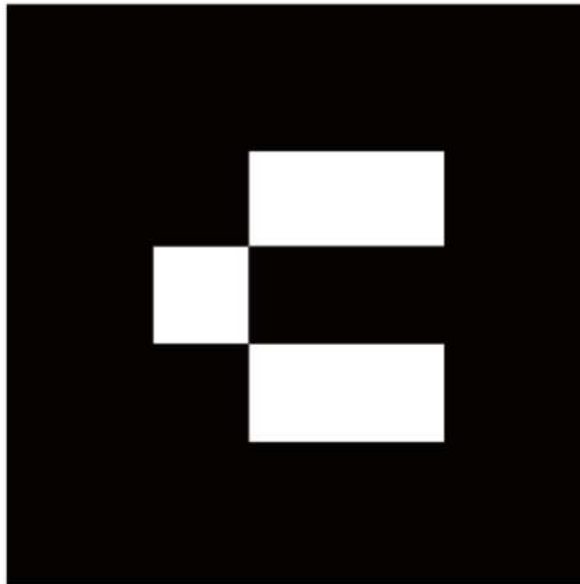
27- Memorandum confirming new ownership of the vessel, now "Shean", and due annual survey

FULLAGAR



28- 1930 photo of another ship on dry dock, in Victoria, British Columbia

NEW OWNER INSPECTION & RENAME



Meanwhile, the new owners had renamed the ship "Shean". From 1925, there is a memorandum reminding the ship's new owners in Canada that the Fullagar must undergo its annual inspection. This memorandum²⁷ states:

"Steel motor vessel Shean, ex Caria, ex Fullagar. This vessel again became due for her annual survey at the end of December 1925..."

A letter from A. Scott of Lloyd's Register confirms that in February 1926, he was about to travel to Victoria, Canada, to carry out the ship's inspection²⁶:

"...I have to inform you that I have already received a message from Victoria that the ship is on dry dock and requesting survey of same, and I am leaving for Victoria tonight."

And so the ship's new owners had the inspection carried out and were able to use it for several years before another unforeseen event occurred which, as we will see, was very bad in one way but good in another.

WELDED JOINTS IN SHIP CONSTRUCTION.

THE "FULLAGAR" AFTER ELEVEN YEARS' SERVICE.

THE first sea-going vessel welded throughout was the motor vessel *Fullagar*, and as she has now been in service for eleven years, her behaviour during that period should be of the utmost importance to ship-builders and the classification societies. The vessel has justified the confidence of those who fostered the welded construction and helped by tests and various experiments to convince the builders, Messrs. Cammell, Laird & Co., Ltd., and Lloyd's Register of Shipping, to whose classification the vessel was built, that the vessel would be successful.

The motor vessel *Fullagar*, since re-named *Caria*, and later *Shean*, was built by Messrs. Cammell, Laird & Co., Ltd., Birkenhead, and was launched in February, 1920. The vessel was constructed throughout by electric welding in place of riveting, and the Quasi-Arc Company's methods and electrodes were used exclusively. Her dimensions are as follows:—Length between perpendiculars, 150 ft.; breadth moulded, 23 ft. 9 in.; depth moulded, 11 ft. 6 in.; depth to quarter deck, 15 ft. 6 in.; hold capacity, 26,000 cub. ft.; gross tonnage, 398; and speed, ten knots.

The *Fullagar* on completion was classed 100 A.1, electrically welded, subject to annual survey, experimental, and went into the service of her owners, Messrs. T. & J. Brocklebank, Ltd., Liverpool, in July, 1929, and later, was acquired by the Manx Isles Steamship Company, Ltd., and re-named *Caria*. During the vessel's career with these companies she passed through very strenuous services in the coastal trade, carrying various cargoes such as steel plates, coal, maize, etc., and has on several occasions been in service during heavy weather, whilst other vessels of the same size remained in port.

Effect of Grounding on Welded Joints.

The vessel has been aground through stress of circumstances several times, and on each examination later in dry dock the keel and bottom plating were found to have withstood the excessive strain of grounding without any ill effects to the welded joints, and on no occasion was there any leakage through the shell.

The forward length of bilge keel on the starboard side had been carried away and the welded angle lugs attaching the bilge keel to the shell were bent. Efforts were made to dislodge these lugs from the shell by hammering, the result being that the heel of the lug itself fractured without disturbing the welding. A collision caused serious indentation to the shell plating abreast the after cargo and also in way of the engine room on the starboard side. Here again the welded joints remained intact, whereas a riveted ship in similar circumstances would have had the rivets "started" and an immediate repair would have become necessary.

The vessel had been surveyed annually and her class 100 A.1 maintained, the ship being in a sound condition, in spite of the very strenuous services and rough usage she had experienced.

In June, 1924, a serious accident occurred to the vessel which has in a striking manner proved the superiority of a ship welded with "Quasi-Arc" electrodes over a riveted ship.

The vessel went aground on a sand bank in the Mersey during a voyage from Liverpool to Belfast, when fully laden. She floated off on the next tide and as she was perfectly watertight proceeded on her voyage and discharged her cargo at Belfast. It was then found that she was damaged to a considerable extent, but as the shell was watertight it was decided to take her back to Liverpool under her own power. When docked the vessel was thoroughly examined and by using sights the bottom was found to be set up 11 in. from bilge to bilge over a length of roughly 70 ft. and from the evidence of inside structural work she had been set up more but had settled when placed on the blocks.

"A Remarkable Test."

Whilst in dock in this condition the vessel was thoroughly examined by Lloyd's surveyors, representatives of the underwriters and owners, also Admiralty officials who were greatly interested, and the opinion was expressed that not only had the welding stood a remarkable test, but, which is of greater importance, that had she been a riveted ship she would have been a total loss.

Afterwards the vessel proceeded under her own power to Leith where an official survey was held and the scheme of repair decided upon.

Had the plating and framing been riveted in the usual manner, the unfair shell plating would have been removed and faired, and the floors, etc. faired in place, but in view of the fact that the shell plating was welded with "Quasi-Arc" electrodes and perfectly sound, none had to be removed and the

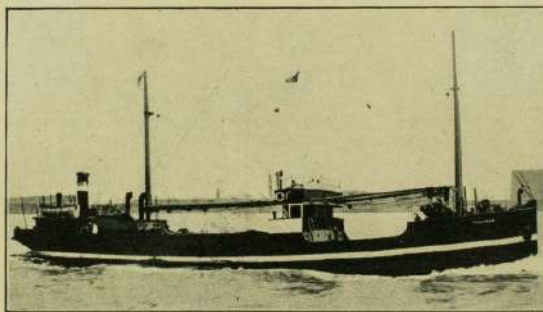


Fig. 1.—The Motorship "Fullagar," the first sea-going vessel to be welded throughout.

bottom as a whole was forced back into line by means of shores and hydraulic jacks from the deck beams. The welding throughout was then examined and found to be quite sound.

As was to be expected, the setting up of the bottom to such an extent, 11 in., and over such a large area, 1,500 sq. ft., caused considerable disturbance to the frames, floors, keelson, etc. These, however, have been partly set back and partly renewed, and made sound and seaworthy; in regard to the keelson, this has been deepened for a considerable portion of its length by the addition of two 8 in. by 3½ in. bulb angles placed back to back on top of the rider plates.

In forcing back the excessive deformation of the plates into their original position, the welds have withstood the reversal of the abnormal stresses equally with the solid plate, which is all one could wish to claim for any form of joint.

Classification Maintained.

Notwithstanding the drastic experience to which the ship had been subjected, it is very interesting to note that the vessel's classification standing at Lloyd's Register Book as "100 A.1, electrically welded, subject to annual survey, Experimental," has been retained without qualification.

A further important point to note is that this vessel, originally designed as a coaster, after passing through all her vicissitudes, is still in such a satisfactory and seaworthy condition that permission was given for her voyage across the Atlantic and through the Panama Canal to the North Pacific Coast, where she has since

been employed in the cement carrying trade, the new owners being the British Columbia Cement Company of Victoria, British Columbia, who have re-named the vessel *Shean*. The owners stated that on October 24, 1930, the *Shean* met with an accident, and the following particulars of the occurrence were given.

The *Shean* struck a rock cliff in the Saanich Inlet, near Victoria, when going at full speed, and had 10,000 bags of cement on board. The photographs show the extent of the damage, and on examination, it was found that in no case did the plates tear apart at the welds, but above and below in the solid plate. Lloyd's and the underwriter's surveyors have stated that the relatively slight amount of damage was a remarkable tribute to the welded vessel.

Had the vessel been riveted, the damage would have no doubt extended beyond the fore peak bulkhead and caused flooding of the cargo space, in which case the cargo would have been irretrievably ruined, whereas less than 400 sacks were damaged, also the vessel would have probably sunk, as she had about 16 ft. of water under her amidships and further aft. The vessel has since been repaired in strict accordance with her class, has passed her tenth annual survey satisfactorily, and is in good condition.

The above is the second occasion on which this vessel has sustained damage which would have resulted in a riveted vessel becoming a total loss.

After more than eleven years' prolonged exposure of the welds to corrosive action of sea water, it is impossible to trace undue corrosion of metal in any part of the structure, which is so satisfactory that Lloyd's have agreed to a Biennial Survey.

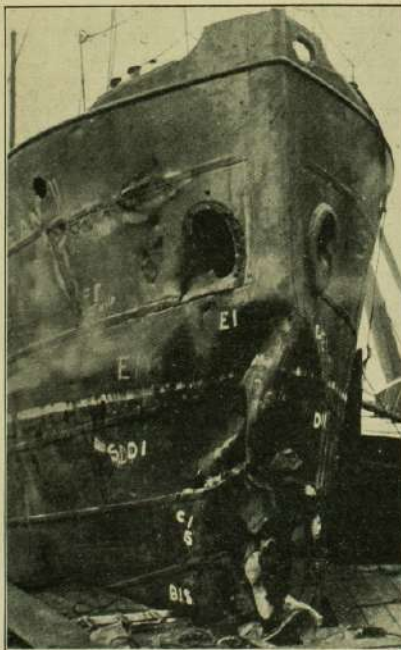


Fig. 2. — Renamed "Carla" and "Shean," the "Fullagar" met with an accident in the Saanich Inlet, near Victoria. At the time she had 10,000 bags of cement on board and was travelling at full speed.

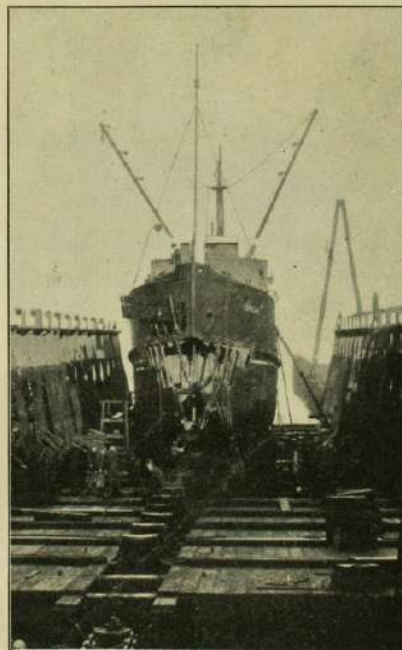


Fig. 3. — Both this illustration and Fig. 2 show the extent of the damage she sustained. Upon examination it was found that in no case did her plates tear apart at the welds, but above and below in the solid plate.

30-1931 article on "The Shipping World" about Fullagar, detailing the 1930 accident



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FULLAGAR



31- Close up photo of Fullagar's metal plate damage after the 1930 crash



32- AI representation of 10000 bags of cement



33- Animated 3D model,
viewable in VR

SECOND ACCIDENT



A 1931 article³⁰ in *The Shipping World* titled "Welded Joints in Ship Construction", mainly dedicated to the Fullagar, states the Fullagar suffered a serious accident but managed to withstand it because welded joints were stronger than traditional construction:

"...the new owners..." "...who have renamed the vessel Shean stated that on October 24 1930..." "...struck a rock cliff in the Saanich Inlet, near Victoria, when going at full speed, and had 10,000 bags of cement on board. The photographs show the extent of the damage, and on examination it was found that in no case did the plates tear apart at the welds..."

The results were quite unexpected:

"Had the vessel been riveted, the damage would have no doubt extended beyond the fore peak bulkhead and

caused flooding of the cargo space, in which case the cargo would have been irretrievably ruined, whereas less than 400 sacks were damaged, also the vessel would have probably sunk, as she had about 16 ft. of water under her amidships and further aft. The vessel has since been repaired in strict accordance with her class, has passed her tenth annual survey satisfactorily, and is in good condition.

The above is the second occasion on which this vessel has sustained damage which would have resulted in a riveted vessel becoming a total loss."

After surviving this accident, in which the iron plates broke but not the welds, Lloyd's Register agreed to allow the ship to be inspected every two years instead of annually. The ship would soon be re-named again and sold.

Provisional

Lloyd's Register of Shipping.

SURVEYS FOR FREEBOARD.

Index No. *28764*
(For London Office only.)

Computation of Freeboard for Steamer, *having a raised quarter deck, bridge and fore-castle*

Port of Survey

Date of Survey *6.8.33*

Name of Surveyor

Ship's Name *Shean*

Nationality and Port of Official Number *143649*

Gross Tonnage *1920*

Date of Build

Particulars of Classification *100 A1 experimental*

Dimensions: Length *150.0* Breadth *23.75* Depth *11.50*

Displacement at moulded draught = 85 per cent. of moulded depth

Depth for Freeboard (D) *11.50*

Depth correction

Round of Beam correction

DEDUCTION FOR SUPERSTRUCTURES.

SHEER CORRECTION.

on for Tropical Freeboard.

on for Winter and Winter North Atlantic Freeboard.

Depth to Freeboard Deck = *15.53*

Summer freeboard = *4.17*

Moulded draught (d) = *11.36*

on for Tropical freeboard and addition for

for Winter North Atlantic Freeboard (#)

SUMMER FREEBOARD amidships from Centre of Disc to top of Deck Line, *Raised Quarter*, Steel Deck:-

Tropical Fresh Water Line above Centre of Disc ... *2 3/4*

Fresh Water Line ... *2 3/4*

Tropical Line ... *4 1/2*

Winter Line below ... *2 3/4*

Winter North Atlantic Line ... *4 3/4*

Tropical Fresh Water Freeboard ... *3 11/4*

Fresh Water ... *3 11/4*

Tropical ... *4 1/2*

Winter ... *4 1/2*

Winter North Atlantic ... *4 3/4*

34-1935 Survey for freeboard

Superstructure bulkheads, trunks, deckhouses, casings, cargo and coaling hatchways, extent and thickness of sheathing on the freeboard deck, gangway, cargo, coaling ports, and any other openings, etc., which would affect the seaworthiness of the ship are to be shown on the following sketches:—

State any special features in the construction of the ship:—

$$\begin{array}{r} \text{Fee} \\ \text{Recn} \end{array} \frac{5.38 \times 12.5}{21.2} = \frac{25.90}{22.73} = 3.17 \text{ equivalent tonnage.}$$

Builder's name and yard number. *Cammell Laird & Co. Ltd. Yard No. 882*

Names of sister ships.

Owners.

For £ Received by me.

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35-1935 Survey for freeboard

PARTICULARS OF PROTECTION TO OPENINGS, ETC.

HATCHWAYS ON FREEBOARD AND SUPERSTRUCTURE DECKS

Description of Hatchway		No. 1	No. 2																	
Dimensions of Hatchway		23'-6" x 13'-6"	28'-2" x 13'-6"																	
COAMINGS	Height above Deck	30"	30"																	
	Thickness	44	44																	
	Stiffeners	7 x 3 x 4 BA	7 x 3 x 4 BA																	
	Brackets, Stays																			
HATCH BEAMS	Number	2	2																	
	Spacing	7'-9 1/4"	9'-5"																	
	Scantling and Sketch	2 1/2 x 4 1/2 31 x 51 x 50	2 1/2 x 4 1/2 31 x 51 x 50																	
	Bearing Surface																			
FORE AND AFTERS	Number	3	3																	
	Spacing	3'-3"	3'-3"																	
	Unsupported Lengths	7'-9 1/4"	9'-5"																	
	Scantling* and Sketch	2 1/2 x 7 6 1/2 x 6 1/2	2 1/2 x 7 6 1/2 x 6 1/2																	
HATCH COVERS	Material	W. P.	W. P.																	
	Thickness	2 1/2"	2 1/2"																	
	How fitted	Hand fitted	Hand fitted																	
	Bearing Surface																			
Spacing of Cleats																				
Number of Tarpanins		2	2																	

*Are wood fore and afters steel shod at all bearing surfaces? ?
 Are battens and wedges efficient and in good condition? ?
 Are tarpaulins in good condition and in accordance with rule requirements? ?
 Are lashings provided in accordance with rule requirements? ?

Particulars of fiddle, funnel and ventilator coamings:—
 ?

Particulars of Flush Bunker Scuttles:—
 ?

Particulars of Companionways:—
 ?

Particulars of Ventilators in exposed positions on freeboard and superstructure decks:—
 ?

Particulars of Air Pipes in exposed positions on freeboard, raised quarter, or superstructure decks:—
 ?

Particulars of Gangway Cargo and Coaling Ports:—
 ?

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Shlan

Particulars of Scuppers and Sanitary Discharge Pipes:—

Particulars of Side Scuttles:—

Particulars of Guard Rails:—

Particulars of Gangways, Lifelines, etc.:—

	Length of Bulwark	Height of Bulwark	Size of Freeing Ports	Number each side	Area each side	Rule area each side
After Well	88.25	3.0	?	2		
Forward Well	26.85	4.0	2.5 x 1.41	3		

State position of each freeing port } After Well:—
(F. and A. position and height above deck edge) } Forward Well:—
State whether the freeing ports are fitted with shutters, bars, or rails, and give particulars of such:—
Additional area where sheer is less than standard.

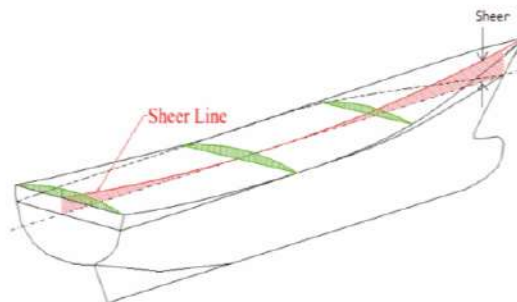
	Coaming	Plating	Stiffeners	Spacing	End Attachments of Stiffeners	Size of Openings	Height of Sills	Height of Casings
Poop Bulkhead	—	—	—	—	—	—	—	—
Raised Quarter Deck Bulkhead ...	2	2	2	2	2	2	2	—
Bridge, After Bulkhead	2	2	2	2	2	2	2	—
Bridge, Forward Bulkhead	28	24	5 x 2 1/2 x 4 BA	30"	brackets	None	—	—
Forecastle Bulkhead	2	2	2	2	2	2	2	—
Trunk, Aft	—	—	—	—	—	—	—	—
Trunk, Forward	—	—	—	—	—	—	—	—
Exposed Machinery Casings on Fore- board or Raised Quarter Decks ...	2	2	2	2	2	2	2	2
Exposed Machinery Casings on Super- structure Decks	—	—	—	—	—	—	—	—
Machinery Casings within Superstruc- tures not fitted with Class I Closing Appliances	—	—	—	—	—	—	—	—
Deckhouses on Finish Deck Ships ...	—	—	—	—	—	—	—	—

Poop Bulkhead	—
Raised Quarter Deck Bulkhead ...	No opening
Bridge, After Bulkhead	No opening
Bridge, Forward Bulkhead	No opening
Forecastle Bulkhead	?
Exposed Machinery Casings on Fore- board or Raised Quarter Decks ...	?
Exposed Machinery Casings on Super- structure Decks	—
Machinery Casings within Superstruc- tures not fitted with Class I Closing Appliances	—
Deckhouses on Finish Deck Ships ...	—

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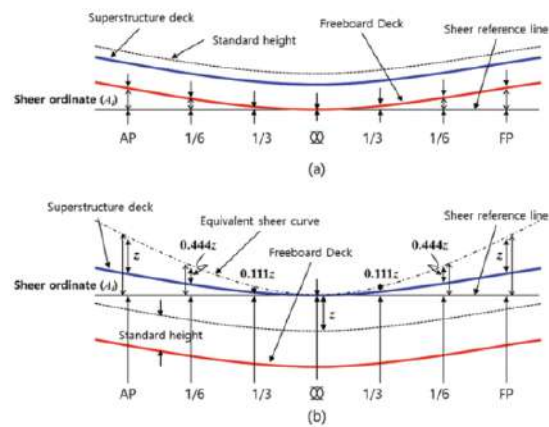
FULLAGAR

Sheer is a measure of longitudinal curvature of a ship's main deck. The sheer is measured from the deck at side to a line of reference drawn parallel to the keel through the sheer line amidships.



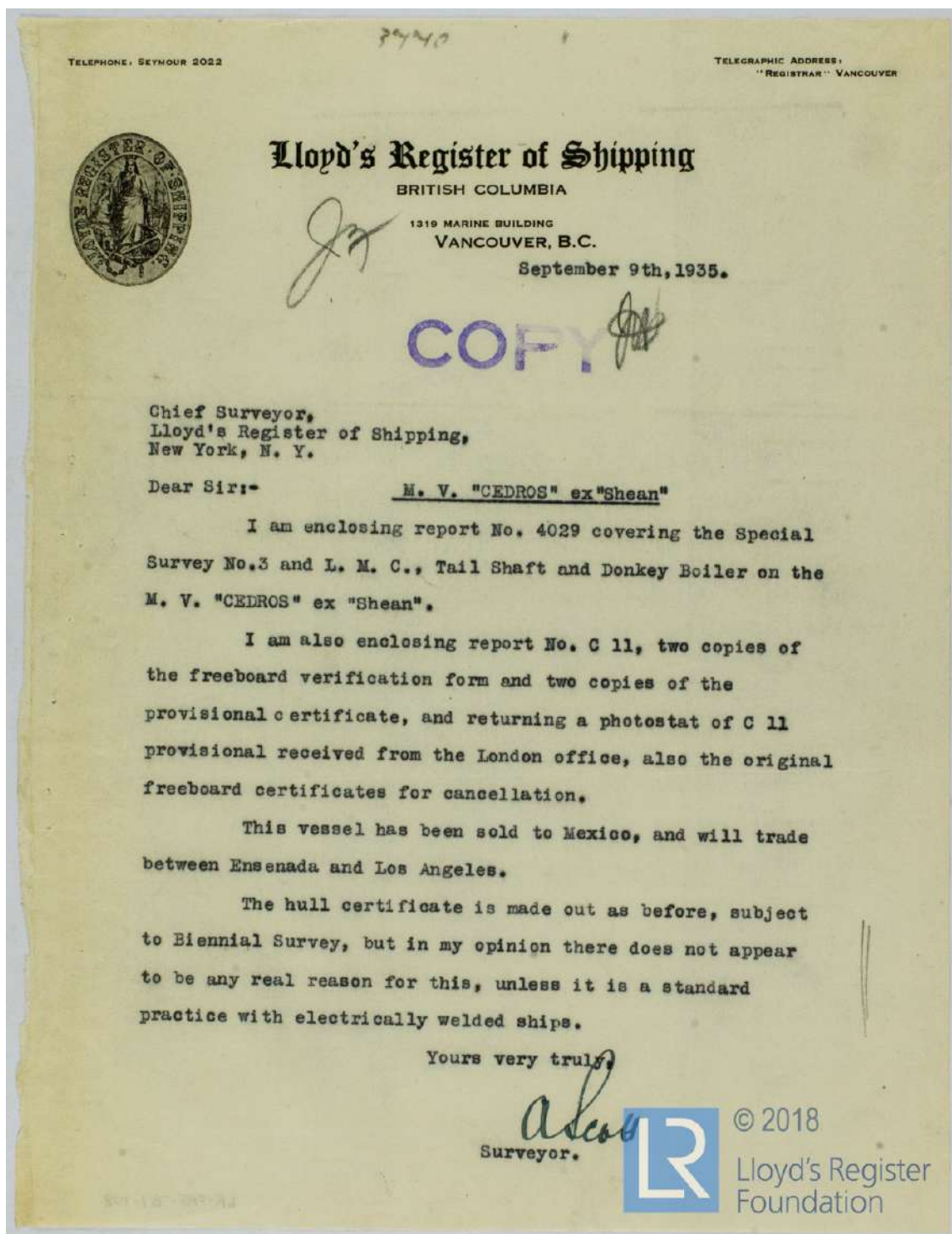
(Example of ship sheer diagram for freeboard calculation)

38- Diagram of sheer correction for freeboard calculations



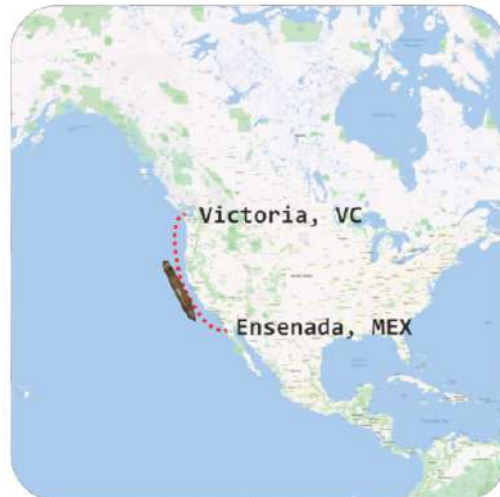
(Example of freeboard calculation diagram)

39- Diagram of superstructure compensation for freeboard calculations

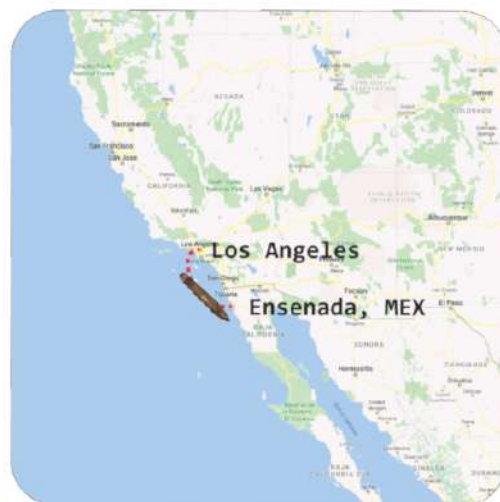


40- 1935 letter confirming vessel rename to "Cedros" and sale to Mexico

FULLAGAR

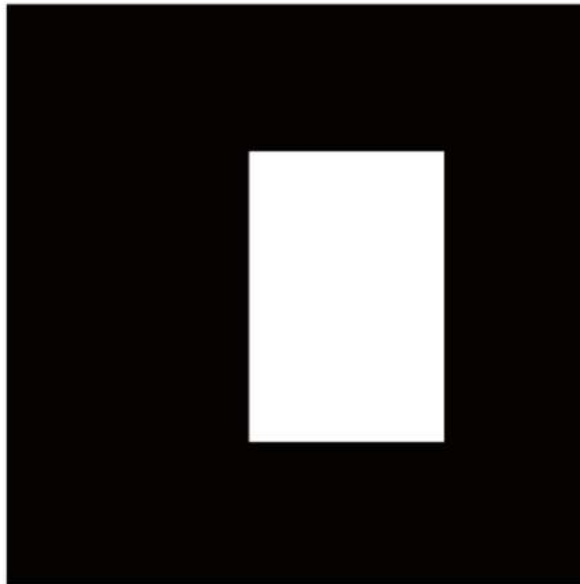


41- Animated 3D model, viewable in VR



42- Animated 3D model, viewable in VR

SURVEY FOR FREEBOARD, SALE AND RENAME



In 1935, an inspection certificate for the ship related to freeboard was issued by Lloyd's Register, titled "Survey for Freeboard". That year, the ship was sold to a company in Mexico. A letter from the Chief Surveyor of Lloyd's Register of Shipping in New York stated⁴⁰:

"Motor vessel 'Cedros', formerly 'She-an'..." "...This vessel has been sold to Mexico, and will trade between Ensenada and Los Angeles. The hull certificate is made out as before, subject to Biennial Survey, but in my opinion there does not appear to be any real reason for this, unless it is a standard practice with electrically welded ships"

The ship was sold and made the long journey to Mexico. In that year's freeboard inspection³⁴, terms such as "Deduction for Superstructure" and "Sheer Correction" appear, with various calculations beneath them.

The terms and calculations present are not easily understood by just anyone; extensive technical training is required to interpret them. This demonstrates that, already in 1935, Lloyd's inspections were rigorous and highly technical, ensuring safe navigation of vessels.

FULLAGAR

LLOYD'S REGISTER
No. 134

REPORT OF TOTAL LOSS, CASUALTY, &c. 9382

W/1160

No. 2200 in H.B. Vessel's Name Reel No. 1000 Date of writing this report 1st November 1934

Built at Ensenada Tons 151 Gross 420

Owner's Name C. J. Rodriguez Casualty notice sent to Owner 13/9/34 Owner's reply X

Address Ensenada, Lower California, Mexico

Case previously before Date Particulars of Classification 25 for MS-9-25

Classing Committee Last Minute +1000/1 5.34 HMC 9.35 HMC(M) 5.34 DMS 5.34 ONE 10.21 Electrically welded

Date of Casualty 31st August, 1934

Precis of particulars of Casualty

This vessel was reported to have sunk after collision with the m/s "Hidalgo" 30 miles south of Ensenada, Lower California, Mexico, on the 31st August.

A casualty notice was sent to the Owner on the 13th September, but no reply has been received.

Upon enquiry at Lloyd's by telephone today, it was ascertained that the vessel has been accepted by the Underwriters as a total loss & all claims settled.

SOURCE OF INFORMATION.

1000000 - Ensenada, Lower California, Aug. 31 - Steam vessel HIDALGO, 151 tons, collided with and sank the motor launch COLUMBIA, 420 tons, in the bay. The cause of the collision was the failure of the launch to stop in time. The launch was reported to have been on the beach at the time of the collision. The launch was reported to have been on the beach at the time of the collision. The launch was reported to have been on the beach at the time of the collision.

W/1160
W134

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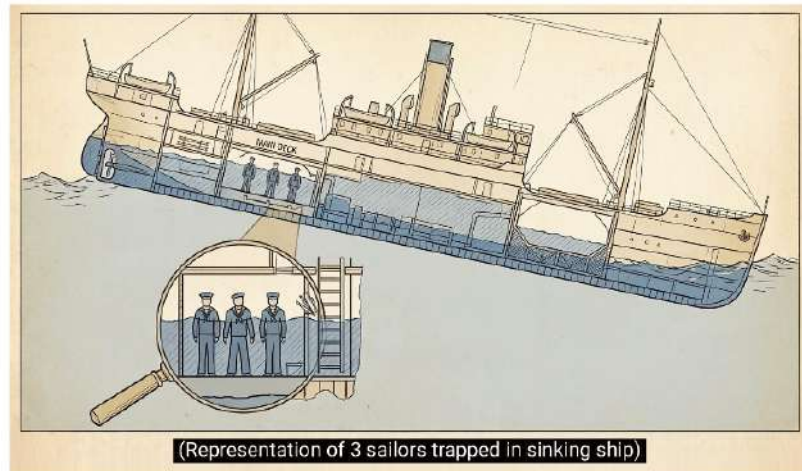
43- Animated 3D model, viewable in VR

THIRD ACCIDENT - TOTAL LOSS

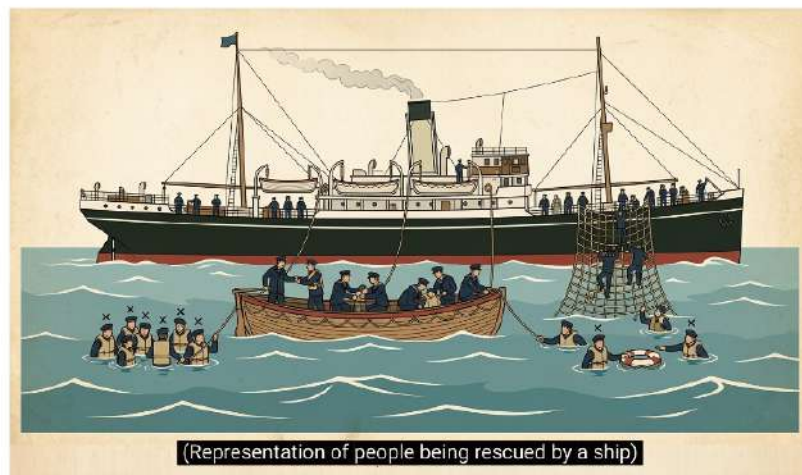


44- Animated 3D model, viewable in VR

FULLAGAR

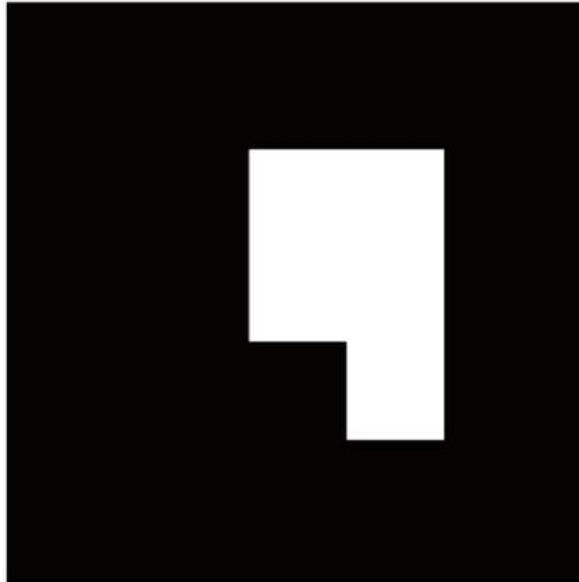


45- Representation of the 3 trapped sailors



46- Representation of the 14 rescued passengers

THIRD ACCIDENT - TOTAL LOSS



Unfortunately, the final voyage of the "Fullagar", now "Cedros", took place in 1937. A total loss report⁴³ was submitted from Ensenada, Mexico, which stated:

"This vessel was reported to have sunk after collision with the 'Hidalgo' 30 miles south of Ensenada, Lower California, Mexico, on the 31st August..." "...Upon enquiry at Lloyd's by telephone today, it was ascertained that the vessel has been accepted by the underwriters as a total loss..."

Clippings attached to this report, under "Source of Information", state:

"...Mexican motor vessels Hidalgo and Cedros were reported in collision off Ensenada. Former put into ensenada leaking, latter reported sunk."

"...Owners of the motor vessel Cedros advise total loss by collision with motor vessel Hidalgo..."

"...Motor vessel Hidalgo collided with and sank the motor vessel Cedros thirty miles south of here today, and three seamen on board the Cedros were trapped below the decks and drowned. Fourteen passengers were rescued by the Hidalgo from the Cedros, which sank twenty minutes after the collision..." "...The Cedros, southbound toward Mazatlan, was owned by Abalaro Rodriguez, former President of Mexico..."

This ends the story of the Fullagar, which over its life proved the effectiveness of welded ship construction.

Its final voyage, with the loss of lives and of the ship itself, revealed that even technological advances and rigorous maintenance could not eliminate all the risks of the sea.