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Practical implementation of a system for personalised containers in the zero-waste retail sector

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Abstract

The increasing amount of packaging waste represents one of the greatest environmental challenges of our time, particularly in the retail sector. Zero-waste concepts and reusable container systems offer sustainable alternatives, yet they are often associated with organizational hurdles and a lack of user-friendliness. This thesis explores the development of a digital system for managing personalized reusable containers, utilizing modern technologies to enhance their usability and return process.

By analyzing the theoretical foundations of sustainable consumption and existing waste reduction approaches, this study establishes the basis for all further discussions. A detailed examination of relevant digital technologies, including Radio Frequency Identification (RFID), Near Field Communication (NFC), Quick Response codes (QR codes), blockchain and steganography, to determine the most suitable solution for a digital container management system bridges then from theory into concrete digital solutions. The analysis indicates that NFC is the most practical technology for this application, as it enables easy-to-use interaction and can be implemented cost-effectively.

Based on these findings, an app is designed and implemented, allowing consumers to digitally manage their containers, organize refills, and for handling in participating retail stores. The technical implementation employs React Native for the frontend and Spring Boot with PostgreSQL for the backend. Special emphasis is placed on integrating NFC technology to ensure a seamless and user-friendly experience.

The final evaluation demonstrates that a digital solution for reusable container management can significantly contribute to reduce packaging waste. The developed concept offers a practical approach to promoting sustainable consumption in retail. Future research could focus on scaling the system, providing economic incentives for retailers and integrating additional technologies such as blockchain or artificial intelligence to further enhance adoption and efficiency.

Contents

Acronyms

ACID atomicity, consistency, isolation, durability
API Application Programming Interface

BCrypt Blowfish-based crypt

CRUD Create, Read, Update, Delete

EU European Union

HTTP Hypertext Transport Protocol

iOS Iphone operating system

JPA Java Persistence API
JUnit Open Source Java Unit Testing Tool
JWT JSON Web Token

MVC Model-View-Controller

NFC Near Field Communication

QR codes Quick Response codes

REST REpresentational State Transfer
RFID Radio Frequency Identification

UI User Interface
UID Unique Identifier

XSS Cross-Site-Scripting

1 Introduction

1.1 Problem statement

The global increase in packaging waste represents one of the greatest environmental challenges of the 21st century. Plastic packaging, in particular, contributes significantly to environmental pollution and resource depletion. According to a 2024 report by the European Union (EU) [1], each person living in the EU generated 36.1 kilograms of plastic packaging waste on average in 2021. The volume of plastic packaging waste per inhabitant increased by approximately 29% (+8.1 kilograms per person) between 2010 and 2021. However, only around 40 percent of this waste gets recycled, while a significant portion ends up uncontrolled in the environment, causing long-term damage to ecosystems and threatening biodiversity.
In the food retail sector, single-use packaging remains the dominant solution, as it is perceived as cost-effective, easy to handle and convenient. However, awareness of sustainable consumption is growing. The zero-waste movement reflects this societal shift, advocating for a transition from disposable materials to reusable alternatives. Despite numerous efforts, implementing these principles remains a challenge for many consumers, particularly when it comes to organizing their shopping routines and managing reusable containers.

1.2 Objective of the thesis

The objective of this thesis is to develop a digital system for managing personalized reusable containers. Specifically, an app is designed and implemented that enables users to efficiently manage their containers, utilize them in participating stores and thus contribute to reducing packaging waste.
To establish the best possible technical foundation for this app, an analysis is first conducted to determine which technologies are suitable for digital container management. Based on these findings, a concept for the app is developed, integrating the selected technologies. Finally, the application is implemented and the thesis concludes with a reflection on the main research questions.

1.3 Research questions

To structure the objectives of this thesis, the following research questions are addressed:

1. **Technological foundations:**
    - Which technologies are best suited for efficiently managing reusable containers within an app?
    - What are the advantages and disadvantages of RFID, NFC, QR codes, blockchain and steganography in managing and tracking reusable containers?

2. **Technical implementation of the app:**
   - Which technical requirements and architectures are necessary to develop a user-friendly and scalable app for managing personalized reusable containers?
   - What challenges arise during the implementation of such a system and how can they be addressed?
3. **Integration into the retail sector:**
   - How could such a system be integrated into existing retail structures?
   - What challenges and opportunities arise for retailers when implementing a digital reusable container system?
4. **Future prospects and sustainability:**
   - To what extent could such a system contribute to the long-term reduction of packaging waste?
   - What future developments could further enhance the adoption and use of a digital reusable container system?

1.4 Procedure and structure of the thesis

This thesis is structured in a way that allows a step-by-step understanding of the app development process.
To achieve this, the initial situation is examined, analyzing the challenges associated with zero-waste shopping and how digital solutions can contribute to making sustainable shopping more efficient. This is followed by a comprehensive examination of relevant technologies to determine which are best suited for managing and tracking reusable containers.
The app concept itself is based on the results of the technology analysis. This chapter provides a detailed description of the app's features, how it facilitates the usage of reusable containers and the technical requirements necessary for its implementation. Following the conceptual development, the practical implementation of the app is presented, including the technical architecture, the implementation of key functionalities and the integration of the selected technology.
In the final section of this thesis, the initially formulated research questions are addressed. The findings are critically reflected upon, and the effectiveness of the developed solution is evaluated.
This structured approach enables a systematic understanding of the entire development process, starting with the initial analysis, through the selection of the most suitable technology, to the practical implementation of the app.

2 Theoretical foundations

2.1 Introduction to the fundamentals

Before examining the technical aspects and the concrete development of the app, it is essential to first understand the theoretical foundations of the zero-waste principle and sustainable consumption. This section explains key concepts that serve as the basis for the development of a digital reusable container system. This includes an analysis of both the core principles of the zero-waste movement and existing approaches to waste reduction in the retail sector.

2.1.1 Zero-waste and sustainable consumption

Zero-waste is about more than just avoiding waste. It is a holistic philosophy aimed at reducing resource consumption and promoting a sustainable lifestyle. The term "zero-waste" literally means "no waste, no wastage" and, according to the Zero Waste International Alliance, encompasses the responsible production, consumption, reuse and recovery of materials without disposing of them through incineration or landfill [2]. The goal is to decouple economic activities from environmental destruction while building resilience and preserving natural capital for future generations.

The 5 R's of the zero-waste concept

A central component of the zero-waste philosophy is the so-called 5 R's: refuse, reduce, reuse, recycle and rot (composting). These principles form the foundation of a sustainable circular economy and serve as both a guideline for individuals and a framework for policymakers and economic decision-makers [3].

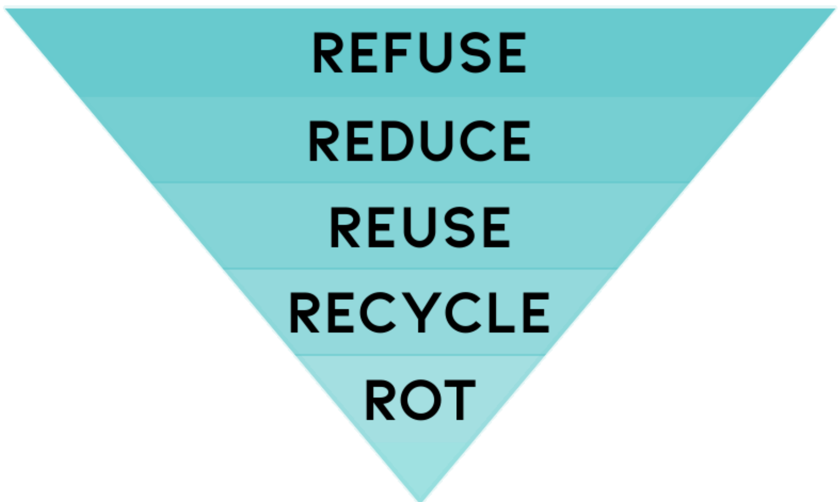


Figure 2.1: *The 5 R's of the zero-waste concept: refuse, reduce, reuse, recycle and rot [3]*

1. **Refuse:** Avoiding unnecessary consumption and rejecting single-use items to prevent waste generation at its source. This includes purchasing unpackaged products and using reusable containers.
2. **Reduce:** Limiting personal possessions and focusing on essentials. A minimalist approach helps conserve resources and prevent waste.
3. **Reuse:** Encouraging reusable solutions instead of disposable ones and repairing existing products to extend their lifecycle.
4. **Recycle:** Returning materials to the resource cycle when reuse is no longer possible. While recycling is important, it is only the second-to-last option in the zero-waste hierarchy, as it can be energy-intensive.
5. **Rot (composting):** Rather than disposing of organic waste in traditional waste disposal sites, composting helps turn food scraps and other biodegradable materials into nutrient-rich soil. Whether done at home or in local composting facilities, it is a natural way to return valuable resources to the earth and support plant growth.

Zero-waste as a process and long-term goal

Zero-waste should not be seen as a short-term measure but rather as an ongoing process. This approach calls for a fundamental shift in how resources are managed, starting with product design and extending to how waste is repurposed. A key element in this transformation is the promotion of a circular economy, where goods and materials are kept in use for as long as possible [4].

According to the Circularity Gap Report 2021, around 70% of global greenhouse gas emissions are linked to the way materials are handled, many of which eventually become waste. Implementing waste prevention strategies and circular economy models can therefore make a significant contribution to climate and environmental protection [2].

2.1.2 Packaging waste: Scope and impact

Packaging waste is one of the most pressing environmental problems of our time. In 2021, approximately 19.7 million tons of packaging waste were generated in Germany, marking a 4.9% increase compared to the previous year [5].

Packaging is an integral part of our daily life, yet its growing volume presents significant challenges for waste management systems. The majority of packaging waste consists of paper, plastic, glass, metal and biodegradable materials [6].

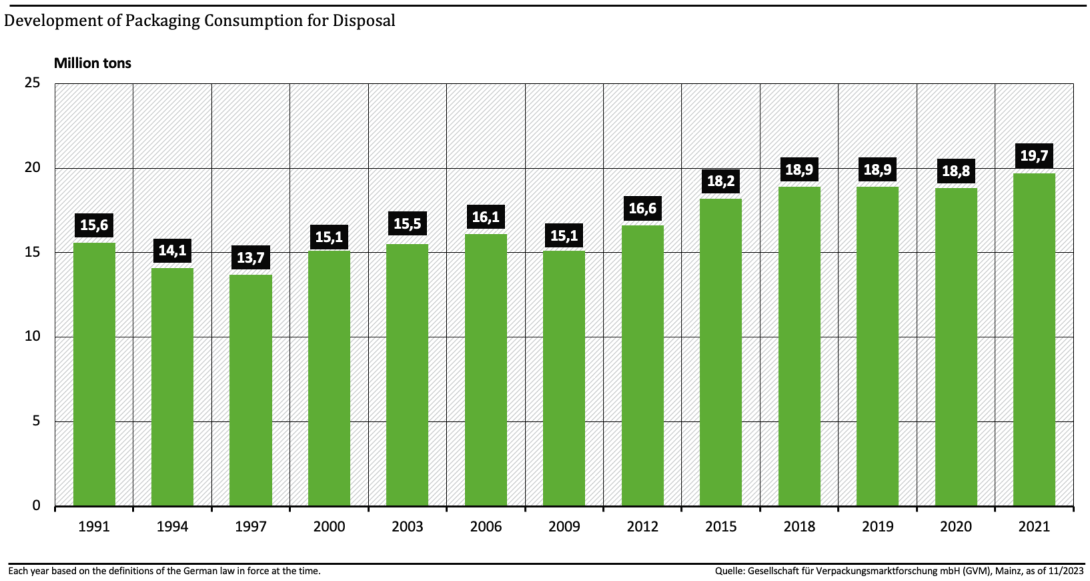


Figure 2.2: *Development of packaging consumption in Germany up to 2021 [5]*

Causes of increasing packaging waste

The rise in packaging waste can be attributed to various societal developments. The increase in smaller household sizes, the growing demand for ready-to-eat foods and the boom in online retail are significant contributing factors [5].
Today, packaging not only serves protective functions but also plays a role in dosing, portioning and handling - resulting in its further increasing consumption. In particular, the e-commerce sector has significantly contributed to the rise in packaging waste in recent years, as each shipment requires additional packaging materials [5].

The global challenge of plastic waste

A significant portion of packaging waste consists of plastic. On average, each person in the EU generates 36.1 kilograms of plastic packaging waste per year [1].
Plastic is a highly versatile material, but it also poses severe environmental challenges. According to the State Agency for Civic Education Baden-Württemberg, approximately 8.3 billion tons of plastic were produced worldwide by 2015, yet only 9% of it was recycled [7].
A substantial amount of non-recycled plastic ends up in the environment, particularly in the world's oceans. According to the report "The New Plastics Economy," by 2050, there could be more plastic in the oceans than fish [7].
This pollution has severe consequences for ecosystems and wildlife. Many marine animals mistake plastic for food, which often proves fatal.

The role of the EU and national strategies

To address this issue, the EU has implemented various measures, including increasing recycling rates and banning certain single-use plastics [1].

In Germany, approximately 67.9% of packaging waste was recycled in 2021, while the remainder was either used for energy recovery or disposed of in landfills [5].
Innovative approaches, such as reuse systems and biodegradable packaging, could play a crucial role in reducing packaging waste in the future [6].

The importance of waste prevention

In addition to recycling, preventing packaging waste is a key aspect of sustainable waste management. Measures such as the use of reusable containers, package-free shopping and avoiding single-use plastics significantly contribute to reduce waste generation [6].
Every piece of packaging that is avoided helps conserve valuable resources and reduces CO_2 emissions associated with the production and disposal of packaging.

2.1.3 Relevance of digital solutions for sustainable consumption

Digitalization offers new opportunities to integrate sustainable consumption into consumers' daily lives. While the traditional zero-waste lifestyle is often perceived as cumbersome and impractical, such as bringing one's own containers or weighing products, digital solutions provide innovative approaches to overcoming these challenges. Technologies such as apps, digital platforms and cloud-based systems facilitate the implementation of sustainable consumption patterns and increase user-friendliness at the same time.

Digitalization as a key to behavioral change

Digital solutions pursue three central objectives:

1. **Increasing transparency:** Consumers can find out about the origin, composition and production conditions of goods.
2. **Promoting reuse and resource conservation:** Digital systems facilitate access to reusable concepts and resource-sharing networks.
3. **Personalized recommendations:** Through data analysis, users can receive targeted suggestions on how to make their consumption more sustainable.

A particular focus is placed on waste reduction apps, which track individual plastic consumption and provide concrete improvement suggestions. These apps not only encourage sustainable decisions but also motivate users to reduce their CO_2 footprint in the long term [8].
Additionally, digital platforms contribute to networking and awareness-raising by providing information on plastic-free alternatives and local zero-waste offerings. Businesses also benefit from digitalization: IT-supported inventory management and supply chain optimization systems help reducing packaging materials and make processes more sustainable. This not only decreases packaging waste but also improves the efficiency of operational workflows [8].

Future perspectives

The integration of digital technologies will play an increasingly important role in promoting sustainable consumption in the coming years. Smart container systems, intelligent shopping lists and digital platforms for resource sharing have the potential to revolutionize the zero-waste concept and make it accessible to a broader audience.

2.2 Existing systems and approaches in the zero-waste retail sector

In recent years, zero-waste retail has become increasingly established, offering consumers alternatives to conventional consumption behavior. Various approaches exist, differing in their practical implementation, target audience and level of technological support. Some of these systems focus on reducing single-use packaging, while others use digital solutions to organize and manage reusable containers.

2.2.1 Unpacked stores: Pioneers of zero-waste retail

Unpackaged stores are one of the most well-known approaches in the zero-waste retail sector. Here, consumers can purchase products such as food, household items and cosmetics without single-use packaging. Purchases are made in containers that consumers bring with them, which are filled and weighed on site.

Advantages:

- Reduction of single-use plastic
- Promotion of conscious consumption
- Support for local producers

Challenges:

- High planning effort for consumers
- Limited product range compared to conventional supermarkets
- Logistical effort and hygiene regulations

2.2.2 Reusable systems in the food service industry

Another growing sector is reusable systems for food and beverages. Particularly in the food service industry and the to-go segment, reusable containers are being used more and more frequently. Companies such as RECUP and Vytal offer deposit systems for cups and food containers, allowing customers to return them at designated drop-off locations after use.

Example: RECUP

- **Product:** Reusable coffee-to-go cups and bowls
- **Technology:** QR codes for tracking and managing containers
- **Success:** Over 10,000 participating partner locations in Germany [9]

Reusable systems contribute significantly to waste reduction. According to the RECUP Impact Report 2022/2023, the deposit system has already saved 1.3 million single-use cups, preventing the emission of 830,000 tons of CO_2 [9].

Challenges

- The return rate must remain high to ensure economic and ecological viability.
- High logistical effort required for cleaning and redistribution.
- Consumer acceptance still has room for improvement.

2.2.3 Digital marketplaces for zero-waste products

In addition to physical stores, digital marketplaces are playing an increasingly important role. One example is the Too Good To Go app, which connects consumers with restaurants and supermarkets to save surplus food. Since its launch, over 121 million meals have been saved from waste, preventing the emission of more than 325,000 tons of CO_2 (Too Good To Go, 2023).
The Refill app also facilitates access to zero-waste concepts by displaying water refill stations where consumers can refill their water bottles for free. These platforms not only promote sustainable consumption but also support local businesses.

2.2.4 Packaging-free supermarkets with digital support

Some supermarkets are now integrating digital technologies to make zero-waste concepts more practical. Examples include pilot projects by Tegut and Edeka:

- **Tegut:** In around 100 stores, Tegut offers multiple products in reusable glass jars. These jars can be returned at any reverse vending machine and reused up to 50 times [10].
- **Edeka:** With the regood system, Edeka has introduced its own reusable system for takeout meals. Reusable cups and bowls can be purchased with a deposit and returned at participating stores [11].

Digital solutions such as QR codes and app-based systems support the tracking and management of these reusable containers, making the system more attractive for consumers.

Conclusion

The described systems illustrate the diversity of existing approaches in the zero-waste retail sector. From unpackaged stores and digital marketplaces to large supermarket chains, they all share the same goal: reducing packaging waste and promoting sustainable consumption.
In the next chapter, technological solutions and digitalization in this context will be examined in greater detail, analyzing their advantages and disadvantages.

3 Technology and digitalization in the zero-waste context

3.1 Overview of digital technologies for container systems

In the zero-waste context, digitalization offers innovative opportunities to make reusable systems more efficient, sustainable and user-friendly. By leveraging digital technologies, containers can be managed automatically, their usage can be transparently documented and communication between consumers and systems can be optimized.
The key technologies that are relevant in this context, which will be analyzed in detail in the following sections, include:

- **RFID:** A radio-based identification technology that transmits data over longer distances.
- **NFC:** A short-range communication technology that operates via electromagnetic induction and is used for contactless data transmission.
- **QR codes:** Optical markers that can be scanned with cameras to provide information.
- **Blockchain technology:** A decentralized system for securely and transparently storing transactions and product histories.
- **Steganography:** A technique for hidden information storage within digital media, which can be used for secure container labeling and authentication.

Each of these technologies offers specific advantages and disadvantages, which will be evaluated in terms of user-friendliness, cost, security and integration possibilities. The following analysis aims to determine which technology presents the best solution for digital container systems in the zero-waste retail sector.

3.2 Detailed analysis of technologies

3.2.1 Radio Frequency Identification (RFID)

RFID is a wireless technology used for the automated identification of objects via radio waves. RFID systems are well-established in many fields, particularly in logistics, retail and access control [12].

Functionality:

RFID systems consist of two main components:

- **RFID tag (transponder):** Contains a microchip and an antenna for data storage and transmission.
- **Reader:** Emits radio waves to activate the RFID tag and read the stored data.

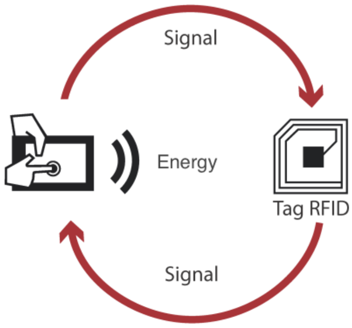


Figure 3.1: *Working principle of RFID [13]*

RFID systems can operate both with and without a central database. In database-driven systems, the RFID tag sends an identification number to the reader, which then retrieves the corresponding information from a database. A well-known example is the use of RFID in electronic passports, where biometric data is stored on the chip [12].

Advantages and challenges of RFID

Advantages:

- **Range:** RFID tags can be read over several meters, depending on the frequency range.
- **Automated identification:** Enables fast and efficient inventory management.
- **Wide range of applications:** Particularly beneficial in logistics and warehouse management.

Challenges:

- **Privacy concerns:** RFID tags can, in theory, be read without the owner's knowledge.
- **Costs of implementation:** Higher than QR codes, especially in complex systems.
- **Standardization issues:** Different frequency ranges and protocols can complicate interoperability [14].

Use cases in zero-waste retail

1. **Inventory and container tracking:** RFID can help automatically identify reusable containers over longer distances.
2. **Fast processing of returns:** RFID enables contactless and automatic detection of containers upon return.

RFID is a powerful technology for tracking and identifying reusable containers. Due to its extended range, it is particularly well-suited for logistics applications. However, privacy concerns and implementation costs remain key challenges.

3.2.2 Near Field Communication (NFC)

NFC is a wireless communication technology specifically designed for data transmission over very short distances. It enables contactless information exchange and is widely used in various aspects of daily life, including mobile payment, access control and logistics [15].

Functionality:

NFC is based on RFID technology and operates on the license-free frequency band of 13.56 MHz [16]. Communication occurs through magnetic induction between an active and a passive device:

- **Active devices** generate a high-frequency magnetic field, which is used both for communication and to power the passive device.
- **Passive devices (e.g., NFC tags)** do not require their own power source but instead use the magnetic field of the active device for voltage induction and data transmission [17].

Figure 3.2: *Working principle of NFC [18]*

An NFC-enabled smartphone can, for example, read an NFC tag and retrieve information about a product or a reusable container.

Advantages and challenges of NFC

Advantages:

- **User-friendliness:** Fast and intuitive handling by simply scanning the item.
- **Security** Short range makes unauthorized eavesdropping difficult; additional, encryption methods are integrated.
- **Integration:** NFC is built into almost all modern smartphones and does not require additional hardware.

Challenges:

- **Cost:** NFC tags are more expensive than QR codes.
- **Limited range:** Communication is restricted to just a few centimeters.
- **Infrastructure dependency:** Requires compatible reading devices and backend systems for data processing [16].

Use cases in zero-waste retail

The use of NFC in reusable container systems goes along with various advantages:

1. **Digital container management:** Each container is assigned a unique NFC tag storing information on contents, usage history and shelf life.
2. **User-friendly reordering:** Customers can place a refill order simply by scanning the tag.

In summary, NFC provides a user-friendly and secured solution for managing personalized reusable containers. With contactless communication and widespread integration into modern smartphones, it presents a practical technology for zero-waste retail.

3.2.3 QR codes

QR codes are two-dimensional barcodes that store information and can be read using cameras or specialized scanners. They were developed in 1994 by Denso Wave to improve logistics processes in the automotive industry, but have since become widely used in many areas of daily life [19].

Functionality:

QR codes consist of a matrix of black and white squares that encode binary data. They contain several key components:

- **Position markers:** Three large squares in the corners of the code that help the scanner determine orientation.
- **Data area:** Stores the encoded information.
- **Error correction:** Using Reed-Solomon coding, up to 30% of the code can be damaged without making it unreadable [20].

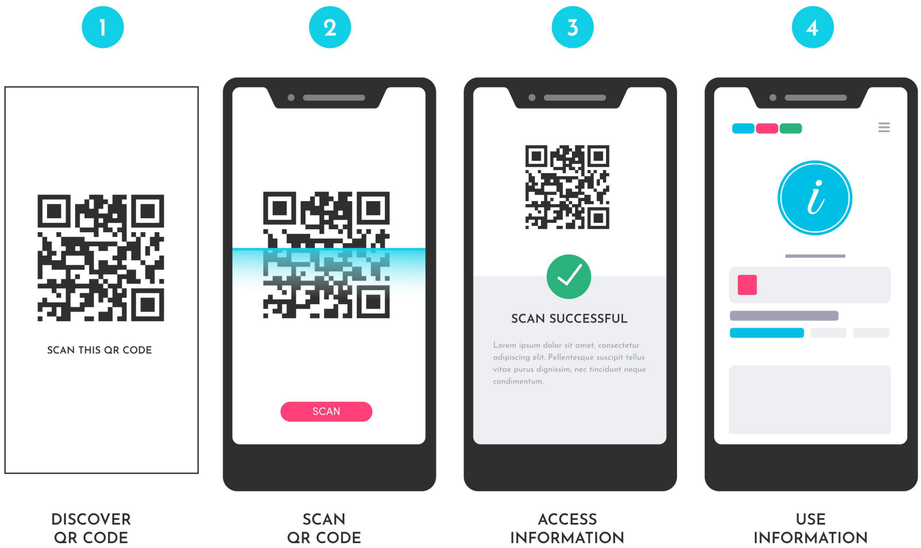


Figure 3.3: *Working principle of QR codes [21]*

QR codes can be printed on paper, displayed digitally or engraved into various materials. Smartphones and tablets can scan QR codes using their cameras and automatically process the embedded data.

Advantages and challenges of QR codes

Advantages:

- **Cost-effective and scalable:** QR codes can be generated and printed easily at minimal cost.
- **Automated identification:** No special hardware required—smartphone cameras are sufficient.
- **Versatile applications:** Compared to traditional barcodes, QR codes can store significantly more data [22].

Challenges:

- **Security risks:** QR codes can be manipulated to redirect users to malicious links.
- **Line of sight required:** Unlike RFID or NFC, the code must be clearly visible to be scanned.
- **Dependence on external factors:** Dirt, damage or poor lighting conditions can interfere with scanning.

Use cases in zero-waste retail

1. **Providing product information:** Customers can scan QR codes on reusable containers to access details about contents or usage instructions.
2. **Fast processing of returns** QR codes can be used to directly open order forms or refill options.

QR codes offer a simple, cost-effective and widely used technology for providing information. Despite their advantages, they have limitations in terms of security and user-friendliness, especially when compared to RFID or NFC.

3.2.4 Blockchain technology

Blockchain is a decentralized technology for storing and managing data that prevents manipulation and enables transparent tracking. Originally developed for cryptocurrencies such as Bitcoin, it is now used in various fields, including supply chains, digital identities and logistics [23].

Functionality

A blockchain consists of a chain of blocks that are linked through cryptographic hash functions. Each block contains:

- **Data:** Information about the stored transaction
- **Hash value:** A unique digital signature of the block
- **Hash of the previous block:** Ensures the integrity of the entire chain

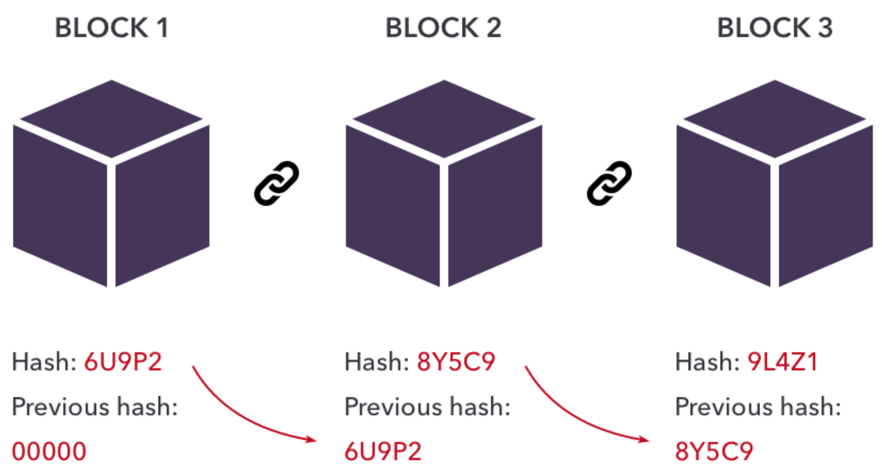


Figure 3.4: *Working principle of Blockchain [24]*

This system creates a tamper-proof data structure that is managed by many participants simultaneously. Changes to individual blocks are almost impossible, as any change would affect all subsequent blocks [25].

Advantages and challenges of blockchain technology

Advantages:

- **Tamper-proof security:** Once stored, data cannot be altered
- **Decentralized storage:** No central authority that can control or fail
- **High transparency:** All transactions are visible to authorized participants

Challenges:

- **High energy consumption:** Particularly in public blockchains using the Proof-of-Work consensus mechanism.
- **Scalability issues:** High transaction times in heavily congested networks.
- **Complex integration:** Systems must be specifically adapted to blockchain technology [26].

Use cases in zero-waste retail

Blockchain can be utilized for various processes in reusable and circular systems:

1. **Traceability of reusable containers:** Each container could be registered as a transaction in the blockchain to document a complete history.
2. **Authentication of containers:** The blockchain can ensure that only registered and authenticated containers are used within the system.
3. **Automated inventory management:** Smart contracts can be used to automate refilling or returns.

Blockchain is a secured and transparent technology that is particularly suited for tamper-proof documentation of transactions. In reusable systems, it can provide significant value by tracking container movement and optimizing processes. However, implementation requires careful consideration of scalability, energy consumption and integration into existing systems.

3.2.5 Steganography

Steganography is the art of hiding information within other data so that its existence remains unnoticed. Unlike cryptography, which encrypts data, steganography makes a message invisible. It is commonly used in images, audio files or text and can be applied for secured data transmission [27].

How does steganography work?

Steganography uses various media as carriers for hidden information. These include:

- **Text files:** Inconspicuous changes in fonts, spaces or character sequences can hide data.

- **Images:** Data is embedded in individual pixels through minimal color modifications that are invisible to the human eye.
- **Videos:** Data is hidden within specific frames or through slight variations in color wavelengths.
- **Audio files:** Information is encoded by altering frequencies that are inaudible to humans.

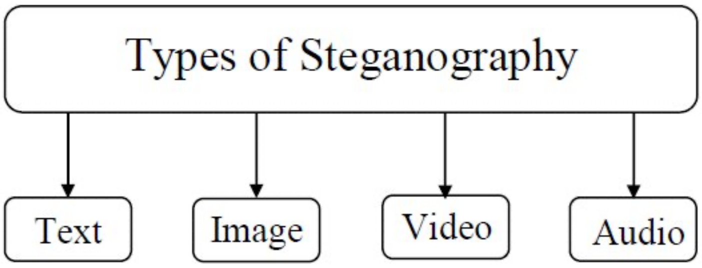


Figure 3.5: *Types of steganography [28]*

One commonly used method is the Least Significant Bit (LSB) technique. This approach embeds data into the least significant bits of image or audio files, ensuring that no visual or auditory differences are detectable.

Example of image steganography

To demonstrate that hidden data in images is undetectable to the human eye, two images are presented:

1. **Original image:** A regular image without embedded data.
2. **Steganographic image:** The same image with hidden data, visually identical to the original.

Figure 3.6: *Example of image steganography [29]*

Advantages and challenges of steganography

Advantages:

- **Invisibility:** The data remains hidden from unauthorized access.
- **Enhanced security:** When combined with encryption, data can be transmitted securely and discreetly.
- **Versatility:** Can be applied to images, audio files or text [30].

Challenges:

- **Complex implementation:** Specialized algorithms are required to embed data securely and discreetly.
- **Limited storage capacity:** The amount of data that can be hidden within a medium is restricted.
- **Risk of detection:** If poorly implemented, steganography can be identified and removed [31].

Use cases in zero-waste retail

Steganography can be used to discreetly store customer data within containers, enabling identification and managing refills within the system:

- **Hidden identification markers:** Customer data can be embedded within container labels to document usage and ensure seamless refill management.

Steganography presents an innovative way to discreetly store and transmit data, allowing for secured and personalized integration of information in reusable systems. However, its implementation requires careful planning to ensure both security and efficiency.

3.3 Comparison of the technologies

After examining each technology individually, the following section provides a direct comparison based on relevant criteria. The goal is to analyze the strengths and weaknesses of each technology to determine the most suitable option for the app. To achieve this, several criteria have been evaluated, including:

- **Range:** How close a device must be to the container in order to carry out identification or data transfer.
- **Security:** Protection against tampering, unauthorized access and data misuse.
- **Cost:** Financial aspects of implementation and the scalability of the technology.
- **User-friendliness:** How simple and intuitive is the technology for customers and businesses.
- **Scalability:** The ability to integrate the technology into various business models and operational sizes.

- **Design & aesthetics:** Unobtrusiveness of the technology to ensure it does not disrupt the user experience.

These criteria were selected as they represent essential requirements for a successful and sustainable reusable container management system. The evaluation is conducted through a direct comparison of technologies in comparison table 3.1, followed by a detailed discussion of the results.

Technology	Range	Security	Cost	User-friendliness	Scalability	Design & aesthetics
RFID	Medium (up to several meters)	Medium (depends on frequency)	High	User-friendly (automatic detection possible)	Very high (bulk processing supported)	Invisible, integrated into systems
NFC	Very short (up to 10 cm)	High (encrypted communication)	Medium	Very user-friendly (direct smartphone scanning)	Limited (short-range only)	Discreet, embedded in tags
QR codes	Requires line of sight	Low (easily copied)	Very low	Very user-friendly (easy to scan)	High (can be printed or displayed digitally)	Highly visible, may affect design
Blockchain	Global (network-based)	Very high (tamper-proof)	High (depends on implementation)	Medium (complex integration required)	Medium (scalability varies)	Digitally stored, not physically visible
Steganography	Depends on the medium	High (if well implemented)	Medium	Low (requires special software for extraction)	Limited (restricted by data capacity)	Invisible, requires decryption

Table 3.1: *Comparison of RFID, NFC, QR codes, Blockchain and Steganography [32]*

After an initial analysis of the table, it becomes evident that RFID, NFC and steganography emerge as the most promising solutions. Design plays a crucial role, the technology should be as unobtrusive as possible to avoid negatively impacting the visual appearance of the containers.

- **QR codes** were excluded because they must be clearly visible, significantly affecting the container design.
- **Blockchain** proves to be too complex and less practical for direct application on containers.

Steganography offers a unique way to hide data invisibly within digital media. It could be used in a reusable container system to store identification data discreetly. However, implementation requires specialized algorithms for encoding and extraction and a dedicated software for detection and retrieval, making it more complex than other solutions. Due to these factors, despite its subtlety, steganography was not considered further.

Ultimately, RFID and NFC were chosen, as both integrate easily into existing systems, are user-friendly and do not require specialized software. To further evaluate their suitability, these technologies are compared in Table 3.2.

Direct comparison of RFID and NFC

Feature	RFID	NFC
Interaction type	Automatic detection without user interaction	Active scanning by the user
Infrastructure requirement	Requires specialized readers and backend system	No additional readers needed, smartphones are sufficient
Power supply	Active	Passive
Multiple tag detection possible?	Yes, multiple tags can be detected simultaneously	No, only one tag per scan
Reading speed	Fast, as multiple tags can be read simultaneously	Slower, as user must actively scan
Cost	\$0.50–\$5.00 per tag, requires specialized readers and infrastructure	\$0.10–\$0.50 per tag, no additional hardware required
Use case in reusable containers	Ideal for logistics & inventory management	Ideal for end users (scanning, orders)

Table 3.2: *Direct comparison of RFID and NFC [32]*

The decision to use NFC is primarily based on the fact that each container is equipped with a tag and is intended to be scanned by a single user. This means that multi-item detection, which is possible with RFID, is not relevant for this use case. While RFID is ideal for warehouse management and large-scale scanning, NFC is best suited for direct user interaction. Customers can simply scan their container with the app to place refill orders, without requiring additional readers or complex backend infrastructures.

Conclusion

While each technology has its specific advantages, NFC proves to be the most practical solution for a sustainable reusable container system. Due to its cost-effective implementation, high security and ideal range, NFC is well suited for zero-waste retail. The following chapters focus on the practical implementation of NFC within the system. First, a detailed analysis of different NFC chip types will be conducted to understand their differences and respective applications.

3.4 Analysis of NFC chip types

After NFC has proven to be the best technology for the reusable system, it is important to conduct a detailed analysis of the different NFC chip types. NFC chips differ in storage capacity, security, cost and application possibilities.
This chapter examines and compares the most relevant NFC chip types to determine the optimal choice for implementation in zero-waste retail.

3.4.1 Overview of NFC chip types

NFC chips can be categorized into different types, with the most well-known being NTAG, MIFARE and DESFire [33]. These chips primarily differ in their storage capacity, security architecture and usage possibilities.

- **NTAG Series (NTAG213, NTAG215, NTAG216)**
  - Affordable and widely used
  - Ideal for simple applications such as identification and URL storage
  - Various storage capacities: 144 - 888 bytes
  - Supports password protection with 32-bit encryption
- **MIFARE Classic:**
  - Designed for applications with higher security requirements
  - Used in access control and public transport systems
  - Available with 1 KB or 4 KB storage
  - Supports basic encryption methods
- **MIFARE DESFire:**
  - Highest security standards with AES encryption

- Used in payment systems and high-security applications
- High storage capacity of up to 8 KB
- Supports additional security measures, such as hash values for messages

3.4.2 Comparison of the NFC chip types

Feature	NTAG (213,215,216)	MIFARE Classic	MIFARE DESFire
Memory capacity	144B - 888B	1KB - 4KB	Up to 8KB
Security	Basic (password protection)	Medium (proprietary encryption)	High (AES encryption)
Cost	Low	Medium	High
Use case	Simple identification, URL storage	Access control, transport systems	Payment, high-security applications
Compatibility	All NFC-enabled devices	Limited (not all devices support)	Requires advanced readers

Table 3.3: *Comparison of NTAG, MIFARE Classic and MIFARE DESFire [33]*

The following criteria are essential for reusable containers:

- **Low cost** for scalable implementation
- **Sufficient storage capacity** for container information
- **Easy integration with mobile devices** without requiring specialized readers

Based on these requirements, the NTAG series is the best choice, as it is cost-effective, widely available and compatible with all NFC-enabled smartphones. MIFARE or DESFire chips would be excessive for this application since high-security transactions or large storage capacities are not required.

Selecting the right NTAG chip is crucial, as the models differ not only in storage capacity but also in functionality. While all NTAG chips support basic security features such as password protection, there are significant differences in data capacity, which affect the range of possible functions.

Feature	**NTAG213**	**NTAG215**	**NTAG216**
Available memory	144 Bytes	504 Bytes	888 Bytes
Security	Password protection		
Use case	Simple identification, small data storage	Medium data storage	Advanced data storage, container tracking
Write cycles	100,000		
Data retention	10 years		
Cost	\$0.10 - \$0.20	\$0.30 - \$0.50	\$1.50 - \$3.00

Table 3.4: *Comparison of NTAG213, NTAG215 and NTAG216 [34]*

Although the NTAG216 offers the highest storage capacity within the NTAG series, the NTAG215 emerges as the most practical choice for the reusable container system. The key reasons for this decision are:

- Sufficient storage capacity for the required information, including product details, quantity specifications and identification numbers.
- Lower cost compared to NTAG216, making large-scale implementation more economical.
- Compatibility with all modern NFC-enabled smartphones, ensuring easy integration into the app.
- Support for password protection to prevent unauthorized data access.
- Long lifespan with 100,000 write cycles and 10 years of data retention, making it ideal for reusable systems.

Due to its better price-performance ratio compared to the NTAG216, the NTAG215 provides an ideal trade-off between storage capacity and cost. Since the required data can be easily stored within 504 bytes of memory, the NTAG216 would be excessive, resulting in unnecessarily high costs [34].

Conclusion

The choice of the right NFC chip strongly depends on the specific requirements of the system. Within the NTAG series, the NTAG215 proves to be the best solution, as it offers sufficient storage capacity at a significantly lower cost compared to the NTAG216. This enables a cost-effective implementation of the reusable container system without compromising on functionality or security.
The following chapters will focus on the practical integration of these NFC tags into the system.

3.5 Practical integration of NFC into the system

After identifying the NTAG215 as the most suitable NFC chip for the reusable container system, the next step is to determine how it can be practically integrated into the system. This chapter outlines the implementation process, from the physical placement of NFC tags to their interaction with the app. The goal is to ensure a user-friendly and efficient application of NFC technology.

3.5.1 Physical integration of NFC tags

Optimal placement of NFC tags

The NFC tags must be positioned in a way that makes them easily accessible to users without compromising the design or handling of the container. Based on ergonomic considerations, the following positions are particularly suitable:

- **Lid:** Simply scanning by placing the smartphone on top, but risk of abrasion due to frequent opening and closing.
- **Side vessel wall:** This position is particularly advantageous, as the container's design is often placed on this surface. The NFC tag can be discreetly integrated behind the design, ensuring that aesthetics remain unaffected. Additionally, scanning remains intuitive, as users can always scan at a consistent location.
- **Bottom of the container:** Provides an unobtrusive placement but can be impractical if the container is filled when scanning.

The best placement depends on the specific container type. Due to aesthetic requirements and user-friendly handling, the side position is the most suitable choice, as the NFC tag can be seamlessly integrated into the design.

Material compatibility and protective measures

As NFC tags operate via electromagnetic induction, the container material plays a crucial role in ensuring interference-free communication:

- **Suitable materials:** Plastic, glass, wood
- **Problematic materials:** Metal (can block the NFC signal [34])

If metal is used, the following measures must be taken:

- Use of NFC tags with a special isolation layer
- Placement on a non-metallic surface (e.g., a plastic label attached to the metal container)

Additionally, NFC tags should be protected against moisture, abrasion and scratches using a protective layer (e.g., lamination or sealed stickers).

3.5.2 Interaction with the app

Usage process

To ensure that users can easily interact with NFC tags, the app must provide an intuitive user experience. The typical interaction process follows these steps:

1. **Scanning the container:** The user holds the smartphone near the NFC tag (max. 10 cm distance)
2. **Automatic identification:** The app reads the container ID, product information and fill level
3. **Displaying the order option:** Users can place refill orders or check the status of their container
4. **Data transmission and storage:** The scanned information is processed within the app and synchronized with the backend

General challenges and solutions

Various challenges may arise when using NFC tags:

- **Unrecognized NFC tag:** In some cases, a tag may not be detected immediately. Repositioning the smartphone or bringing it closer again can improve recognition.
- **External interference:** Disruptions from metallic surfaces or strong electromagnetic fields could affect functionality. Proper placement and, if necessary, shielding can help mitigate this issue.
- **Device compatibility:** Not all mobile devices support NFC equally well. If a device does not support NFC, the app will display a notification informing the user accordingly.

Considering these factors ensures a reliable and intuitive use of NFC technology.

3.5.3 Implementation of NFC integration on the container

Each reusable container is customized designed, allowing users to select their preferred design. This design is applied directly to the front of the container. The NFC chip is placed centrally behind the design due to the following reasons:

1. **Optimal scan capability:** The tag is always positioned in the same location, making scanning easier
2. **Preservation of design:** Since the NFC chip is hidden behind the label, the container's exterior remains unchanged
3. **Practical usability:** The scanning process should take only a few seconds to ensure smooth and efficient use

To better illustrate the NFC tag placement, the figure below shows the planned integration. The container features a custom design, with the NFC tag placed between the container and the design layer.

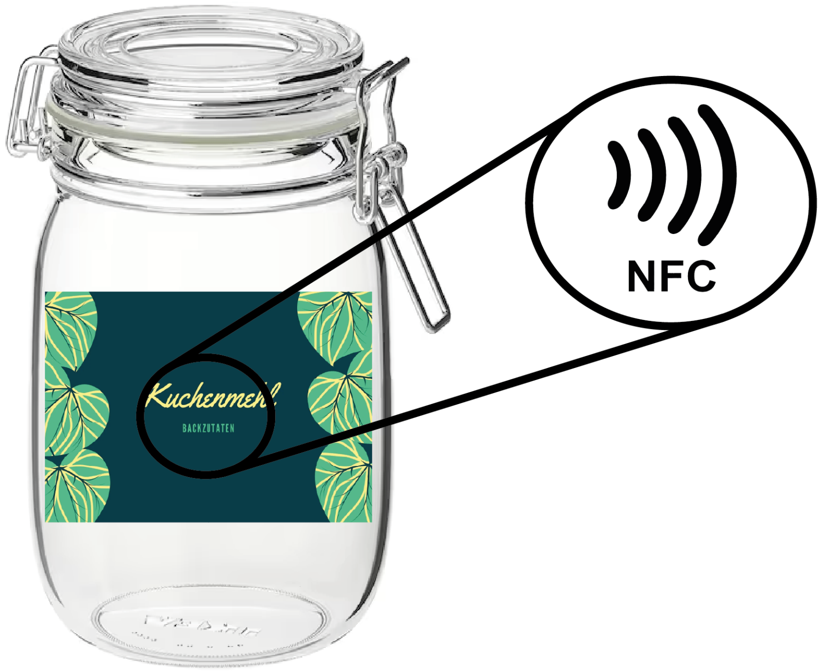


Figure 3.7: *Planned NFC tag placement in the reusable container [35, 36, 37]*

Positioning the NFC tag behind the custom design enhances user-friendliness, protects the chip from external influences and ensures an aesthetic solution. This method enables seamless NFC recognition while maintaining design flexibility for users.

Conclusion

Chapter 3 explored the key role of NFC in the reusable container system, from technology selection to practical implementation. Various technologies were compared, with NFC proving to be the most effective solution. A detailed analysis of NFC chip types led to the selection of NTAG215 as the best choice.
Additionally, the practical integration of NFC tags into the container was examined to ensure a user-friendly and discreet placement. With this, the theoretical foundation is established and based on these insights, the following chapter will focus on developing the app concept.

4 App: Idea and concept

Before discussing the technical implementation of the app, this chapter outlines the underlying concept. It analyzes the features of the application and how it aims to address existing challenges in sustainable shopping.

4.1 Objective of the app

The goal of the app is to simplify sustainable shopping for consumers by enabling the use of reusable, personalized containers with integrated NFC technology. This technology is designed to support the digital management and reordering of groceries.
The current zero-waste retail market presents several challenges that the app aims to address:

- Customers must bring their own containers and have them weighed on-site
- Refilling requires precise quantity specifications and an organized approach
- Hygiene concerns lead some stores to reject customer-brought containers
- The logistical effort for sustainable shopping can be seen as a barrier

The app aims to reduce these challenges by offering a digital ordering and management system that seamlessly integrates into existing sustainable shopping systems.

4.2 Functionality of the app

The application operates within a closed-loop system that integrates both users and retailers. Its functionality can be described in several steps:

1. Ordering a storage Container

- Users select a reusable container within the app and can personalize it
- Various design categories are available, allowing users to choose a pattern
- Alternatively, users can upload their own design
- Each container is equipped with an NFC chip that enables unique identification
- The container is assigned to the user and can be reused multiple times

2. Management and use of containers

- By scanning the NFC chip with their smartphone, users can manage the contents of the container
- The app allows users to specify which food items and quantities should be stored
- The app records the container history, enabling users to keep track of their supplies

3. Reordering products

There are two ways users can reorder products, either through in-store pickup or home delivery:

a) In-store pickup

- Users specify in the app which products and quantities should be refilled in the container
- This data is stored on the NFC chip of the container
- The container can be dropped off at a participating store
- The store cleans the container and refills it according to the stored specifications
- The user receives a notification when the container is ready for pickup

b) Home delivery

- Users can schedule a home pickup for their containers
- A delivery service collects the empty containers
- The containers are professionally cleaned and refilled according to the information stored on the NFC chip
- The refilled and cleaned containers are then delivered back to the user

4.3 Use cases / scenarios

To illustrate the functionality, the following sections describe some typical usage scenarios:

Scenario 1: First container purchase and personalization

A user downloads the app and orders a personalized storage container with a custom design. The container can either be delivered by post or picked up directly from a participating store. The NFC chip in the container is automatically linked to the user's account, eliminating the need for additional scanning.

Scenario 2: Refilling via in-store drop-off

A user plans the shopping by selecting the desired product and quantity in the app. This data is stored on the NFC chip of the container. The user then brings the container to a participating store, where it is accepted for refilling. The store cleans and refills the container according to the stored specifications. Once ready, the user receives a notification and can pick up the container or take it back immediately if available.

Scenario 3: Delivery and automatic refilling

A user wants to refill the container(s). Therefore, the user scans the NFC chip and store the desired products and quantities in the app. Next, a pickup through a delivery service can be scheduled. The service collects the empty containers, cleans them and refills them in accordance to the stored information. Finally, the refilled and sanitized containers are delivered back to the user.

4.4 Distinction from existing solutions

There are already several sustainable shopping approaches, including:

- Unpackaged stores, where customers bring their own containers
- Reusable deposit systems for to-go products
- Digital marketplaces offering plastic-free products

The app differentiates itself through the following features:

1. **Digital NFC management:** Users do not need to maintain manual lists or reminders
2. **Convenient ordering:** No cumbersome refilling at the store, the NFC chip stores all relevant data
3. **Flexible refill options:** Both in-store pickup and home delivery are available
4. **Customizable designs:** Containers can be personalized according to user preferences
5. **Sustainable system:** Containers are reused multiple times and professionally cleaned

The concept of this app aims to simplify sustainable shopping and overcome existing obstacles to the successful use of reusable containers. By leveraging NFC technology, container management becomes more streamlined, allowing both retailers and consumers to benefit from a digital solution.
This chapter provides the foundation for the further examination of the app's technical implementation. The next section will detail the development process, key functionalities and overall system architecture of the app.

5 Technical implementation of the app

5.1 Technology stack

This section describes the technology stack used for the development of the app. The stack includes various components for the frontend, backend, data management and NFC integration. The selection of technologies is based on factors such as scalability, user-friendliness, security and efficiency.

5.1.1 Frontend technologies

The app's frontend is developed using React Native. This technology enables cross-platform development for iOS and Android with a single codebase. The key advantages of React Native include:

- **Cross-platform compatibility:** A single codebase for both Android and iOS
- **High performance:** Utilizes native modules for critical functions
- **Large community and ecosystem:** Extensive support through open-source libraries
- **Easy integration with backend APIs**

IntelliJ IDEA is used as the development environment, as it provides powerful support for Java and modern web technologies.

5.1.2 Backend technologies

The backend is developed with Java and Spring Boot. This choice is based on the experience from my studies and the numerous advantages of this combination:

- **Proven enterprise technology:** Java and Spring Boot are widely used in professional applications
- **High scalability:** Enabled by Spring Boot's modular architecture
- **Extensibility:** Supported by various Spring modules such as Spring Security and Spring Data
- **Seamless integration with databases and RESTful APIs**

Spring Boot enables rapid and efficient development of web services and APIs, which are essential for communication between the frontend and backend.

5.1.3 Database

PostgreSQL is used for data storage and management. The choice of this relational database is based on the following advantages:

- **ACID compliance:** Ensures high data integrity

- **Scalability:** Suitable for both small and large applications
- **Extensibility:** Supports JSON data types and powerful indexing options
- **Seamless integration with Spring Boot via Spring Data JPA**

5.1.4 NFC integration

Since the app utilizes NFC tags for container management, specific libraries are required:

- **React Native NFC Manager:** A library for NFC integration in React Native
- **NDEF (NFC Data Exchange Format):** A standard format for reading and writing NFC tags

These libraries enable the efficient integration of NFC data into the application and ensure synchronization with the backend.

5.1.5 API interfaces

The communication between the frontend and backend is handled via RESTful APIs developed with Spring Boot. These interfaces enable:

- User authentication and authorization
- Storage and retrieval of product information
- Management of orders and refill processes
- Storage and retrieval of NFC data

The API is implemented using Spring Boot and Spring Web, adhering to REST principles to ensure a scalable and maintainable interaction between components.
The selected technology stack combines proven technologies, ensuring efficient development and maintainability of the app. Cross-platform development with React Native, a robust backend with Java and Spring Boot and powerful data management with PostgreSQL provide a solid foundation for the app's technical implementation.
The next section will detail the architecture of the application.

5.2 App architecture

5.2.1 Overall architecture concept

The application follows the client-server model, ensuring a clear separation between the user interface (frontend) and data processing (backend). While the frontend is developed using React Native, the backend is built with Spring Boot. Communication between both systems is handled via a RESTful API, which serves as the interface.
In the previous section, the technology stack was described. Building on that foundation, this section provides a detailed overview of the system architecture. The application follows a multi-layered architecture, ensuring clear separation of responsibilities among

components. This approach enhances modularity, simplifies maintenance and improves scalability.
The architecture can be divided into three main components:

- **Client (Frontend):** The React Native app serves as the user interface, sending Hypertext Transport Protocol (HTTP) requests to the backend. It also enables interaction with NFC tags.
- **Server (Backend):** The Spring Boot application acts as the central control unit, processing requests, executing business logic and managing the database.
- **Database (Persistence layer):** The PostgreSQL database stores persistent data and is managed via Spring Data JPA.

Spring Boot leverages the full capabilities of the Spring ecosystem, including Spring MVC, Spring Data JPA and Spring Security. It follows the Model-View-Controller (MVC) principle, where controllers receive HTTP requests from the client and forward them to the service layer. The JPA repository layer interacts with the database to perform CRUD operations (Create, Read, Update, Delete) [38].
Through dependency injection, services can efficiently communicate with repositories, resulting in a modular and testable architecture. Invalid requests or incorrect data are handled by Spring mechanisms before a HTTP response is returned to the client.
The following diagram visually represents this fundamental client-server architecture:

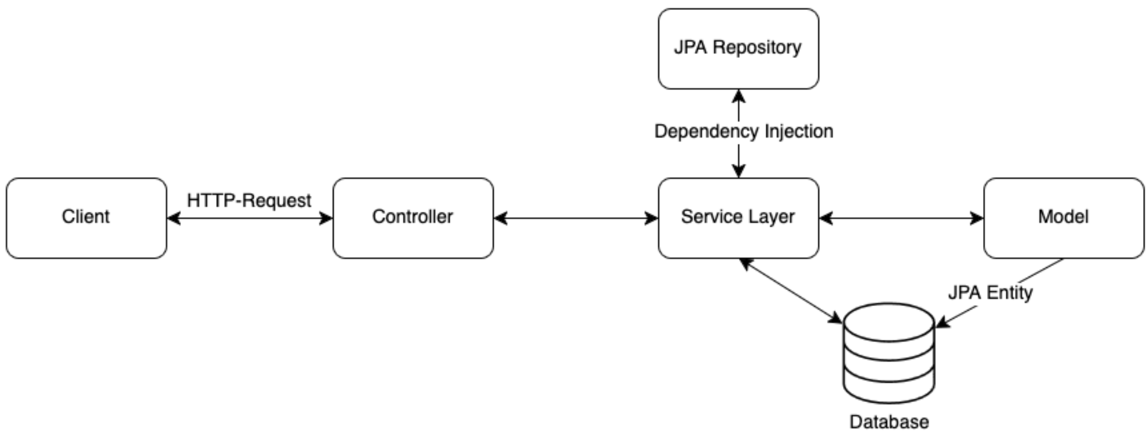


Figure 5.1: *Client-Server architecture with Spring Boot and JPA [39]*

The following sections will first describe the frontend architecture, followed by an in-depth explanation of the backend architecture.

5.2.2 Frontend architecture

The frontend architecture follows a layered model, which is divided into various functional areas. Top layer is the Navigation Layer, responsible for managing the application's navigation flow.

Directly below it is the Presentation Layer, which contains the user interface and interaction components. This layer communicates with the State Management Layer, which is responsible for managing both global and user-specific states within the app.
Finally, the Networking Layer ensures backend connectivity by handling API calls and processing HTTP requests.
The following diagram illustrates the structure of the frontend and how its individual layers interact:

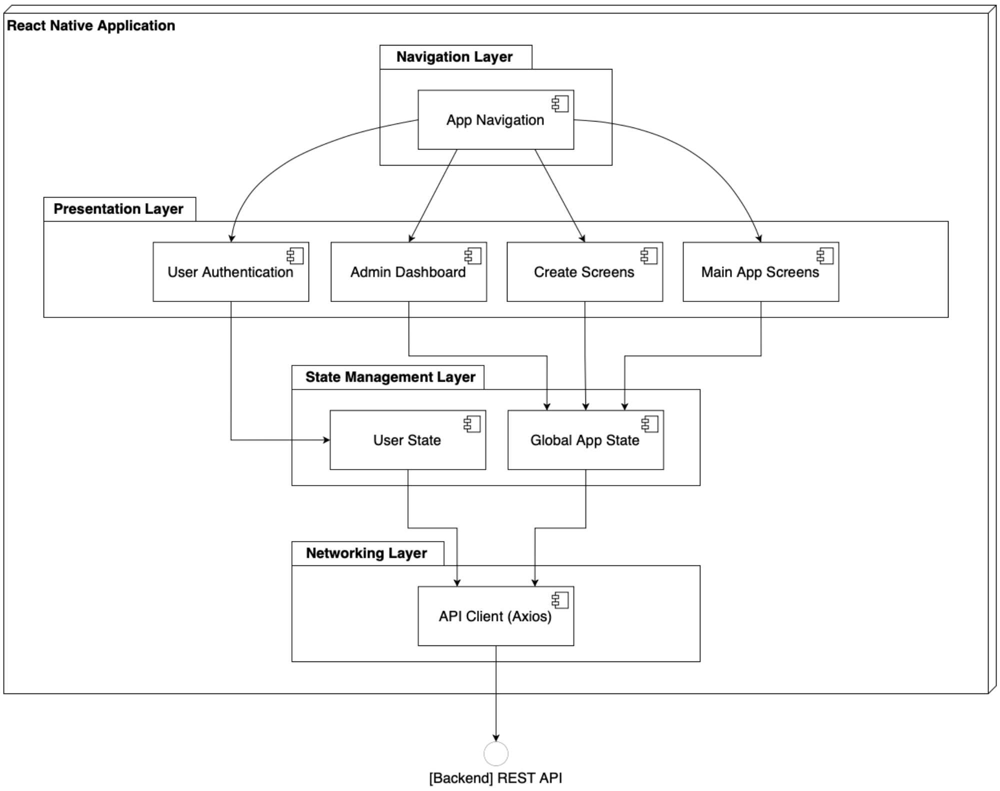


Figure 5.2: *Frontend layered architecture with navigation, UI, state management and API communication*

The frontend interacts with the backend through REST API calls, which are managed by the Networking Layer. This interface serves as the foundation for the transition to the backend, which will be described in detail in the following section.

5.2.3 Backend architecture

The backend architecture follows a multi-layered structure, ensuring a clear separation of responsibilities within the application.
At the top layer, the Application Layer contains the REST controllers, which receive HTTP requests from the frontend and forward them to the appropriate services. These services hold the business logic of the application and interact with the Persistence Layer, which is responsible for data access. The Persistence Layer is implemented using JPA repositories,

which are connected to the PostgreSQL database to efficiently store and retrieve persistent data.

The following diagram visually represents the backend architecture and illustrates the interaction between its components:

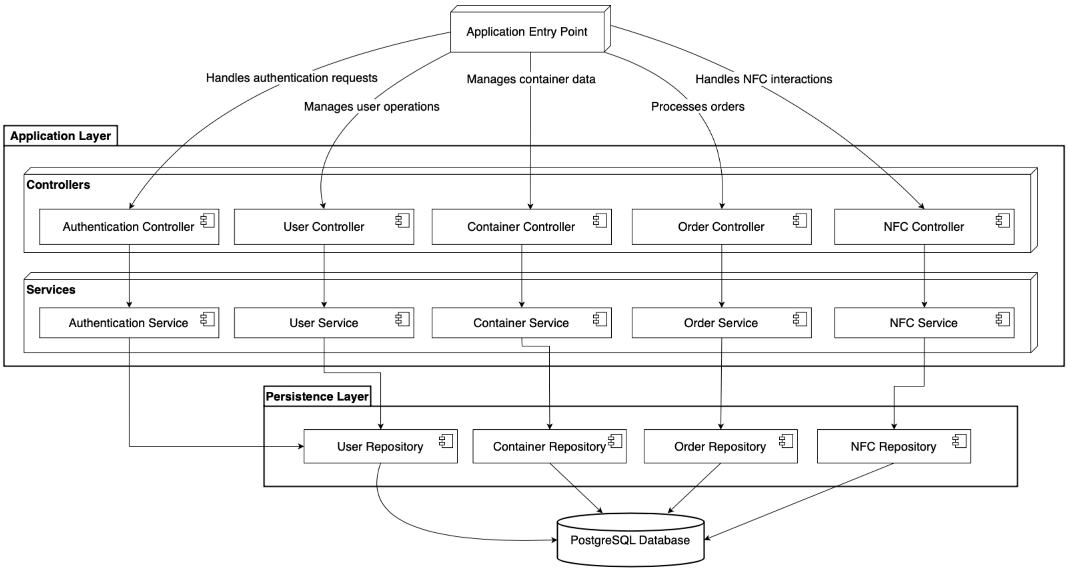


Figure 5.3: *Backend layered architecture with controllers, services and repositories*

This architecture ensures a clear separation between the frontend and backend, facilitating easy maintenance and scalability.
In the next section, we will take a closer look at the database structure and data management within the system.

5.2.4 Database architecture

The database architecture serves as the foundation for data storage and management within the application. PostgreSQL is used as a relational database, integrated into the backend via Spring Data JPA.

The following diagram presents the Entity-Relationship Diagram (ERD) of the database architecture, illustrating the relationships between the key tables:

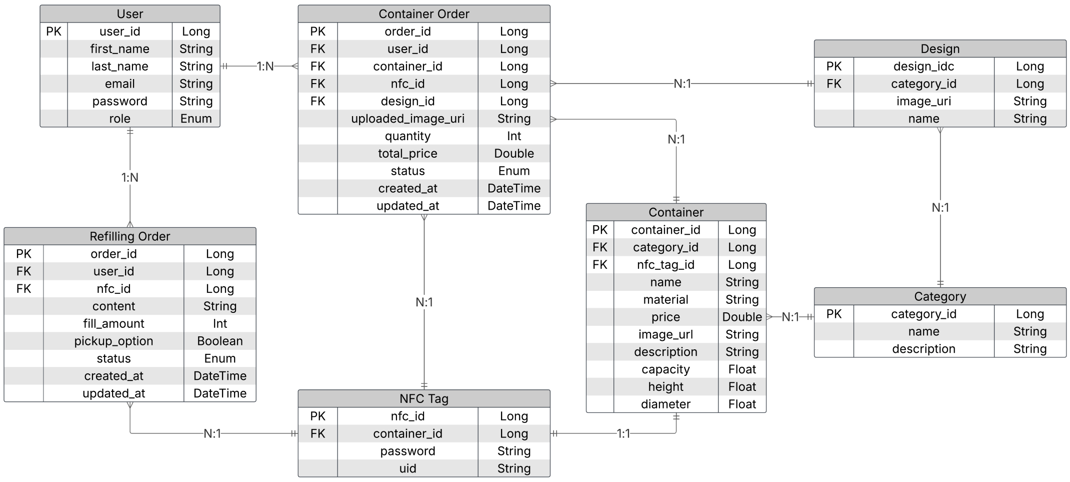


Figure 5.4: *Entity-Relationship Diagram (ERD) of the application database.*

The most important tables in the application are:

- **Users:** Stores user data (ID, name, email, password)
- **Containers:** Contains information about containers (material, size, NFC tag)
- **Orders:** Manages container orders & refills
- **NFCTags:** Stores NFC tag data linked to containers

These tables are connected through relationships (foreign keys) to ensure consistent database queries.
The interaction between the backend and database is managed via Spring Data JPA, enabling efficient execution of CRUD operations. The JPA repository layer establishes the connection to the database and provides functionalities for:

- Storing and retrieving data
- Managing user and order data
- Ensuring data consistency through transactions

This architecture ensures high-performance and scalable storage and processing of application data.

5.3 UI design and user experience

Before examining the implementation of app functions, it is essential to analyze the user interface (UI) and the underlying design principles. A well-structured UI plays a fundamental role in ensuring usability and intuitive navigation within the app.
The design process began with a planning phase in Sketch, a popular digital design tool, aimed at establishing a clear structure and a consistent visual style. This early-stage planning helped to account for different use cases and develop an intuitive user experience.

Building on this foundation, the technical implementation was carried out in React Native, with a focus on navigation structures and consistent UI components.
This chapter first explains how the app was conceptually designed before detailing the technical implementation of navigation and UI components.

5.3.1 User interface planning

A well-thought-out design starts with structured planning. Therefore, the UI of the app was first created using Sketch to define the navigation, screen layouts and user interactions.
During this phase, all essential screens were sketched and structured:

- **Authentication pages** – including login, registration and password recovery to manage app access
- **Main navigation** – featuring the home screen, NFC scanning, orders and settings for a clear user experience
- **Admin panel** – providing special functionalities for administrators, such as container and order management
- **Ordering process for storage containers** – allowing users to select containers, personalize designs and complete their orders

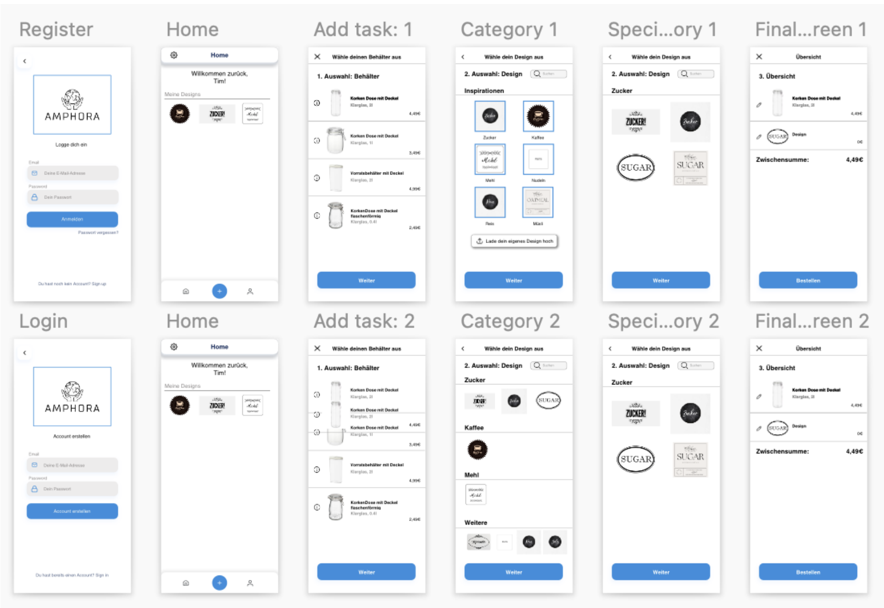


Figure 5.5: *Overview of the UI design process in Sketch*

These sketches helped to develop a consistent design approach and ensure usability at an early stage.

5.3.2 Navigation structure and UI implementation

The app utilizes a multi-level navigation system to ensure intuitive user guidance. Various navigation concepts are implemented:

- **Stack navigation:** Used for sequential processes such as authentication or order flows
- **Tab navigation:** Provides quick access to the main sections of the app
- **Admin-specific navigation:** A separate section for administrators with dedicated functionalities

The app's navigation is structured into different areas to ensure an intuitive and efficient user experience. Each area covers specific use cases, allowing users to access the required features quickly and effortlessly.

Authentication screens (AuthStack)

This section includes all pages required for user login and registration. Users start on the landing page, where they can either sign up or log in. If they forget their password, a password recovery option is available.
This navigation flow ensures that only registered and authorized users can access protected areas of the app.

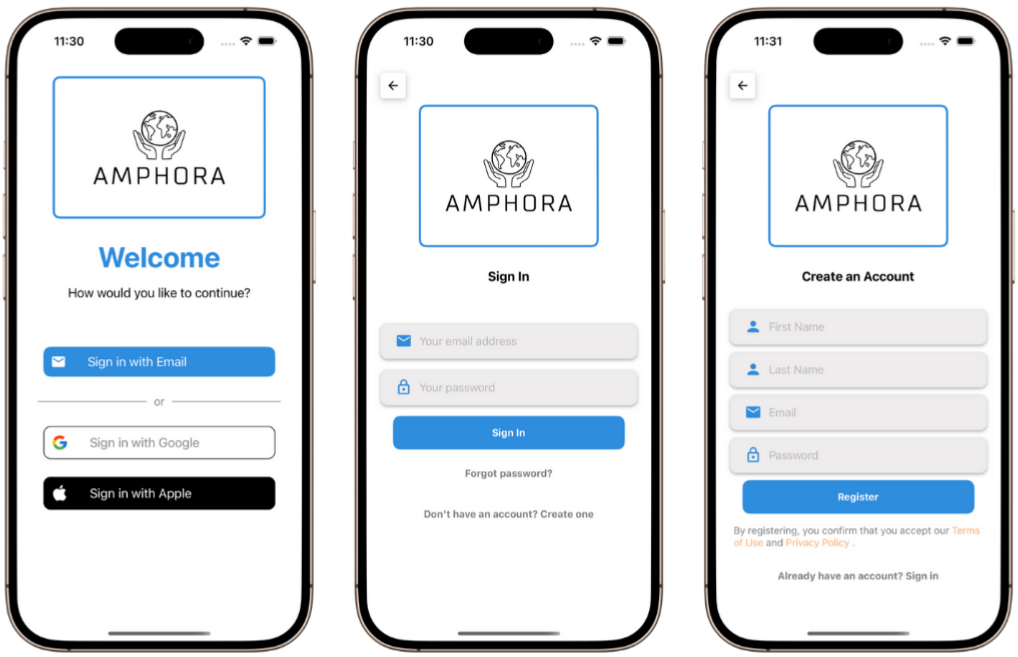


Figure 5.6: *User authentication flow and navigation (AuthStack)*

Main navigation (MainTabs)

The main navigation connects the core functions of the app, allowing users quick access to its most important sections:

- **Home screen:** Provides an overview of current orders and relevant information
- **NFC scan:** Allows users to scan containers for refilling or pickup
- **Settings:** Enables users to manage personal data and app preferences

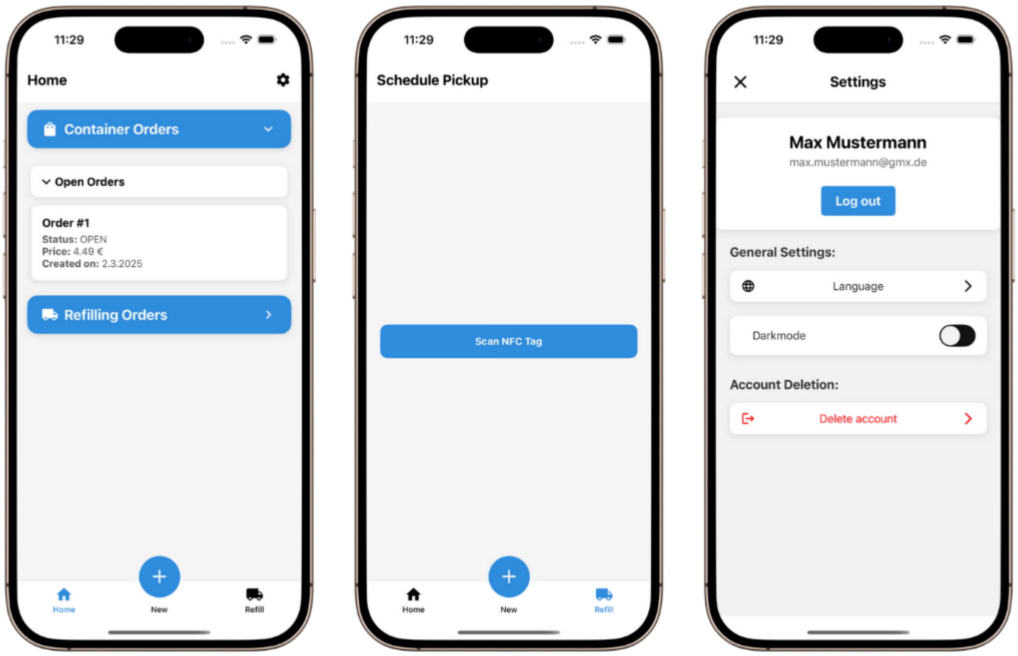


Figure 5.7: *Overview of the app's main navigation*

Ordering process (CreateTabs)

The ordering process for a storage container has its own navigation flow, structured into multiple steps:

1. **Container selection:** The user chooses a model from the available list
2. **Choose design category:** The user can either upload an individual design or select a category from the available options
3. **Select design:** The user picks a specific design within the chosen category
4. **Order summary:** The user reviews the order and completes the purchase

This step-by-step navigation ensures a structured and user-friendly ordering process.

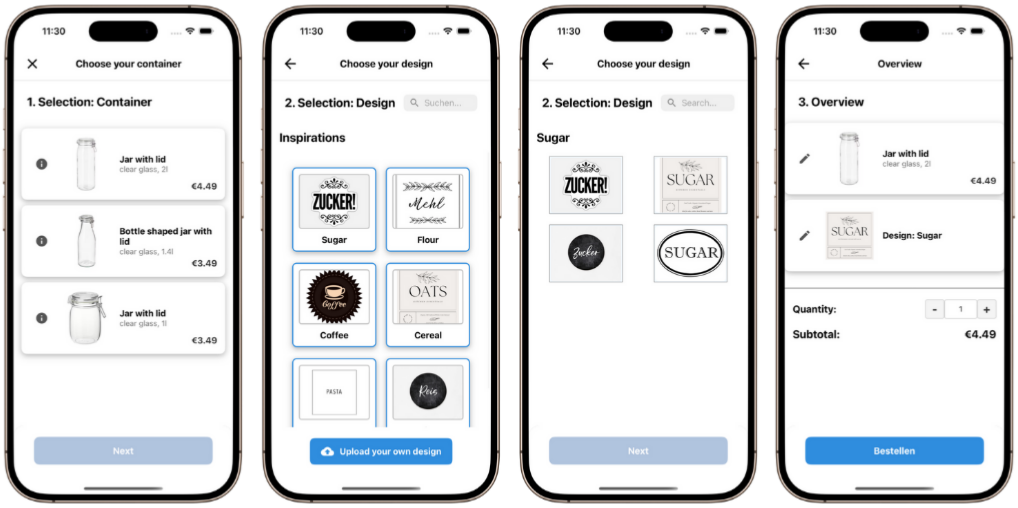


Figure 5.8: *Navigation flow for container orders*

Admin panel (AdminTabs)

Administrators have access to special management functions. They can:

- View a dashboard displaying an overview of all active orders
- Manage refill and container orders and update their status

Since these functions are not relevant for regular users, a separate navigation was implemented for administrators to maintain usability for end users.

Consistent UI elements and components

A well-structured UI relies on consistent and reusable components to simplify app usage and establish a clear design language. Throughout the app, the following uniform elements have been implemented:

- **Buttons:** All buttons follow a consistent design, using uniform colors and shapes
- **Form fields:** Standardized input fields ensure a cohesive user experience
- **Navigation bars:** Consistent navigation bars provide a structured user flow

By maintaining consistency across these elements, the app appears visually appealing and enhances usability for the end user.

Conclusion

Through careful planning with Sketch and the implementation of a structured navigation architecture, an intuitive and user-friendly interface was successfully created. The combination of stack and tab navigation ensures clear user guidance, making all key features easily accessible.
The next section will provide a detailed overview of the app's functionalities.

5.4 App functions

5.4.1 Security & authentication

This section provides a detailed explanation of user registration and authentication using JSON Web Token (JWT) and access control via Spring Security. Security is a critical aspect of the application to prevent unauthorized access and protect user data.

Registration & login with JWT authentication

Authentication is handled via a JWT-based approach, where users log in with their credentials and receive a secure token upon successful authentication. This token is used for subsequent requests to identify the user without requiring repeated credential submission.

1. User registration & data storage

During registration, users enter their personal information. The data is validated, the password is hashed using BCrypt and then securely stored in the database.

```java
@Transactional
public AuthenticationResponse register(RegisterRequest request) {
    Optional<User> userExists = userRepository.findByEmail(request.
        email());
    if (userExists.isPresent()) {
        throw new UserAlreadyExistsException("This email is already
            taken");
    }

    // Create user
    User user = new User();
    user.setFirstName(request.firstName());
    user.setLastName(request.lastName());
    user.setEmail(request.email());
    user.setPassword(passwordEncoder.encode(request.password()));
    user.setRole(RoleEnum.ROLE_USER);

    user = userRepository.save(user);

    // Generate JWT
    String token = jwtService.generateToken(user);
    RoleEnum role = user.getRole();

    return new AuthenticationResponse(request.firstName(), request.
        lastName(), request.email(), token, role);
}
```

2. Login process & token generation

After successful login, the user receives a JWT token, which is used for future requests.

```
    public AuthenticationResponse authenticate(LoginRequest request) {
        try {
            authenticationManager.authenticate(
                new UsernamePasswordAuthenticationToken(
                    request.email(), request.password()
                )
            );
        } catch (AuthenticationException e) {
            throw new WrongCredentialsException("Email or password do not match");
        }

        User user = userRepository.findByEmail(request.email())
            .orElseThrow(() -> new UsernameNotFoundException("User not found"));
        String token = jwtService.generateToken(user);
        return new AuthenticationResponse(user.getFirstName(), user.getLastName(), user.getEmail(), token, user.getRole());
    }
```

The login process is implemented via a login form in React Native. After a successful login, the received JWT token is stored and used for subsequent requests.

Roles & access control with Spring Security

The application distinguishes between regular users and administrators. Access control is managed through Spring Security, ensuring that only authorized users can access specific areas of the application.

- **User (ROLE_USER):** Can order containers and manage orders
- **Administrator (ROLE_ADMIN):** Has extended permissions, such as managing orders and user data

Spring Security allows precise control over which user roles can access specific API endpoints. This access control is implemented through a combination of role-based and permission-based management.
At the API level, requests are filtered based on user roles. For example, only administrators can access administrative functions, while regular users can only access their own orders. Additionally, a middleware layer validates every incoming request by checking:

- Whether the JWT token is valid
- Whether the user role stored in the token matches the required permissions for the requested endpoint

To further enhance the security of JWT authentication, the following measures have been implemented:

- **Token expiration:** JWTs have a limited lifespan to prevent misuse
- **Token renewal:** If the token expires, the user must re-authenticate
- **Signature verification:** The backend validates that the token is authentic and has not been tampered with
- **Secured storage:** On the client side, the token is stored securely to prevent XSS attacks

By implementing JWT authentication, role-based access control and secure NFC data processing, the application ensures that all security-critical processes are well protected. These mechanisms guarantee high data integrity and prevent unauthorized access.

5.4.2 Ordering process for storage containers

A core feature of the app is the ability to order personalized storage containers. The ordering process is designed to allow users to easily and intuitively select a container, choose a design and complete their purchase.

A key aspect of this process is that each ordered container is automatically assigned with an NFC tag. This NFC tag is later used for identification and refilling purposes. However, this assignment is not handled directly within the app — instead, it is managed through the backend after production.

The following section provides a detailed breakdown of the ordering process, covering both user interaction and the technical implementation.

Ordering process: Step-by-step

1. Selecting a container

The first step in the ordering process is choosing a suitable storage container. Users can select from various containers, differing in material, shape, size and price.

The selection is made through a clear and user-friendly interface, where containers are displayed with:

- Images
- Names
- Descriptions

Additionally, users can view more detailed information about each container.

Once a container is selected, it is visually highlighted and users can proceed to the next step by clicking the “Next” button.

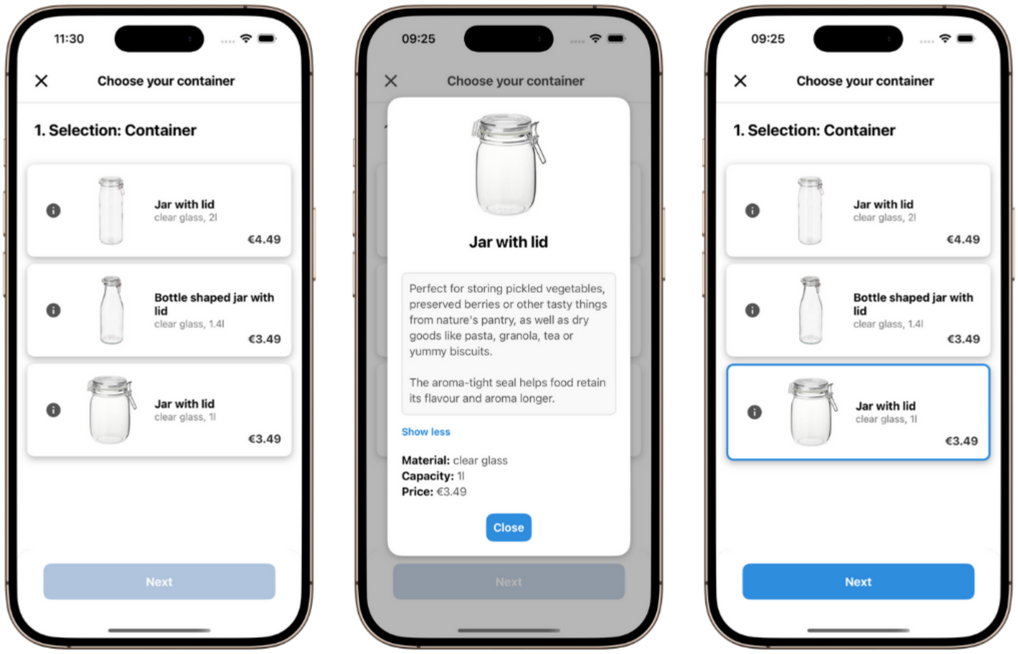


Figure 5.9: *Step 1: Choosing the right container*

The available containers are fetched via an API from the database and displayed in the app.

2. Selecting a design

After choosing a container, users can now select a design for the label. There are two main options available:

- Choosing a pre-designed template from a list of categories (e.g., sugar, flour, coffee)
- Uploading a custom design to personalize the container

If a predefined design is selected, users can navigate through categories and pick an option. If a custom design is uploaded, it is immediately displayed in the order summary.

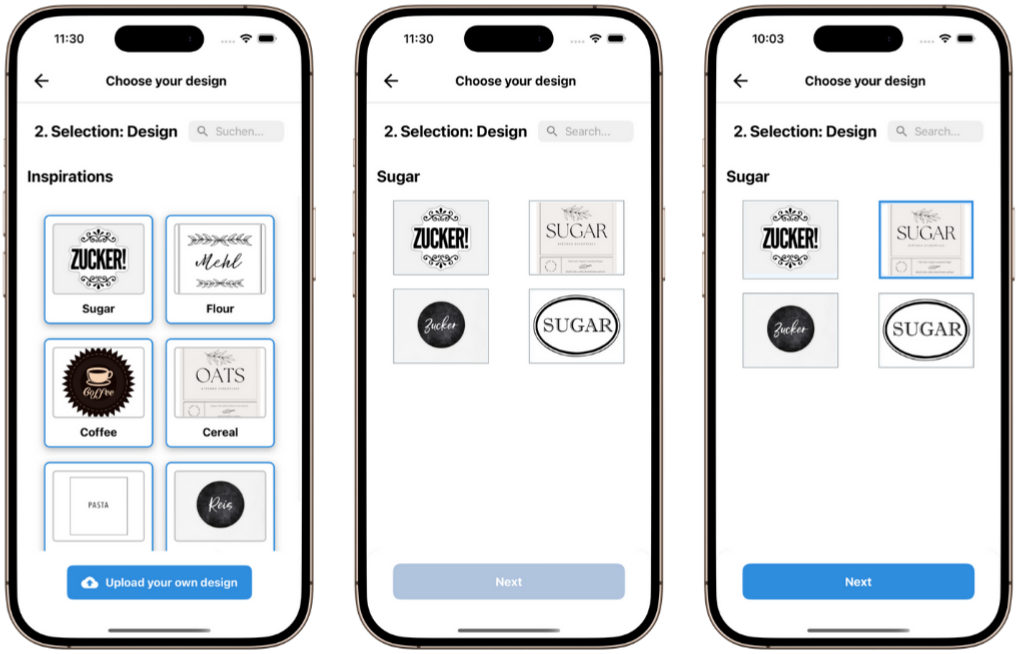


Figure 5.10: *Step 2: Selecting a label design*

To provide users with a seamless selection experience, the design grid is dynamically generated.
If users prefer to upload their own design, they can select an image from their gallery and import it into the app using the following method:

```
const handleUploadImage = async () => {
    const result = await ImagePicker.launchImageLibraryAsync({
        mediaTypes: ImagePicker.MediaTypeOptions.Images,
        allowsEditing: true,
        quality: 1,
    });

    if (!result.canceled) {
        const imageUri = result.assets[0].uri;
        navigation.navigate('OverviewOrder', { containerId: containerId, uploadedImageUri: imageUri });
    }
};
```

3. Order summary

noindent Before completing the order, users are directed to an overview page where all previous selections are displayed. Here they can:

- Review their selections (container type and design)
- Adjust the quantity of containers ordered
- Modify their choices if necessary

The order is only submitted after this final confirmation.

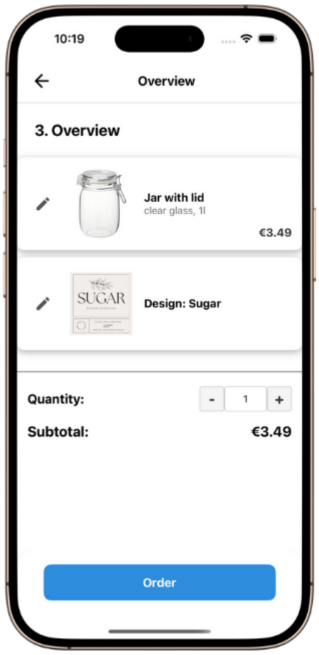


Figure 5.11: *Step 3: Checking and confirming the container order*

When the user clicks "Order", the request is sent to the backend, including the following information:

- The selected container
- The chosen or uploaded design
- The desired quantity

Upon successful submission, the user receives an order confirmation.
The order is transmitted to the backend as follows:

```
const placeOrder = async () => {
    const token = await getToken();
    const orderData = {
        containerId: selectedContainer.id,
        designId: selectedDesign.id,
        quantity: orderQuantity,
    };

    axios.post(SERVER_URI + "/order/create", orderData, {
        headers: {
            Authorization: `Bearer ${token}`,
            'Content-Type': 'application/json',
        },
    }).then(response => {
        console.log("Order successful:", response.data);
    }).catch(error => {
        console.error("Order failed:", error);
    });
};
```

This implementation ensures that all relevant data is accurately transmitted to the back-end.

NFC tag assignment after order completion

After completing the order, each container is automatically assigned with an NFC tag, which will later be used for identification purposes. This assignment process is handled in the backend, not within the app.

```
public void createOrder(ContainerOrderRequestDTO requestDTO, String
    token) {
    Container container = containerRepository.findById(requestDTO.
        getContainerId())
            .orElseThrow(() -> new RuntimeException("Container not
                found"));
    // NFC-Tag is generated
    NfcTag nfcTag = generateNfcTagForContainer(container);

    ContainerOrder order = new ContainerOrder(user, container, design,
        requestDTO.getQuantity(), nfcTag);
    orderRepository.save(order);
}
```

The ordering process for storage containers is designed to be simple, intuitive and flexible. Users can easily select a container, choose a predefined design or upload a custom one and complete their order effortlessly.
A key feature of the system is the automatic NFC tag assignment, which takes place after ordering. This ensures that each container is uniquely identifiable and can be seamlessly used for future refilling processes.

5.4.3 NFC functionality and implementation

Once a storage container has been ordered, it is automatically assigned an NFC tag for unique identification. This allows the app to quickly recognize the container later and provide relevant information, such as current contents and fill level.
NFC integration is therefore a core feature of the app, significantly simplifying the management of storage containers. Users can easily scan their containers, update the fill level and, if needed, trigger a reorder or pickup request.
This section provides a detailed explanation of how NFC integration was implemented. It starts with an overview of the user experience, followed by a technical breakdown and a discussion of security measures.

How NFC interaction works

The NFC functionality is divided into two main processes:

1. **Scanning an NFC tag:** The user scans an NFC tag linked to their account to retrieve the current status of the container.
2. **Updating container data:** After scanning, the user can adjust the contents and fill level and specify whether a pickup is required or if the container will be returned to a participating store.

Once the user saves the updated information, the new status is transmitted to the server and the data is written to the NFC tag.

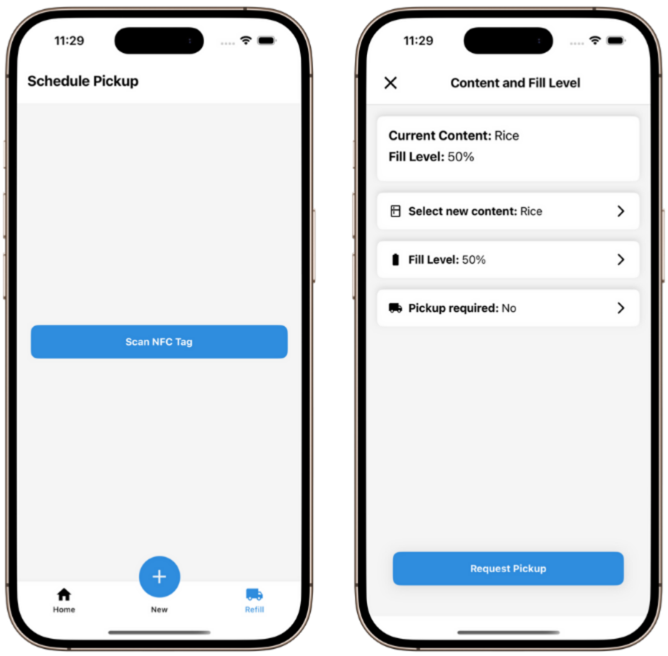


Figure 5.12: *Step-by-Step process of scanning and updating container data*

Implementation in the app

The NFC functionality was implemented using the react-native-nfc-manager library. The implementation consists of the following steps:

1. **Initializing the NFC Manager:**

```
NfcManager.start();
```

   This ensures that NFC functions are activated on the device.

2. **Scanning an NFC tag:**
   - The user presses the “Scan NFC tag” button
   - The app activates NFC and starts searching for a tag
   - After a successful scan, the UID of the NFC tag is read

```
await NfcManager.requestTechnology(NfcTech.Ndef);
const tag = await NfcManager.getTag();
const uid = tag.id;
```

3. **Verifying the NFC tag with the backend:** The UID is sent to the server to check if the scanned tag belongs to the logged-in user

4. **Displaying the current contents:** If the NFC tag is recognized, the stored information (e.g., current content and fill level) is displayed in the app

5. **Updating contents and fill level:**
   - The user can select a new content and fill level
   - If needed, a pickup request can be submitted

6. **Writing new data to the NFC tag:** After confirmation, the updated data is written back to the NFC tag

```
const data = `${newContent}|${newFillLevel}`;
const bytes = Ndef.encodeMessage([Ndef.textRecord(data)]);
await NfcManager.ndefHandler.writeNdefMessage(bytes);
```

7. **Sending data to the backend:** To ensure data consistency, the new values are transmitted to the server

```
const orderData = {
    nfcUid: uid,
    content: newContent,
    fillAmount: parseFloat(newFillLevel),
    pickupOption: isPickup === 'Yes'
};
await axios.post(`${SERVER_URI}/refilling`, orderData);
```

Security of NFC data

The security of the NFC data plays a crucial role, as NFC tags serve as unique identifiers for the containers. Without proper security measures, these tags could potentially be manipulated or accessed by unauthorized parties. To mitigate such risks, several security mechanisms have been implemented, with plans for future enhancements.

- **Access control & user binding:** Each NFC tag is permanently linked to a user account, ensuring that only authorized users can access its data.
- **Data encryption:** NFC information is not stored in plain text, but is secured using a secured hashing method.
- **Backend verification:** The backend validates each NFC scan, ensuring that the scanned tag belongs to the logged-in user. If the tag is not associated with the user, access is denied.

Conclusion

The implementation of NFC functionality provides users with a simple and efficient way to manage their containers. By directly scanning NFC tags, users can quickly update contents and process orders. The combination of local data storage on the tag and synchronized server storage ensures both high usability and data security.

5.4.4 Admin page: Managing orders and refills

In addition to the user view, the app provides a dedicated admin interface that allows for centralized management of all orders and refill requests. While users can view their own open and completed orders in their dashboard, the admin has comprehensive access to all incoming and processed orders.

Admin page features

The admin interface includes the following core functions:

- **View all orders:** The admin has access to a complete list of all orders, filtered by status (open, completed, ready for pickup).
- **Manage orders:** Each order can be opened and manually updated, for example, changing the status from “open” to “completed” or “ready for pickup”.
- **Handle refill requests:** In addition to container orders, the admin can monitor and process refill requests.
- **Send notifications to users:** Any order or refill status changes are communicated to users via notifications or dashboard updates.

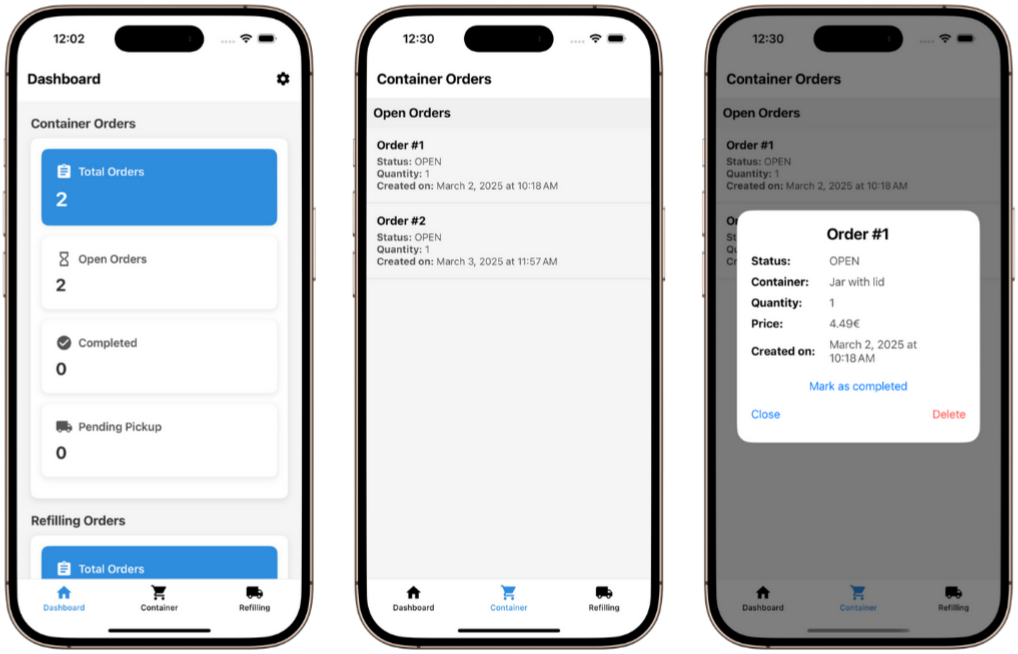


Figure 5.13: *Admin: Managing orders and refills*

Admins have the ability to access detailed order information, including items, quantity, price and creation date. In an expanded menu, orders can be completed or canceled. These changes are immediately reflected in the user app, ensuring transparency between users and administration.
The admin page serves as the central element for managing order processes, making the handling of container and refill requests more efficient.

5.5 Quality assurance & testing strategies

To ensure the stability and reliability of the application, the backend was extensively tested. Using JUnit and Mockito, the core functionalities of the system were systematically verified to detect and resolve errors at an early stage.

Test areas

The tests covered various layers of the backend architecture:

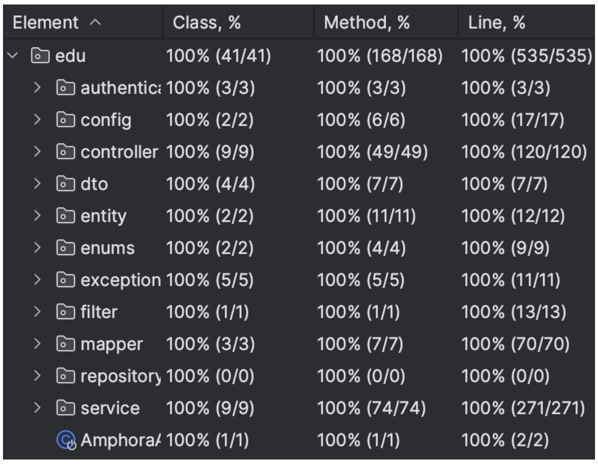
- **Controller:** API endpoints were tested to ensure that requests are correctly processed and return the expected responses.
- **Services:** The business logic was validated, particularly the management of orders, containers and user accounts.
- **Mapper:** The conversion of entities into DTOs (Data Transfer Objects) and vice versa was tested to ensure error-free data transfer between layers.

- **Authentication & security:** The JWT-based authentication process was verified to confirm that only authorized users could access specific functionalities.
- **Exception handling:** Various error cases were simulated to verify that the system correctly handles unexpected inputs or database failures and returns meaningful error messages.

Testing methodology & coverage

- **Unit tests:** Using mocking techniques (e.g., with Mockito), dependencies were isolated to specifically test individual components.
- **Integration tests:** The interaction between different backend layers was verified to ensure that data is correctly processed and transferred.
- **Security tests:** Scenarios involving failed authentication and authorization were deliberately tested to identify potential vulnerabilities.
- **Error handling scenarios:** Invalid inputs and faulty requests were simulated to assess how robustly the system responds to unexpected situations.

Through this comprehensive testing strategy, a 100% test coverage was achieved, ensuring that all critical functions of the application are secured by automated tests. This is illustrated in the following diagram.



Element	Class, %	Method, %	Line, %
edu	100% (41/41)	100% (168/168)	100% (535/535)
authentic	100% (3/3)	100% (3/3)	100% (3/3)
config	100% (2/2)	100% (6/6)	100% (17/17)
controller	100% (9/9)	100% (49/49)	100% (120/120)
dto	100% (4/4)	100% (7/7)	100% (7/7)
entity	100% (2/2)	100% (11/11)	100% (12/12)
enums	100% (2/2)	100% (4/4)	100% (9/9)
exception	100% (5/5)	100% (5/5)	100% (11/11)
filter	100% (1/1)	100% (1/1)	100% (13/13)
mapper	100% (3/3)	100% (7/7)	100% (70/70)
repository	100% (0/0)	100% (0/0)	100% (0/0)
service	100% (9/9)	100% (74/74)	100% (271/271)
Amphora	100% (1/1)	100% (1/1)	100% (2/2)

Figure 5.14: *Overview of test coverage*

Conclusion

The tests confirm that the backend operates stably and reliably. Invalid inputs are correctly handled, security mechanisms function as intended and all core features perform as expected. With high test coverage, the system is well-prepared for production deployment and can efficiently accommodate future expansions.

5.6 Conclusion and outlook on app implementation

The implementation of the app represents a significant step towards simplifying sustainable shopping. By combining NFC technology with an intuitive user interface, the application offers an efficient solution for managing reusable containers.
The app enables users to digitally manage their containers, easily place orders and keep track of their container status at all times. At the same time, the platform facilitates interaction with retailers and delivery services by ensuring seamless communication between all involved parties.

Future perspectives

Despite the successful implementation, there is still potential for further development:

- **Enhanced NFC security:** Future versions could focus on even stronger NFC security measures, such as advanced encryption or dynamically generated tokens to further minimize the risk of manipulation.
- **Expanded design options:** The ability to create personalized container designs could be further improved. A potential enhancement could involve collaborations with influencers or brands to develop exclusive, limited-edition designs, increasing the app's market reach.
- **Integration into additional markets:** The application could be extended to new areas, such as the gastronomy sector or retail industry, helping to establish reusable systems across more industries.

With these enhancements, the app could not only broaden its functionality but also make a long-term impact in promoting sustainable reusable systems.

6 Answering the research questions

After covering the theoretical foundations, technical implementation and integration into the retail sector in previous chapters, this section now provides a conclusive reflection on the initial research questions posed at the beginning of the study.
These questions served as a guiding framework for the development of the system and will now be reviewed to summarize the key insights gained and assess the added value of the implemented concept.

1. Which technologies are best suited for efficiently managing reusable containers within an app?

As part of this study, five technologies were evaluated: RFID, NFC, QR codes, blockchain and steganography. The analysis revealed that NFC is the most suitable option for practical use in the zero-waste retail sector.

- **RFID:** Efficient for warehouse management and large-scale retailers, but impractical for individual customers as it requires specialized readers.
- **NFC:** Provides a user-friendly, cost-effective and easily integrable solution. NFC tags can be seamlessly embedded into containers and read via smartphones.
- **QR codes:** Easy to implement but prone to manipulation and design limitations. Additionally, a direct line of sight is required, making handling less convenient.
- **Blockchain:** Offers tamper-proof traceability but comes with high costs and complex implementation.
- **Steganography:** An interesting approach for invisible data storage but technically challenging and difficult to implement.

Conclusion: Within the app developed in this study, NFC proves to be the most practical solution, as it enables direct user interaction with the containers while remaining cost-effective and intuitive. However, in other application scenarios, RFID or QR codes could also serve as viable alternatives.

2. How can the app be technically implemented?

The app was developed using React Native for the frontend and Spring Boot with PostgreSQL for the backend. The key technical aspects include:

- **Integration of NFC tags:** Each container is equipped with an NFC chip that stores information such as ownership, usage history and product details.
- **Database:** Storage of container and user data in a PostgreSQL database, connected via a REST API.
- **Ordering process:** Users can scan the NFC chip to refill products or manage the fill level of their containers.

- **Security:** Data is password-protected and encrypted to prevent misuse.

The app enables smart management of reusable containers and facilitates a seamless zero-waste shopping experience.

3. How can such a system be integrated into existing retail structures?

The integration is achieved through a network of participating retailers that support the system. The key aspects include:

- Participating stores offer reusable containers equipped with NFC tags.
- Containers can be returned, cleaned and refilled at designated retail locations.
- Users can purchase containers in selected stores, such as furniture retailers like IKEA, while refilling and returning them at partner stores, including supermarkets and unpackaged stores.
- Digital billing systems facilitate seamless integration into existing checkout systems.

This flexible structure makes the system attractive for both large retail chains and smaller unpackaged stores, enabling a scalable and widely applicable solution.

4. To what extent could such a system contribute to the reduction of packaging waste in the long term?

The widespread adoption of NFC-based reusable containers could lead to:

- A significant reduction in packaging waste by replacing single-use packaging with intelligently managed reusable containers.
- Enhanced sustainability in retail, making zero-waste concepts more digital and appealing to a broader audience.
- A seamless and digital solution for customers, making sustainable shopping more convenient and accessible.

Conclusion: The system has the potential to make a significant impact on waste reduction while increasing the acceptance of zero-waste concepts in society.

7 Conclusion and outlook

This study developed a digital system for managing personalized reusable containers in the zero-waste retail sector. The starting point was the question of how a technological solution could facilitate sustainable shopping and leverage the acceptance of reusable containers with improved user-friendliness. To establish a solid foundation for development, challenges in the zero-waste sector were first analyzed and various technologies were evaluated for their suitability in digital container management. Based on this analysis, an app was designed that utilizes NFC technology, enabling consumers to digitally manage their containers, easily organize refills and use them in partnered retail stores.

The evaluation of the research questions has shown that such a digital solution can make a promising contribution to reducing packaging waste. The ease of use and integration into existing retail structures are key advantages of the developed concept. At the same time, it became clear that user acceptance and collaboration with retailers are crucial factors for the long-term success of such a system.

An important aspect that could be explored further in future research is the scalability and widespread adoption of the system. While this study focused on a specific scope, further investigations could examine how such a solution can be implemented on a larger scale and what economic incentives could be created for retailers. Additionally, technological advancements, such as combining NFC with other tracking technologies or using blockchain for transparent container tracking, offer potential for further optimizations.

In conclusion, the app developed in this study represents a practical solution to promote sustainable consumption and support the zero-waste concept through a digital approach. The findings demonstrate that modern technologies not only facilitate sustainable behavior but can also contribute in the long run to establish resource-efficient alternatives in the retail sector.

List of Figures

List of Tables

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Declaration

I hereby declare that I have written the bachelor's thesis independently, have not submitted it elsewhere for examination purposes, have used only the sources and aids specified and have marked all verbatim and paraphrased quotations as such.

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