LEAN Model Based Experimentation on UI Prototypes

Using Task Based Usability Testing

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“Creativity is just connecting things. When you ask creative people how they did something, they feel a little guilty because they didn’t do it, they just saw something. It seemed obvious to them after a while.”

— Steve Jobs, co-founder of Apple Inc.

“If anybody here has trouble with the concept of design humility, reflect on this: It took us 5,000 years to put wheels on our luggage.”

— William McDonough, Designer, Author, and Thought Leader

“Daydreaming about your goals won’t bring results unless you start making a consistent effort. You have to engage the part of your brain to plan and organize, not just the creative dreaming part…”

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Acknowledgements

And I would **like** to acknowledge …

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Abstract

The user interface (UI) layer is one of the essential aspects of software applications since it associates end-users with the functionality. For interactive applications, the usability and convenience of the UI are essential factors for achieving user acceptability. Therefore, the software is successful from the end user's perspective if it facilitates good interaction between users and the system.

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Chapter 1

Introduction

This chapter motivates the readers about the topic (see section 1.1), explains the problems faced by the companies during software development (see section 1.2), our research approach (see section 1.3), and finally, our solution approach (see section 1.4).

1.1 Motivation

Over the last decade, software development had a tremendous impact with increasing customer demand and requirements [2], which increases product complexity and ambiguity, significantly impacting software development. Therefore, the developers have come up with different techniques to meet this requirement criteria. Early user feedback from potential customers in the industry is crucial for creating successful software products because of the growing market uncertainties, and consumers' desire to receive integrated solutions to their issues rather than unique software developments [3]. With the increasing complexity of products, it becomes challenging to determine user requirements making it more difficult for developers to assess their opinions. As a result, the developers of these products are biased toward some requirements and can ignore what the user wants. So, the developers must detect the user's needs and requirements to reduce these risks early. Giving users a "partially functioning" system is the most excellent method to determine their requirements and suggestions [4]. This ensures that the developers with high uncertainties in the early product development phase can improve the product by testing the underlying assumptions [5]. Developers can use this feedback to validate the most critical assumptions about the software product. This validation can decide whether to add, remove or update a feature [6]. This process of determining the best fit for the product through user feedback is called experimentation. There has been an increase in interest in the types of experimentation that can take place in product development. Software products have shown the benefits of conducting experiments in many use cases with incremental product improvement [7]. In experimentation, the product designers design different UI variants (e.g., buttons with different colors), and the developer integrates these variants and assigns them to a distinct group of users. As per some evaluation criteria (e.g., more clicks on the button), the variant with better results is deployed for the entire set of users. So, an experiment can be valuable when it improves the software products. Hence, for experiments to be successful, they should offer one or more solutions that will benefit users.

1.2 Problem Statement

The motivation section shows some gaps in software development between the developers and the designers. This section explains the problems and determines their research and solution approach.

Problem 1: Product designers create many UI prototypes, and the developers implement them. To determine the best variant, the developers create experiments with the users [6]. This concrete implementation of designs uses a lot of resources and time for the developers. Therefore, the product designers need to be integrated into the development process so that they would be able to create experiments independent of the developers.

Problem 2: When the product designers develop the prototypes, testing them with many users is difficult as the product is still not developed. Therefore, it is not easy to conclude a “winner” variant with a small amount of data as it is statistically difficult to prove one of the variants outperforms the others [8]. Therefore, it is necessary to develop an idea that the designers can use to determine the best prototype or variant with a small group of users.

Problem 3: Most often, the software application collects data from the experiments. Some data is used in qualitative analysis, while others are in quantitative analysis. Many companies fail to reap the benefits of using both qualitative and quantitative analysis. Similarly, not all the data is used in the analysis phase reducing the software applications to improve based on customer feedback [9]. Therefore, finding a solution that combines qualitative and quantitative data analysis is necessary.

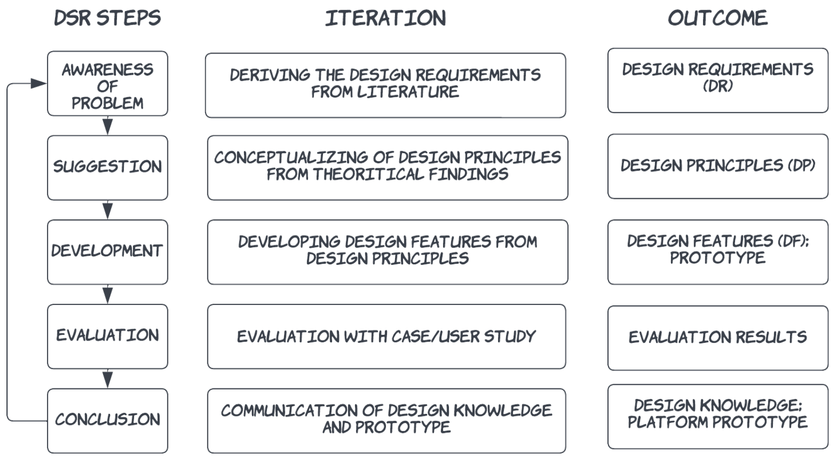


Fig. 1.1 Design Science Research Cycle [1]

1.3 Research Approach

The process of creating experiments and testing their variants is usually not systematically arranged, creating anomalies, and leading to unsuccessful experiments. Therefore, this section identifies the research question (RQ) and defines an approach to answer the question.

RQ: *How to develop a platform suitable for product designers to conduct experiments on UI prototypes, increasing its usability and, simultaneously, independent of developers?*

Prescriptive knowledge about the design of artifacts, such as software techniques, models, or concepts, is what design science research (DSR) aims to provide. Due to this design knowledge, future projects can design artifacts methodically and scientifically with the aid of study and practice [1]. Therefore, we will conduct a design science research (DSR) study to answer our research question and obtain abstract design knowledge and an implementation tool. From the abstracted knowledge, we will obtain some Design Principles (DPs) defined for the whole process of experimentation [1]. In this design, the product designers will iteratively validate their prototypes with the users (or the crowds). Here, DPs capture and codify that knowledge by focussing on the implementer, the aim, the user, the context, the mechanism, the enactors, and the rationale [10]. The DPs explain the design information that develops features for software applications. We propose to use the variation of the cycle of Kuechler and Vaishnavi [1] consisting of five iteratively conducted steps (see figure 1.1). As a result, this design and application may provide design-focused information that adds to the DSR knowledge corpus [11]. Every element within a DSR project is built upon and systematically analyzed to add to the overall DSR knowledge corpus. Therefore through the use of DSR, a group of issues is resolved by concentrating on a single issue and abstracting the consequences of the resolution.

Design Requirements (DRs): In design science research, abstracted *Design Requirements (DRs)* refer to the general, high-level requirements that a design must meet to succeed. These requirements are typically derived from the research question identified as relevant to the problem. Abstracted design requirements provide a broad framework for the design process and help to ensure that the design solution addresses the key issues and challenges identified in the research problem. They can also help guide the evaluation of the design solution and ensure that the solution is grounded in the design principles identified as necessary.

Design Principles (DPs): In design science research, concrete *Design Principles (DPs)* refer to specific, detailed guidelines that a design must follow to be successful. These principles are derived from the abstract design requirements identified as relevant to the research problem and provide more specific guidance on how the design should be implemented. DPs can also be defined as the codification of our knowledge during the design study while identifying the DRs. Concrete DPs are essential in DSR as they help ensure that the design solution meets the needs and goals of the research problem and is grounded in the design principles we identified as necessary [12]. More details about the DRs and DPs can be found in section **??**.

1.4 Solution Approach

To solve the problems mentioned above, the designers should be able to create UI prototypes and experiments on their own on a set of users. Since we do not have a large set of users for testing the prototypes, we use supervised task-based usability testing [13]. The fundamental principle of task-based usability testing is to have the users attempt to use the prototypes to do certain activities or tasks (e.g., Locate a movie M1) and get feedback (e.g., the time required for the task to be completed by the user). We propose to use `Low-code` or `No-Code` approach to achieve this. This approach helps to have a UI for the designers to understand, develop, and create experiments and tasks with the software prototypes [14]. So, the designers would be able to create the UI prototypes and their variants, assign them to the users in an experiment, get feedback from the users and decide on the best prototype. At the same time, the low-code has become more accessible for Model-driven development [15]. Therefore, we plan to create models for the UI prototypes and have the feasibility for creating experiments and tasks. Because of using the models, it is easier to store the prototypes in the database and conduct experiments with the users.

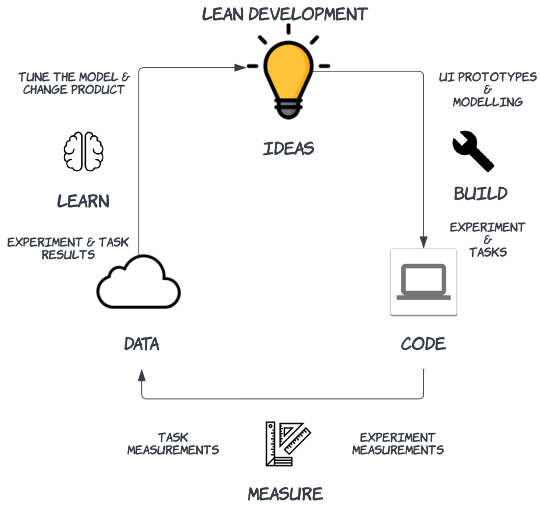


Fig. 1.2 LEAN Development technique

In our solution, we use the LEAN development technique (see figure 1.2) for development as it is used to develop customers friendly products [16]. Using LEAN, the company creates a Minimum Viable Product (MVP) throughout development, tests it with potential customers, and leverages their input to make incremental changes. While this technique can be used for every product, there are also approaches specific to software products. LEAN development technique can be divided into a Build, Measure, and Learn cycle. In the `(1) Build` phase, we plan to create the `UI Prototypes`, `Models`, `Experiments`, and `Tasks` for the users. In the `(2) Measure` phase, we plan to assign the Experiments and Tasks to the users and measure the `Task and the Experiment measurements` and perform some analysis on the data received. And finally, in the `(3) Learn` phase, we display the `Analyses results`, `Tune` our models to decide the better variant among the others, and `Modify` the prototype. As per figure 1.2, we complete one cycle of iteration and start a new one with the updated prototype.

1.5 Thesis Structure

This thesis presents the...

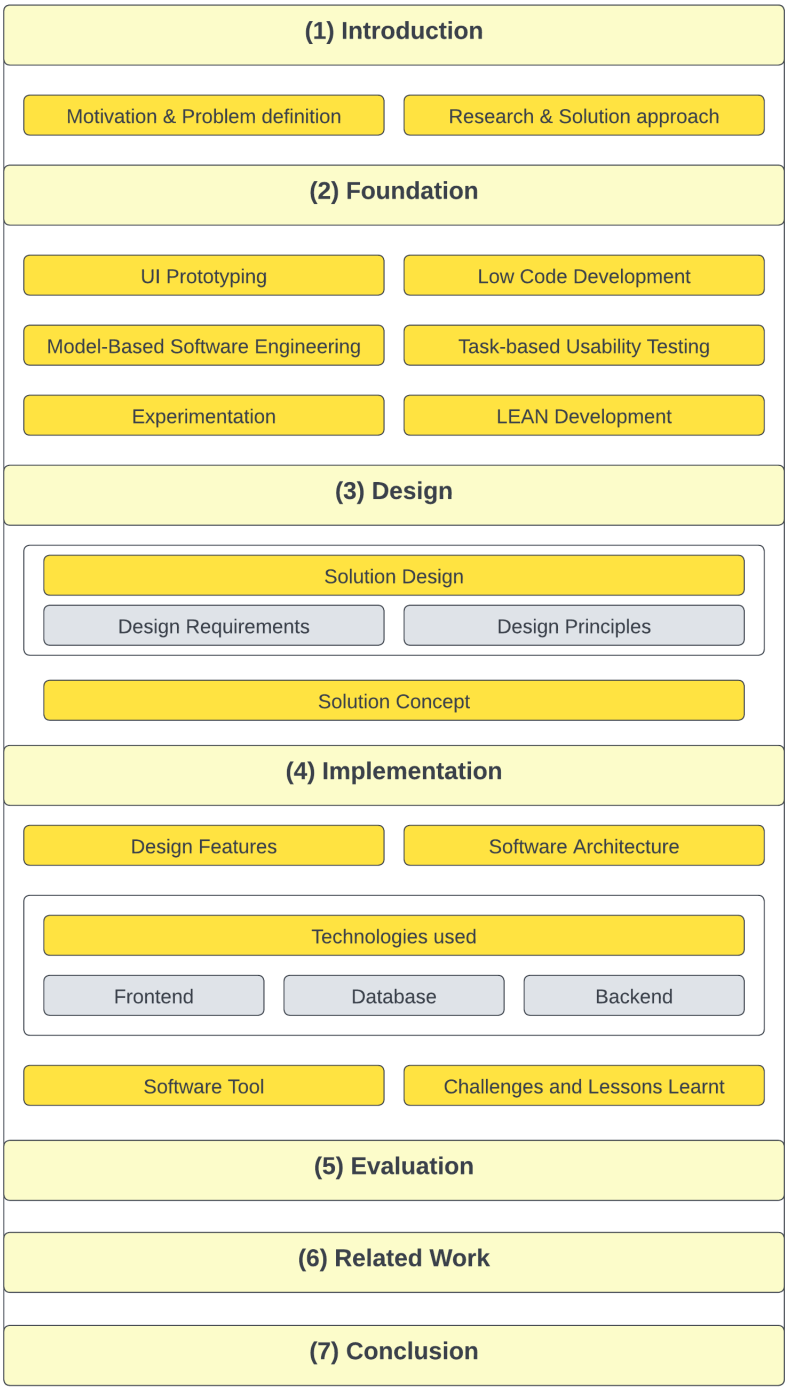


Fig. 1.3 Thesis Structure

Chapter 2

Foundations

The foundation of this research is built upon the existing knowledge and theories developed in the field of Software Engineering. This chapter provides an overview of the relevant literature and identifies the key concepts and theories necessary for the research. Firstly in section 2.1, we will discuss *UI Prototyping* explaining the creation of a User Interface (UI) simulation and testing and refining the design ideas and user requirements. Then, in section 2.2, we explain *Low/No-code methods* and citizen development of the software products. Then, in section 2.3, we describe the *Model-Based Software Engineering (MBSE)* approaches and meta-models. In section 2.4, we clarify *Task-based Usability Testing* for reviewing and refining the product. Later in section 2.5, we define the concept of *Experimentation* and *A/B testing*. Finally, in section 2.6, we explain the *LEAN software development process*, explaining the Build, Measure and Learn phases.

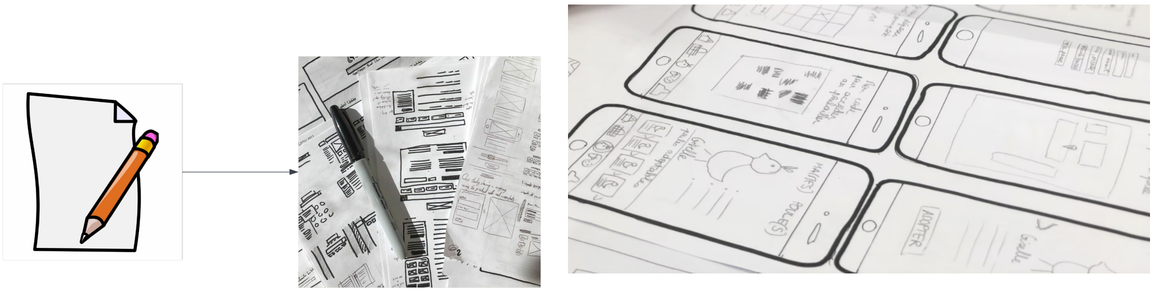
2.1 UI Prototyping

UI prototyping creates a simplified UI version to test and iterate on design ideas before building the final product. UI prototyping is a valuable tool for designers, allowing them to quickly and easily test and refine UI designs [17]. It also helps gather feedback from users and stakeholders [18] and identify any usability issues before investing significant time and resources into the final product. From paper to Hypertext Markup Language (HTML) code, everything could be a prototype, including various techniques like `Paper Prototypes`[1],

[1]**Paper prototyping:** It is a method of creating a preliminary version of a UI using paper and pen.

`Wireframes`[2], `Mockups`[3] and `Interactive Prototypes`[4]. Moreover, UI Prototypes can be classified as *High-Fidelity* and *Low-Fidelity* prototypes. The comparison by Jim Rudd et al. [19] on high and low-fidelity prototyping, based on its advantages and disadvantages, is explained further.

Low-Fidelity Prototypes: *Low-fidelity* prototypes (see figure 2.1) are prototypes usually with limited functions and little interaction prototyping effort. They mainly focus on explaining concepts, design alternatives, and screen layouts. Storyboard presentations, cards, proof of concept prototypes, paper prototypes, etc., come under this category. E.g., Paper-based prototypes are simple, low-fidelity mockups that can be quickly and cheaply created using paper and pencil (see figure 2.1a). In this case, the UI designers use simple text, lines, and forms to hand-draw concepts. Instead of aesthetics, the focus is on speed and creative ideas. To simulate user flows (as shown by figure 2.1b), designers lay paper screens on the floor, table, or pinned to a board. Therefore, these prototypes emphasize communicating, educating, and informing rather than training, testing, and codification [20]. The advantages of low-fidelity prototypes are rapid development, lower development cost, addressing issues, and usefulness for a proof-of-concept [19]. Similarly, the disadvantages include limited error checking, difficulty with usability testing, navigation, flow limitation, etc.



(a) Sketches and whiteboard for prototyping

(b) Example on how the paper-based prototypes are developed [21]

Fig. 2.1 Low fidelity prototyping

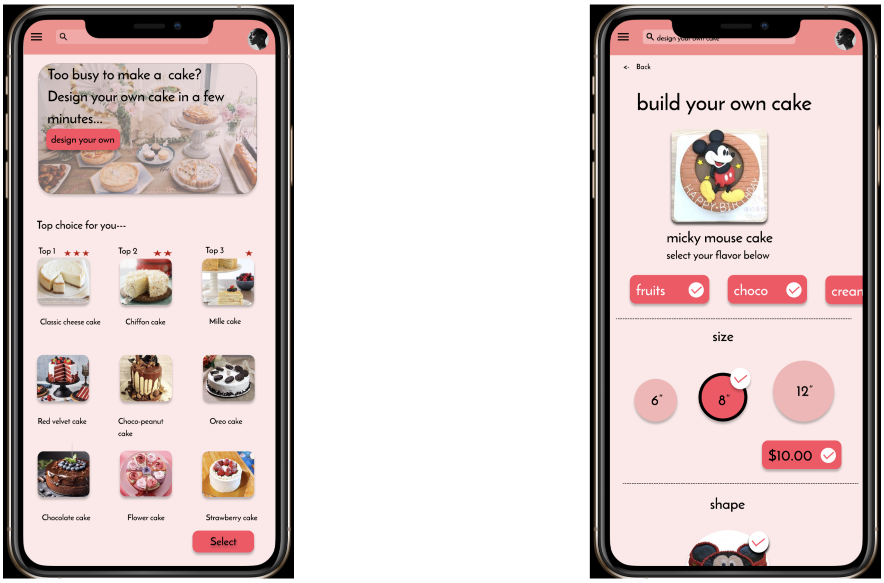
High-Fidelity Prototypes: Contrary to low-fidelity prototypes, *High-fidelity* prototypes (see figure 2.2) have full functionality and focus on flow, and the user models of the system

[2]**Wireframe:** A wireframe is an essential visual representation of the layout and structure of a product, showing the placement of text, images, and buttons.

[3]**Mockup:** A mockup is a more detailed version of a wireframe, typically created in color and with more realistic graphics and images.

[4]**Interactive Prototype:** An interactive prototype is a fully functional representation of a product, design, or feature.

[22]. These prototypes are detailed, interactive mockups of a UI designed to mimic the look and feel of the final product closely. High-fidelity prototypes are often created using interactive prototyping tools, which allow designers to create realistic, interactive mockups of UI designs [23]. These tools typically include a library of UI elements and templates and the ability to create interactive transitions and animations. The users can operate these prototypes, and the developers can collect information from the users through measurements. Some advantages of high-fidelity prototypes are that they are user-driven, used for navigation and tests, and can also be served as a marketing tool for attracting potential customers [19]. Therefore, these prototypes are typically more realistic and interactive than those created using other tools but may require more time and resources to develop and maintain. At the same time, high-fidelity prototypes allow designers and developers to test and refine complex UI concepts and interactions, ensuring that the final product is user-friendly and practical. Overall, low-fidelity prototypes and high-fidelity prototypes are both valuable tools in the design process, and the choice between the two will depend on the specific needs and goals of the project.



(a) Prototyping page of a cake company (b) Prototyping page to customize a cake

Fig. 2.2 High Fidelity prototype: Model-based UI Prototyping [24]

UI prototyping is an evaluation and testing technique according to User-Centered Design (UCD) methodology since the 1990s [25]. The evaluation of prototypes by users gives crucial feedback in iterative approaches for Information Technology (IT) project management, especially agile methodologies [26]. Therefore, to build an exemplary UI, a company can use this approach: develop a preliminary version of the UI, test it with people, and make as many revisions as possible (without building the actual software) [17]. Figure 2.3 shows a cycle representing the iterative development with prototypes. The designers start the process by developing the UI prototypes, which the stakeholders (e.g., customers and product managers) review. The UI prototypes are refined from the feedback received, reiterating the cycle. Therefore, designing UI prototypes enables designers and stakeholders to communicate more effectively. Similarly, an interactive prototype helps visualize design concepts and

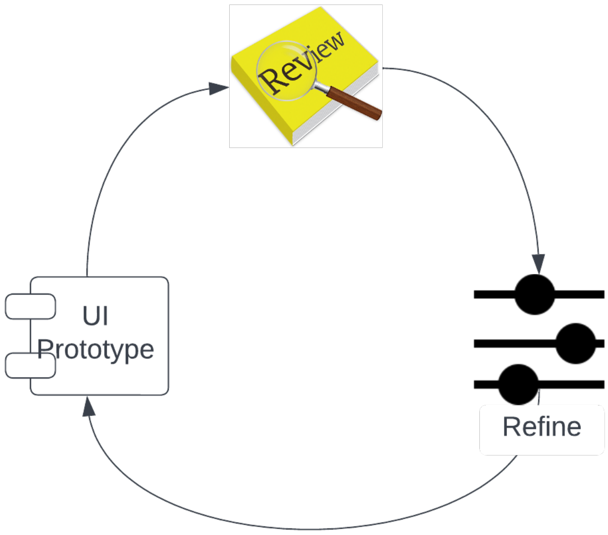


Fig. 2.3 Prototyping steps for an iterative development

communicate new requirements and expectations about a prospective system. Iterative design requires multiple updates to the design's execution.

Since developing and updating the entire software system is complex and expensive, prototyping is a crucial technique [27]. Simultaneously, software prototypes might exclude many requirements, making the software more accessible, smaller, and less expensive to construct and change [27]. Thus, the main difference between a prototype and a software application is that in a prototype, the displays are designed images with no additional capabilities to display the design and flow. Moreover, usability testing to validate user requirements and prototype functionality is part of the evaluation process for UI prototypes [28]. Thus by using prototyping, there is usually more contact between the designers and users, resulting in fewer usability flaws and corrections at the end of development. And finally, these mockups are then converted into actual UI elements in a software application, and a flow is available.

Overall, UI prototyping is an essential part of the design process. It allows designers and developers to quickly test and refine UI concepts, gather feedback from stakeholders and users, and identify any usability issues before investing significant time and resources into building the final product. Whether using low-fidelity prototypes to test basic layout and navigation concepts or high-fidelity prototypes to test complicated UI concepts and interactions, prototyping can help ensure that the final product is user-friendly and effective. By iterating and refining their prototypes throughout the design process, designers can create better, more intuitive products that meet the needs of their users.

2.2 Low Code / No Code Development Platform

Low code is a software development method that uses less human coding to enable users to construct and manage programs efficiently rather than writing extensive amounts of code [29]. It is a technique used by developers to help non-developers design and develop software applications using a *Graphical User Interface* (GUI) supported by a *Low-Code Development Platform (LCDP)*. An LCDP allows developers to create, deploy, and manage applications quickly and easily using high-level programming languages and techniques such as model-driven and metadata-based programming [30]. It simplifies building and deploying applications using declarative programming abstractions and one-step deployments. LCDP provides pre-built components, templates, and other resources that companies can quickly assemble to create functional applications. These platforms are designed to accelerate the development process and enable companies to quickly build and deploy custom software solutions. Similarly, there is another technique called *No-code development* supported by the *No-Code Development Platform (NCDP)* [31]. Unlike low code, no-code platforms require no programming skills because they offer drag-and-drop techniques for building the apps. The non-developers can easily pick up the components which fit the UI and drag and drop them to the screen and finally create an entire application using this technique. Using the user interface and ready-made automatic tools on these application development platforms, it is feasible to create apps relatively quickly. Due to its simplicity, flexibility, and low cost, companies have started using this platform to meet the high demands of software development and digitalization [29]. Additionally, with its self-configurable components, it lowers the expenses associated with initial installation, training, distribution, and maintenance [32].

High-level architecture of LCDP: As shown in figure 2.4, an LCDP is divided into small modules independent of the other components. Bock et al. [30] have classified these modules according to the three main approaches to systems development: *the static perspective*, *the functional perspective*, and *the dynamic view*.

Static Perspective: LCDPs typically allow data to be stored either in an internal Database Management System (DBMS) or in external systems (see the first part of figure 2.4). Many of these features/components commonly found in LCDPs fall under the *static perspective*. Similarly, most LCDPs include a component for defining Data Structure (DS), usually provided as a conceptual modeling tool that uses a classical Data Modeling Language (DML) such as the Entity-Relationship Model or a Domain Specific Language (DSL). Some LCDPs allow DS to be defined only through UI-based dialogs or lists. For example, you are allowed to upload a Comma Separated Value (CSV) file that contains data that is persisted into the Database (DB) as per the columns in the file. A common feature of LCDPs is the ability to access external data sources using various Application Programming Interfaces (API).

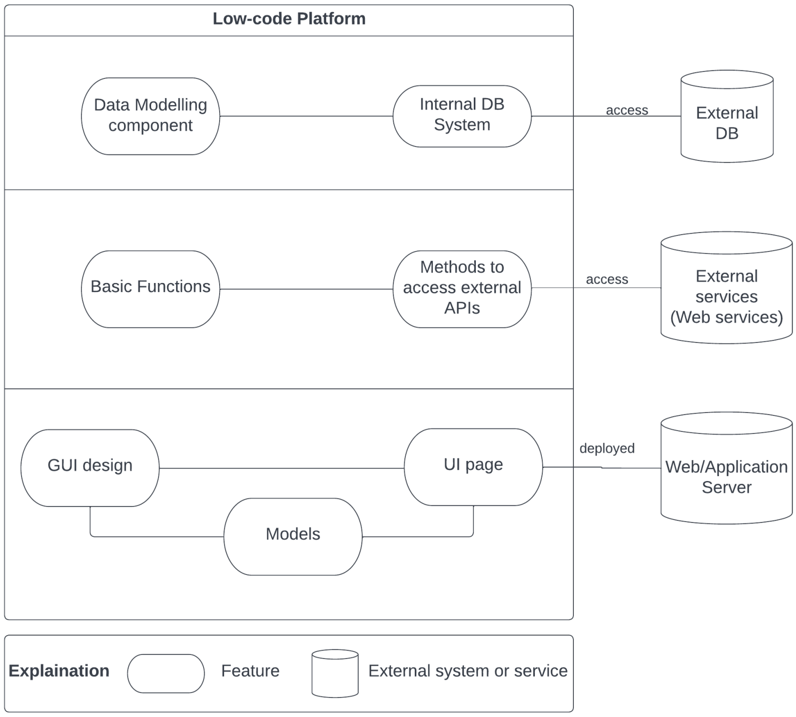


Fig. 2.4 High-level architecture of Low code Development platform

Functional Perspective: LCDPs also offer basic functional specifications (see the second part of figure 2.4). These typically include simple expression languages for decision rules and dialog-based methods for specifying program flow conditions. Each solution consists of a library of generic standard operations, such as mathematical functions. For example, LCDPs will enable the use of traditional approaches such as web services and Representational State Transfer (REST) services, and many modules provide support for a wide range of APIs from individual providers, such as Google APIs, and social media APIs [30].

Dynamic Perspective: The LCDP also includes a Graphical User Interface (GUI) designer module (see the third part of 2.4), which allows for the development of GUIs and their integration with other implementation elements. The GUI designers module specifies pre-defined widgets, although the range varies. It is generally easy to link GUIs and DSs in most of these platforms, as it is optional to implement the Model-View-Controller (MVC) pattern manually. In addition, many of these platforms offer specific support for adapting the GUIs to different target environments, such as desktop browsers, tablets, and smartphones [33]. Another common feature is the inclusion of a component for defining roles and user rights, which is usually part of the platform's governing architecture and is deployed along with the custom application [29].

Main Steps Of ***Low-Code*** *App Development* as per [34]:

Building: In this step, the platform gives you the freedom to alter the provided code and add hand-written custom code to it to specify more complex features in the app as you create the app step-by-step using visual editors and drag-and-drop interfaces. Modules, components, and chart-builders are already incorporated into low-code applications. Charts may be used to display data from modules, while modules are used to specify the type of data that will be stored in the app. Components and pages provide the type of user experience the app will have. These platforms also have a provision for automating repetitive tasks in the app.

Testing: Testing a software application is an integral part of the development cycle. However, the low-code development platform decreases the requirement for testing. Pre-build modules and components on low-code platforms are created with a certain level of application security. The developers of the low-code platform constantly monitor these modules, and they have previously gone through several unit tests. But, in a low code platform, testing can be performed in several ways [35]:
- *Automated testing:* Some low-code platforms have built-in support for automated testing, which allows developers to create and run tests that validate the functionality of their applications.
- *Manual testing:* Even with automated testing, it is necessary to perform manual testing to ensure that an application functions correctly. In a low-code platform, manual testing can be achieved by developers or by dedicated testers who are responsible for verifying the functionality of the application.
- *User Acceptance testing (UAT):* In some cases, it may be necessary to involve end users in the testing process. This can be done through user acceptance testing, which consists in having end users test the application and provide feedback on its functionality and usability.

Overall, testing in a LCDP involves a combination of automated and manual testing, as well as performance and acceptance testing [35], to ensure that the application is functioning correctly and meets the needs of end users.

Deploying: In this step, the application is deployed across apps and to the final users. In LCDP, the packages for installation, configurations, and application setup are included. In terms of deployment, most of the considered solutions offer advanced support, although the specific forms vary. Some systems require the low-code platform environment to be installed on a web server to deploy individual applications. In contrast, others allow the developed solutions to be deployed as self-contained applications on various devices and machines. This means that the LCDP gives freedom to the users in deploying the applications for the customers with just one click.
Docker[5] is a widely used open software platform that allows applications to be deployed as containers. It supports libraries, system tools, code, and various runtimes, making it possible to build, test, deploy, and scale applications across multiple environments. In an LCDP, docker can be used to securely deploy frameworks, services, and platforms in separate containers that communicate with each other using protocols such as Message Queue Telemetry Transport (MQTT)[6] and REST[7]. Additionally, a variety of options are provided for developers with little programming experience, those with coding expertise and seasoned programmers who wish to expand the functionality of the current design [29].

Overall, low-code/no-code development platforms are valuable for organizations looking to build and deploy custom applications quickly and efficiently that can help organizations of all sizes and industries bring their ideas to life.

[5]Docker: https://www.docker.com/
[6]MQTT: The Standard for IoT Messaging https://mqtt.org/
[7]REST API (also known as RESTful API) https://www.redhat.com/en/topics/api/what-is-a-rest-api

2.3 Model-based Software Engineering

MBSE refers to maintaining and developing software while reusing existing code. Similarly, Model Driven Software Engineering (MDSE) is the term used to cover various techniques for creating software using codified models. At the same time, for creating models, the Model Object Facility (MOF) has defined four levels separating the reality, models, meta-models, and meta-meta-models (as shown in the figure 2.5).

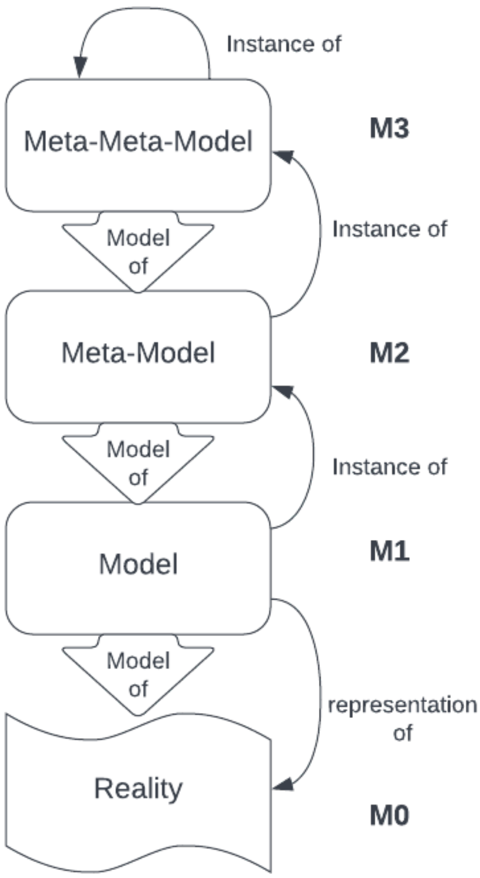


Fig. 2.5 Model Object Facility (MOF) levels

MOF is a standard that defines a meta-model for modeling information. It provides a common framework for creating and using models representing a system or part of a technique used to analyze design or document the procedure. MOF is part of the Object Management Group (OMG) [36] standards and is used in several different contexts, including software engineering, business process modeling, and enterprise architecture. It is based on the Unified Modeling Language (UML)[8] standard notation for modeling software systems. MOF defines a standard set of concepts and notations for creating and using models, which can represent different aspects of a system. This includes concepts such as classes, attributes, operations, and relationships, which describe the system's structure and behavior.

Meta Models: A meta-model is a model of a model or a simplified version of an actual model of a system of interest or a software application that formally represents the structure and behavior of a particular model type in a formal and standardized way. Meta models are often used in Software Engineering (SE) to describe the structure and behavior of DSL or other modeling languages [37]. They can be used to understand how a model works or to improve the performance of a model by making it more efficient or accurate. Meta models are often used in Model Driven Development (MDD), focusing on creating and using high-level abstractions to design and implement software systems [38]. By using meta-models, developers can create a high-level view of a system and then use that view to generate code automatically, which can help improve the development process's efficiency and reliability. A model is usually defined as an abstraction of real-world entities, and a meta-model is another abstraction of the models. Similarly, metamodelling is analyzing and developing the rules, theories, and models helpful in constructing meta-models.

The **M0 layer** refers to the physical system or systems that are being modeled. It represents the *Real World* or the physical components, subsystems, and techniques that comprise the overall system being designed or analyzed. It is the foundation upon which the other layers of the MBSE models are built.

The **M1 layer**, built on top of the M0 layer, represents the functional requirements and system behavior. The functional requirements include system inputs, outputs, and interfaces, and the system's behavior includes its response to different inputs and conditions.

The **M2 layer**, built on top of the M1 layer, represents the system's architecture and design. This layer describes how the system's components, subsystems, hardware, and software interact. The M2 layer includes detailed specifications and design constraints such as interfaces, protocols, and data structures.

Finally, the **M3 layer** represents the system's implementation and verification. It includes the system's specific design details and implementation plans, including the detailed design of its components, selecting particular hardware and software, and testing and validation plans. This layer ensures that the system is built according to the specifications and design constraints defined in the M2 layer and meets the functional requirements and behavior described in the M1 layer.

[8] Unified Modeling Language https://www.uml.org/

After considering the information above, the meta-model can be further developed and refined. There are two approaches to designing a meta-model: *Top-down and Bottom-up* [36]. In the top-down method, we start with the overall process and then break it down into smaller steps. In the bottom-up approach, we begin with the individual steps and group them into more extensive procedures. *Top-down development* of a meta-model involves starting with a high-level representation of the structure and behavior of the models that the meta-model will describe (see figure 2.5). This high-level representation (M3 from figure 2.5) might include the overall design of the models (e.g., the types of elements and relationships that are allowed) and the rules and constraints that must be followed when creating and using the models. Once the high-level structure of the meta-model has been defined, it can be further refined and expanded upon by adding lower-level details (M2 and M1 and M0 levels). They include the attributes and operations allowed for each element, how elements can be related, and the semantics of the relationships between elements.

Bottom-up development of a meta-model involves starting with the specific elements and relationships that will be included in the meta-model and gradually building up to a higher level of abstraction. Once the lower-level details of the meta-model have been defined, they can be organized and grouped into higher-level concepts and structures, such as classes, packages, or packages of packages, to form the overall design of the meta-model [36].

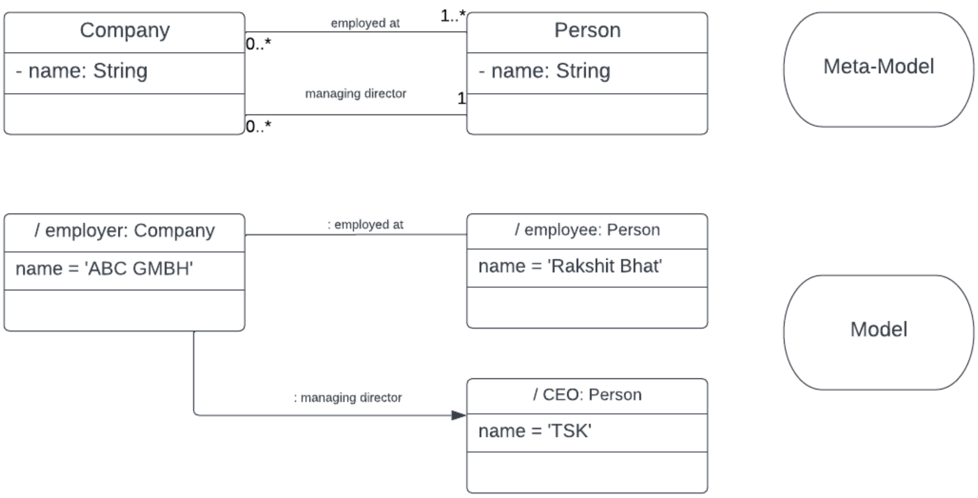


Fig. 2.6 Meta models and Models

Models: As shown in figure 2.5, a *Model* is a simplified representation of the real world or reality. Before any code is written, the model is a schematic that describes how the software system should function. In software development, a model is a representation of a software system. It can be used to visualize the structure and behavior of a system or to analyze the system for potential issues or improvements. Models can take many forms, such as diagrams, graphs, or mathematical equations, and they can be created using various tools and techniques. Models are often used in MDD [38], focusing on creating and using high-level abstractions to design and implement software systems. In this approach, models are used as the primary source of design and implementation information, and the code is generated from the models using a code generator [39]. By using models, developers can better understand a system and identify potential problems or areas for improvement before they start writing code. From the example 2.6, we need to create models for every entity of reality (e.g., An employee and a CEO both are *Person* in meta-model but are separate entities in models). Using models, various adaptive model-driven user interface development systems are developed [40] and the authors defined twenty properties challenges for the Model-driven User interface and compared some tools that implement these properties. Similarly, modeling is a process and method of building models for some purpose or related to some domain. Therefore, models and modeling approaches are used to codify the UIs in different companies.

MBSE is a powerful approach to developing software that relies on using models to represent and analyze software systems. By using models to represent the various components and relationships within a software system, developers can more easily understand and analyze the system and make changes and updates more efficiently. However, these models do not emphasize offering visual notations to aid non-developers in creating such interfaces. Therefore, for our research, we use a recent method [39], which illustrates how to use low-code and Model-driven approaches to close the gap between designers and developers.

2.4 Task-based Usability Testing

The main focus of usability testing is that seeing someone use an interface is the best approach to determine what functions well and what doesn't. It would help if you offered the participants some assignments to observe them. The word "task" is commonly used to describe these assignments. Assigning tasks to the accurate number of participants can help determine the quality of the UI and the problems faced by the users. Overall, the UI design can be improved using the participants' feedback. Task-based usability testing is one way to determine the software's overall usability [41] by measuring the percentage of the tasks the users complete. These tasks need to be some scenarios, not just "*do something*", because it sets the users a stage for *why* they would perform the tasks. To get qualitative feedback from the participants, in [42], the authors provide *three good practices* and task-writing tips for designing better task scenarios.

***(1) Make the Task Realistic*:** So, the participants should be able to execute the tasks which could be completed efficiently and with the freedom to make their own choices. The participants will attempt to accomplish the assignment without genuinely interacting with the interface if you ask them to do something they wouldn't typically do. Therefore, it is necessary to create realistic tasks.
E.g., from *Videostreamer* application: The goal is to offer some movies that the user should watch.
Bad task: Watch a movie if the actor 'Mr. T' and actress 'Ms. K'.
Good Task: Watch a movie with more than 6.5/10 ratings.
In the example, the participants should be free to compare movies based on their criteria.

***(2) Make the Task Actionable*:** Here, the participants should be told what they need to do rather than how they would do it. These types of tasks help us determine if the task isn't actionable enough. If the participants tell the moderator they cannot determine if they need to click on the link or if they are finding it hard to decide the next steps in a specific task, then it is a sign that the task needs to be more straightforward and actionable.

From *Videostreamer* application: The goal is to find a movie and show times.
Bad Task: You want to watch a movie Sunday afternoon. Go to the app and tell where you'd click next.
Good Task: Use the app to find a movie you'd be interested in watching on Sunday afternoon.

***(3) Avoid Giving Clues and Describing the Steps*:** There are frequent hints about how to use the interface or the software in step explanations. These tasks must be more balanced with the users' behavior and give less valuable results. The participants should expose the navigation and some features on their own, giving accurate feedback about the interface. But, at the same time, we should try to include the words used in the UIs as they help the users navigate smoothly and would not lead to some confusion.

From *Videostreamer* application: The goal is to change the user's movie preferences.
Bad Task: You want to change your movie preferences. Go to the website, sign in, and change your movie preferences.
Good Task: Change your movie preferences from 'action' to 'comedy'.

Therefore, it is crucial to create a realistic test environment during usability testing [41]. It is also essential to provide the information required for the participant to complete the task without guiding them on specific actions. If the task scenario is unclear enough, the participant may ask for more information or confirm that they are on the correct path.

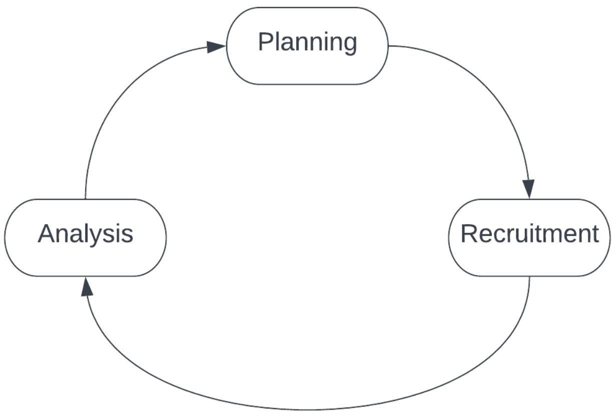


Fig. 2.7 Task-based Usability Testing steps

The fundamental principle of usability testing is to have actual users attempt to carry out essential tasks or assignments on your software, websites, mobile applications, or gadgets. For that, we divide the tasks into three steps.

Planning: In usability testing, planning is an important step. In this step, we decide on a process that fits our research question, hypothesis, and metrics. It is beneficial if we use mixed-methods services for a task-based usability study. The tasks and scenarios must be well-defined in the planning phase. At the same time, we can create pre-study and post-study questions.

Recruitment: In this step, the users are assigned to the task as it is essential to select the correct number of user group sizes. There should be a proper way to interview the users before assigning them tasks so that the participants understand them correctly. The participants should also be able to ask questions or doubts while performing the honorarium tasks.

Analysis: Task-based studies analyze metrics, issues, and insights in great depth. For metrics, we calculate the task completion rates, task time, and task and test level perception questions. The problems that the participants encounter while performing the tasks need to be reported automatically to the development teams by sending screenshots, quotes, etc. There should also be a section to analyze some insights about the software that has worked well for the users while performing the tasks.

Overall, task-based usability testing is a tool for evaluating the usability and effectiveness of software systems. By focusing on specific tasks that users need to complete, we can gather valuable insights into how well the system supports these tasks and identify areas where we could improve the user experience.

2.5 Experimentation

In this section, we discuss the role that experimentation plays in the software development process and how designers can "prototype with real data" to improve the usability of the UI. Experimentation is a vital part of the design process for UI products. It involves testing different design solutions and variations to see which performs best in terms of usability, aesthetics, and other desired characteristics [7]. We can do this through various methods, such as usability testing, A/B testing, and rapid prototyping. Experimentation allows designers to iterate and improve their designs by creating different *'Software Variants'* and gathering data and feedback from real users. It is an important part of creating user-centered designs that effectively meet the needs and expectations of the target audience [6]. Experimentation helps product teams test out ideas early in the process with real-world consumers rather than settling on a single solution and executing it in the final phase [43].

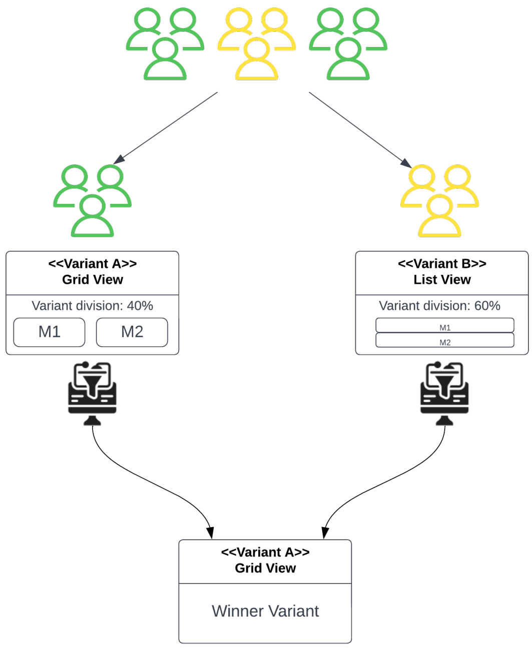


Fig. 2.8 A/B Testing

For conducting experimentation, various steps like *Users distribution*, *Continuous Experimentation (CE)*, *Variants distribution* exist.

User distribution: To conduct a successful experiment, the size of the study, or the number of participants, must be considered first. Statistics suggest that the more people you include in the investigation, the greater its statistical power, which impacts your level of confidence in your findings [44]. Then, the participants should be allocated into groups at random. There are several levels of treatment given to each group (e.g., some prerequisites to the participants before experimenting). For assigning the subjects to groups, users are divided into a *between-subjects design* vs a *within-subjects design*. In a between-subjects design, individuals receive only one of the possible levels of an experimental treatment whereas, in a within-subjects design, every individual receives each of the experimental treatments consecutively, and their responses to each treatment are measured. In figure 2.8, a between-subject design is used where only one of the variants is assigned to the user.

Continuous Experimentation and Variants distribution: CE primarily aims to get users' feedback on the software product's evolution. As per figure 2.8, CE generally uses A/B testing in a primary case of comparing two variants, A and B, which are controlled and test variables in an experiment. First, the users or the participants of the study are separated into groups and are assigned one of the two variants. Since we have `GridView` and the `ListView`, one group of the users are assigned with List and one with Grid View (see figure 2.8). Then both users would be given some tasks (see Section 2.4), and the analysis of these tasks gives the winner among the variants. And in the end, developers make evidence-based decisions to direct the progress of their software by continuously measuring the results of multiple variants performed in an experimental context with actual users [45]. CE is an extension to the introduction of continuous integration and deployment, and all are summarized as constant software engineering [46]. Additionally, continuous experimentation can help designers and developers stay up-to-date with the latest design trends and best practices. By regularly testing and iterating on the design, they can learn from the feedback they receive and incorporate new ideas and techniques into their design. This can help keep the product or service relevant and competitive [7].

Overall, CE is a critical approach to take when developing UIs for products and services. It allows designers and developers to gather valuable feedback and data and use it to improve their products' design and User Experience (UX).

2.6 LEAN Development process

LEAN development is a software development methodology that emphasizes continuous improvement and eliminating waste to deliver customer value as efficiently as possible. It is one method within Agile development [47]. It is based on the principles of the LEAN manufacturing method, which was developed by *Toyota* in the 1950s and aims to eliminate waste and maximize value in manufacturing processes [48]. LEAN development's primary objective was to reduce loss, minimize waste, and encourage sustainable production. And therefore, as an Minimum Viable Product (MVP), in LEAN development, the product has the essential elements necessary to launch successfully and does not have to include any additional components.

In software development, we can apply LEAN principles to various aspects of the development process, including requirements gathering, design, coding, testing, and deployment [47]. The goal is to minimize waste and optimize the use of resources to deliver high-quality software products that meet the customer's needs.

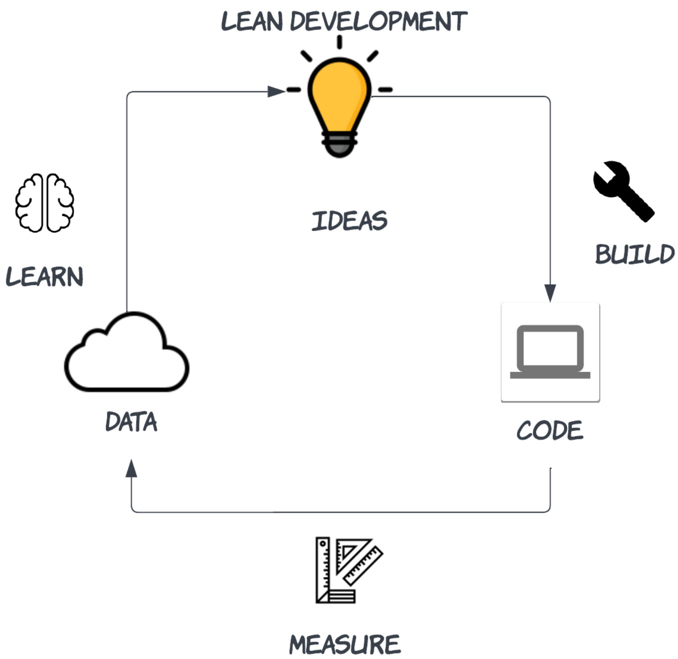


Fig. 2.9 LEAN development cycle[6]

[6]Image adapted from website: https://www.agile-academy.com/en/agile-dictionary/lean-development/

LEAN Development Cycle: The LEAN development cycle often includes three phases: *build, measure, and learn* (see figure 2.9). Steps like these are designed to help the development team continuously improve the product and development process.

Build: In the build phase of LEAN development, the development team works to build and deliver small increments of working software to the customer. This involves gathering requirements, designing, coding, testing, and deploying code [47]. The build phase's goal is to deliver customer requirements as quickly and efficiently as possible. To do this, the development team may follow model-driven development [49], continuous integration and delivery to ensure that the developed code meets the desired functionality and performance requirements.

Measure: In the measure phase of LEAN development, the development team collects data on the product's performance and the development process to identify areas for improvement [47]. It involves collecting data on customer usage and feedback, as well as data on the performance and efficiency of the development process. The measure phase aims to understand how the product is being used and its impact on the customer. It also identifies any bottlenecks or inefficiencies in the development process. The development team may use various tools and techniques, such as user testing, customer surveys, analytics data, and performance monitoring tools, to collect this data [50, 51]. They may also conduct regular reviews of the development process to identify improvement areas.

Learn: In the learn phase of LEAN development, the development team uses the data collected in the measure phase to identify areas for improvement and make changes to the development process and the product [47]. It may involve making changes to the product roadmap, adjusting development practices, or implementing new tools or techniques [52]. The goal of the learning phase is to improve the product continuously and the development process to deliver value to the customer more efficiently and effectively.

The final step in the cycle (see figure 2.9) would be to repeat the process, starting with identifying customer requirements and iterating through the *Build*, *Measure*, and *Learn*[9] phases again. Thus, the development team can constantly improve the product and the development process to deliver value to the customer more efficiently and effectively.

[9] LEAN cycle: https://www.einstein1.net/build-measure-learn/

As per [47], there are some key practices in LEAN development. These principles can be used to guide the discussion on which product development practices might be suitable for an organization, based on its specific circumstances.

Continuous delivery: Continuous delivery is the practice of regularly delivering small increments of working software to the customer rather than waiting until the end of the project to have a complete product. This allows the customer to see the project's progress and will enable them to give feedback and make changes as the project progresses. Continuous delivery helps to ensure that the software being developed meets the customer's needs and reduces the risk of delivering a product that does not meet their requirements [52]. It also allows the development team to identify and fix problems early in the process, saving time and resources. To practice continuous delivery, the development team must have a process for automatically building, testing, and deploying code changes [53].

Continuous improvement: Improving build quality in LEAN development refers to continuously improving the quality of the software being developed through effective coding practices, testing, and quality assurance processes [54]. To improve the build quality, we can use *Code reviews* [47], i.e., conducting regular code review sessions to help identify problems early on and ensure that code meets standards for readability, maintainability, and performance. Similarly, implementing *Quality Assurance* processes, such as testing, to catch and fix defects before they reach the customer can help improve the overall quality of the product.

Lean planning: It is a practice in LEAN development that focuses on maximizing value and minimizing waste in the software development process. It involves continuously prioritizing and reevaluating the work based on customer feedback to ensure that the team is first working on the most valuable features. As per [55], Lean planning aims to quickly identify and deliver the most valuable features to the customer while minimizing time and resources spent on non-critical tasks. This helps to ensure that the team is working on the right things and that the product meets the customer's needs.

In this way, LEAN development can help organizations deliver high-quality products to customers more efficiently and effectively.

2.7 Foundation Summary

Finally, we explained how UI prototyping allows for the rapid iteration and testing of design ideas before committing to development, improving the final product's overall usability and user experience. Then, we discussed how modeling allows for the simulation and analysis of complex systems and processes, enabling behavior prediction, identification of potential issues, and informed decision-making. Then, we also discussed how LCDPs enable faster and more efficient software development by providing visual drag-and-drop interfaces, pre-built components, and automation, reducing the need for extensive coding knowledge. Then, we explained how Task-based usability testing evaluates a system's effectiveness by assigning users to complete specific tasks, providing valuable insights into the product's usability, and identifying areas for improvement. Finally, we explained how lean development could be used for continuous improvement, iterative product delivery, and collaborative teamwork to increase the efficiency of the product.

In conclusion, the foundation chapter of the thesis is an integral part of the overall content. It provides context and background information on the topic being discussed and helps the reader understand the purpose and significance of the thesis. This section ensures the reader has the necessary information to understand and engage with the rest of the document completely.

Chapter 3

Solution Design

In the previous chapter, we defined various terminologies and concepts that we are using for our thesis. Based on that, in this chapter, we derive some design concepts required for our Design Science Research (DSR). Therefore, we explore the Design Requirements (DR) (see section 3.1), Design Principles (DP) (see section 3.2), and an overall solution design (see section 3.3 which gives an incite of the creation of our solution approach) to guide the result of our software tool. Design is a critical aspect of SE, providing the blueprint for implementing functional and non-functional requirements. The design phase is crucial in ensuring that software systems are developed efficiently, effectively, and with high quality. We develop our design approach based on the principles of DSR. Through this exploration, we will provide an in-depth understanding of the design process, highlighting the key factors that must be considered to create effective software solutions.

3.1 Design Requirements (DRs)

DRs in DSR are typically defined as a set of constraints and specifications that must be met by the design artifact to be considered a successful solution. These are functional requirements, such as the features or capabilities the design/tool should have. In our findings of the DRs, we focus more on the functional requirements and ignore the non-functional. To derive a solution, we define the DRs with the help of the literature review and a comparison of some tools. For our research, we conducted a non-systematic literature review by reading research papers and looking at some renowned UI prototyping tools. The related literature is available in Appendix B. In this context, each DR refers to a generalized requirement that can be standardized and applied to future software applications. We covered a wide range of topics including *UI Prototyping*, *Low-Code/No-Code development*, *Model-Based Software Engineering*, *Continuous Experimentation*, *Task-Based Usability Testing*, and the *LEAN* *development process*. The following section presents *nine DRs* for our approach *(solution approach)*.

DR1: Heterogeneous Users states that *the approach should support diverse users with different needs, goals, and capabilities and integrate internal and external users.* It is supported by literature indicating that different users may have different needs, preferences, and levels of technical expertise [5]. By including a diverse group of users, you can get a broader range of feedback and insights into how the software performs for different users [23], and reduces the biases among developers [56]. In this context, the users can be from internal sources, such as employees, or external sources, like Amazon Mechanical Turk[1] for using the software.

DR2: Iterative Design states that *the approach should have an iterative, incremental method and identify and address any technical issues or design flaws early in the development process.* It is supported by literature indicating that the iterative approach involves the idea of breaking down development into small, incremental cycles of work rather than trying to deliver a complete product all at once [47]. The key benefit of an iterative approach is that it allows the development team to get feedback from users and stakeholders early in the development process and to make adjustments [6] to the product as needed.

DR3: Easy Development states that *the approach should be easy to develop and operatable by non-technical individuals with different techniques to create applications without extensive programming knowledge.* It is supported by literature indicating that a tool should have a UI that helps non-technical individuals to build software without including the developers. It can be achieved if the tool provides drag-and-drop interfaces [31], reusable pre-built components [57] (e.g., buttons, textbox, and other UI components) and a logical flow (E.g., *Screen1* is followed by *Screen2* and so on.). In many tools like `Figma`[2], `Invision`[3], and `Axure`[4], we saw these features.

DR4: Integrate Data Models states that *the approach should easily integrate data models (incorporating Create Read Update Delete (CRUD) operations of data models) and iterate them using various UI elements on the screens.* It is supported by literature indicating that by using the tool, citizen developers can easily access and integrate data models from multiple

[1] Amazon Mechanical Turk: https://www.mturk.com/
[2] Figma Prototyping tool: https://www.figma.com/
[3] Invision: https://www.invisionapp.com/
[4] Axure Rapid Prototyping: https://www.axure.com/

sources, including databases, APIs, and external systems [14], without having to write complex code or build custom integrations from scratch [15]. It accelerates the development process, reduces the risk of errors [30], and improves the software tool's overall quality. In many tools like `Figma`, `Invision`, and `Axure`, we saw the use of data models[5].

DR5: Classified UI variants states that *the approach should create multiple UI variants or versions, each with distinct UI elements or features.* It is supported by literature indicating different users may have other preferences regarding how they interact with an application [2]. At the same time, we saw many tools like Google Optimize[6], VWO[7], Convertize[8], and Freshmarketer[9] having provisions to create various UI variants or versions.

DR6: Conduct UI Split tests states that *the approach should conduct various UI split tests on the participants using different UI variants or versions.* It is supported by literature indicating that a product can be tested against different design solutions and variations [46] to see which variant performs the best in terms of usability, aesthetics, and other characteristics [7]. At the same time, continuously improve [45] the product based on the feedback of the best-fit variant.

DR7: Construct User Scenarios states that *the approach should observe and record how users interact with a software tool to evaluate the tool's ease of use.* It is supported by literature indicating that testing of the GUI of a software application is done using functional and usability tests [42]. This helps the developers to identify any usability issues [58] and improve them continuously [17]. And this helps in the identification and preliminary validation of user requirements in the early stages of development [23].

DR8: Collect Feedback states that *the approach should gather various user feedbacks (such as user behavior patterns, click rates or open-ended questions) from the split tests.* It is supported by literature indicating that feedback can be collected while observing the participants performing the tasks [59], like asking open-ended questions about their overall experience. At the same time, it should automatically record any feedback that participants give and analyze it while looking for some pattern in the data [50].

[5] These tools either have their implementation or depend on some third-party data model tool.
[6] Google Optimize: https://marketingplatform.google.com/about/optimize/
[7] https://vwo.com/de/
[8] https://www.convertize.com/
[9] https://www.freshworks.com/crm/marketing/

DR9: Aggregated Feedback states that *the approach should collect the gathered feedback and aggregate them to make improvements to the application.* It is supported by literature indicating that `Qualitative analysis` gathers an in-depth understanding of underlying reasons, opinions, and motivations [60]. Whereas `Quantitative analysis` measures and understands numerical data and helps identify patterns and trends [50]. An aggregation of the qualitative and quantitative analysis can provide a more complete picture of a situation and can be used to validate or disprove findings from one type of analysis [51].

DR10: Improvement states that *the approach should improve the prototypes from the results of the collected feedback in an iterative manner.* It is supported by literature indicating that visualization helps in prototyping by allowing the users to see and understand the design in a way that is easy to understand [61]. It also allows users to identify usability issues [17] early in the design process to make the end product user-friendly and easy to use by improving the prototype. In tools, various methods, like creating *Graphs*, *Charts*, *Plots*, etc. are used for visualization for improving the products.

3.2 Design Principles (DPs)

DPs are guidelines or rules used to guide the design process in DSR [11]. They provide a framework for making design decisions [10] and help to ensure that the final solution meets the goals and objectives of the research. This section codifies our knowledge during the design study and derives DPs from abstract DRs in the iteration cycle of the DSR. The following shows the *nine DPs* for *our solution approach* that is built on the foundation of the mapped DRs (see figure 3.1).

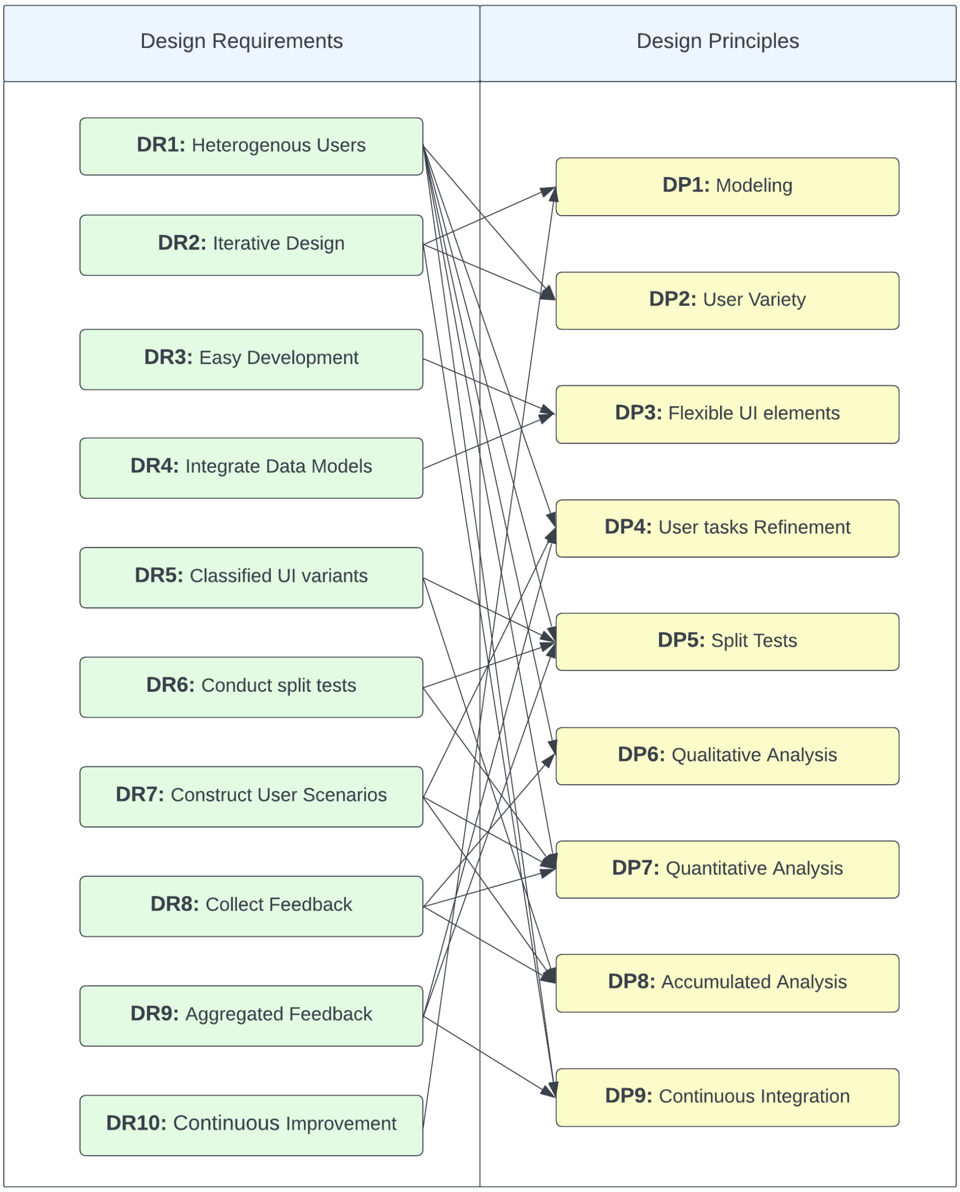


Fig. 3.1 A map between DRs and DPs

DP1: Modeling: *The solution approach is required to provide techniques for incorporating models that can be used to simplify and visualize the UI prototype so that developers can test its functionality and identify potential issues before the actual software is developed.*

Modeling increases transparency among various users, increasing their contribution to the product due to their excellent visualization and improvement capability (i.e., *DR10: Continuous Improvement*). Furthermore, modeling tools can automatically generate code or other documentation from the models, which can help reduce errors, improve efficiency, and decrease development time iteratively (i.e., *DR2: Iterative Design*).

DP2: User Variety: *The solution approach is required to provide techniques for incorporating diverse types of users, both the prototype creators i.e., admin users and participants i.e., users who participate in an experiment, so that developers can engage with various users during the evaluation process.*

Developers have many unclear generalities early in the product development process [5] that they can clarify by testing the underlying assumptions using different types of users (i.e., *DR1: Heterogenous Users*), and involving various product users using an iterative design for continuous improvement (i.e., *DR2: Iterative Design*). This helps to gather the user requirements smoothly, thus improving the product's usability.

DP3: Flexible UI Elements: *The solution approach is required to provide techniques for incorporating a library of UI elements and interactive components that can be easily customized and used in the prototype so that developers can demonstrate how the UI will function.*

A UI Prototyping tool is helpful when different interactive (i.e., *DR3: Easy Development*) re-usable components are used while creating the prototypes and integrate various data models (i.e., *DR4: Integrate Data Models*). These elements can be pre-designed UI elements such as buttons, menus, forms, etc. and interactive components such as textboxes, checkboxes, etc. It helps to get more feedback from the users or the participants, improving the product's usability and functionality.

DP4: User tasks Refinement: *The solution approach is required to provide techniques for incorporating task creation that simulates real-world scenarios and workflows and assign randomly to participants so that developers can collect and improve the UI prototype with the help of data.*

We can improve the usability of software by observing different users (i.e., *DR1: Heterogenous Users*) as they interact with the product and measuring how well they can accomplish specific tasks or goals (i.e., *DR7: Construct User Scenarios*). These tasks are some real-world scenarios and workflows, with clear instructions and defined success criteria. Moreover, the users can provide valuable insights into how easy or difficult it is to use the product and help identify areas where developers could improve the UI or design aggregating user feedback (i.e., *DR9: Aggregated Feedback*).

DP5: Split Tests: *The solution approach is required to provide techniques for incorporating the creation of different versions of UI prototypes and conduct tests to compare the performance of each version so that developers can make data-driven decisions about which UI design works best for their users.*

Split Tests (e.g., A/B tests) are performed on a randomly divided sample group of different users (i.e., *DR1: Heterogenous Users*) by exposing each group to the UI of different versions (i.e., *DR5: Classified UI variants* & *DR6: Conduct Split tests*) to find out the feature that is most usable and functional for the users. The results of the test are then used to determine which version is more effective by aggregating the feedback (i.e., *DR9: Aggregated Feedback*) from the user groups and finally optimizing the whole product.

DP6: Qualitative Analysis: *The solution approach is required to provide techniques for incorporating and analyzing qualitative feedback from participants so that developers can gain insights into the user experience and identify areas for improvement.*

We can conduct qualitative analysis systematically for examining non-numerical data to uncover patterns, themes, and insights from different users (i.e., *DR1: Heterogenous Users*). It can be achieved through various methods (i.e., *DR8: Collect Feedback*) such as content analysis or user feedback analysis, which involve coding, categorization, and interpretation of the data.

DP7: Quantitative Analysis: *The solution approach is required to provide techniques for incorporating quantitative analysis features so that developers can analyze and visualize data from A/B testing and other analytics for improving the UI prototype.*

We can conduct quantitative analysis systematically to test hypotheses, measure relationships between variables, and make statistical inferences about populations based on representative samples from different users (i.e., *DR1: Heterogenous Users*). It can be achieved by assigning tasks to various users in the study (i.e., *DR7: Construct User Scenarios*) and collecting their feedback (i.e., *DR8: Collect Feedback*) for their particular UI variant in the split test (i.e., *DR6: Conduct split tests*).

DP8: Accumulated Analytics: *The solution approach is required to provide techniques for incorporating different analytics and metrics so that developers can track the performance and behavior of the various UI prototype variants being tested.*

Performing various tests (e.g., usability testing) with diverse users (i.e., *DR1: Heterogenous Users*) ensures that the software is accessible and easy to use for different groups of people with an accurate evaluation of the task provided to the users (i.e., *DR7: Construct User Scenarios*). Moreover, diversity in software development feedback mechanisms (i.e., *DR6: Collect Feedback*), received by testing different UI versions (i.e., *DR5: Classified UI variants*), helps ensure the software is inclusive and accessible.

DP9: Continuous Integration: *The solution approach is required to provide techniques for incorporating the tool's design into small, incremental phases in the software development process so that developers can improve software delivery and make product changes and improvements based on customer feedback.*

Using a continuous incremental approach, we can continuously improve software products by delivering value to customers as quickly as possible [48], constantly refining and improving the product [55], and delivering the product as soon as possible. Here, the iterative design should be used (i.e, *DR2: Iterative Design*) to get continuous feedback from a variety of users (i.e., *DR1: Heterogenous Users*). The feedback which is collected should be a combination (i.e., *DR7: Aggregate Feedback*) of various feedback helping significantly improve the application.

3.3 Overall Solution Design

As shown in figure 3.2, we conceptualize the solution design from our codified DPs. The software platform consists of two types of roles consisting of the users for creating the Prototyping tool (Admin users like, *Product Owners*, the *Designers*) and the *Users or Participants* for testing the tool. In this section, we arrange our DPs using a LEAN development approach[10], a cycle consisting of *Build*, *Measure*, *Learn* phases.

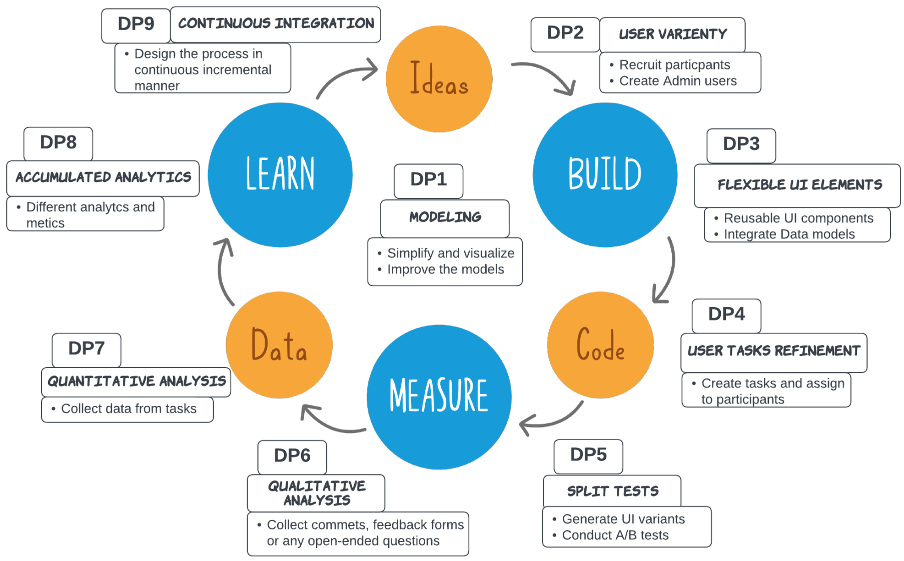


Fig. 3.2 Overall Solution Design for a UI Prototyping tool using LEAN principles

In the LEAN development cycle, the whole process is done in a model-based approach (i.e., DP1) for the improvement of the solution approach.

Build: Initially, different users register to our tool (i.e., DP1) having different rights. The tool administrators (i.e., the users with admin rights) build a UI prototype using various reusable UI components and create data models (i.e., DP3). Using the UI elements, these users make various screens and connect them to various data models to have a logical flow of the prototype. In the next step, users would create various tasks simulating real-world scenarios, assign them randomly to participants and collect feedback (i.e., DP4). After creating the tasks, users create various UI variants or versions for creating split tests (i.e., DP5).

[10] Adopted from LEAN process development: https://www.lean.org/explore-lean/product-process-development/

Measure: In this phase, we measure the data we receive from the tasks by conducting qualitative (i.e., DP6) and quantitative (i.e., DP7) analysis. The quantitative analysis is done from the data the users collect from the tasks. Similarly, the qualitative analysis is done by collecting the comments, open-ended questions etc. after the task is finished.

Learn: In this phase, the data received from the analysis is processed and visualized. The data is processed by aggregating and combining the results of the qualitative and the quantitative analysis (i.e., DP8). Finally, the models are given feedback from the data analysis, improving the UI prototype and updating it with the winner variant (i.e., DP9) as the default UI. The refined product can be deployed for the entire population (or all the users) using the deployment module of a no-code development platform.

Chapter 4

Solution Concept

In the previous chapter, we defined different DRs and DPs for our solution approach. Based on that, in this chapter, we present the conceptual design of the solution, which outlines the system's key features, components, and functionalities. For that, the introduction section (see section 4.1) introduces the reader to the chapter details completing our solution concept, next section explains the core architecture of our solution approach and then the next sections explains the architecture in details.

4.1 Introduction

The Solution Concept chapter in software engineering provides a comprehensive understanding of the proposed solution approach. This chapter bridges the gap between the solution design and the actual implementation of the solution by providing a detailed description of the solution approach. It lays the groundwork for the development process, including the design decisions, and technologies used to build the software implementation. Overall, in this chapter, our solution approach is based on the LEAN development cycle we defined in the previous chapter. To visualize the system's architecture and interactions between components, we have defined software architecture (see section 4.2) to facilitate better planning and implementation decisions. In the next sections, we explain the different components we used for building our solution approach (our UI Prototyping tool). In section 4.5, we explain how data is stored in our database using the data models. In section 4.4, we explain the UI of the tool on how to create experiments and connect participant users to experiments using our tool. In section 4.7, we explain UI interacts with the database. Finally, in section 4.6, we explain the code generation and other deployment processes required to build our tool from a prototype to working software.

4.2 Software Architecture

In this section, we will discuss the software architecture of a UI prototyping tool with provisions for split and task-based usability tests. The software tool uses the MVC architecture, with the main views being the UI prototyping management and the UI experiments management. The models used in the architecture are the UI view for prototyping and the UI experiment for split tests. The diagram (see figure 4.1) shows the different modules and com-

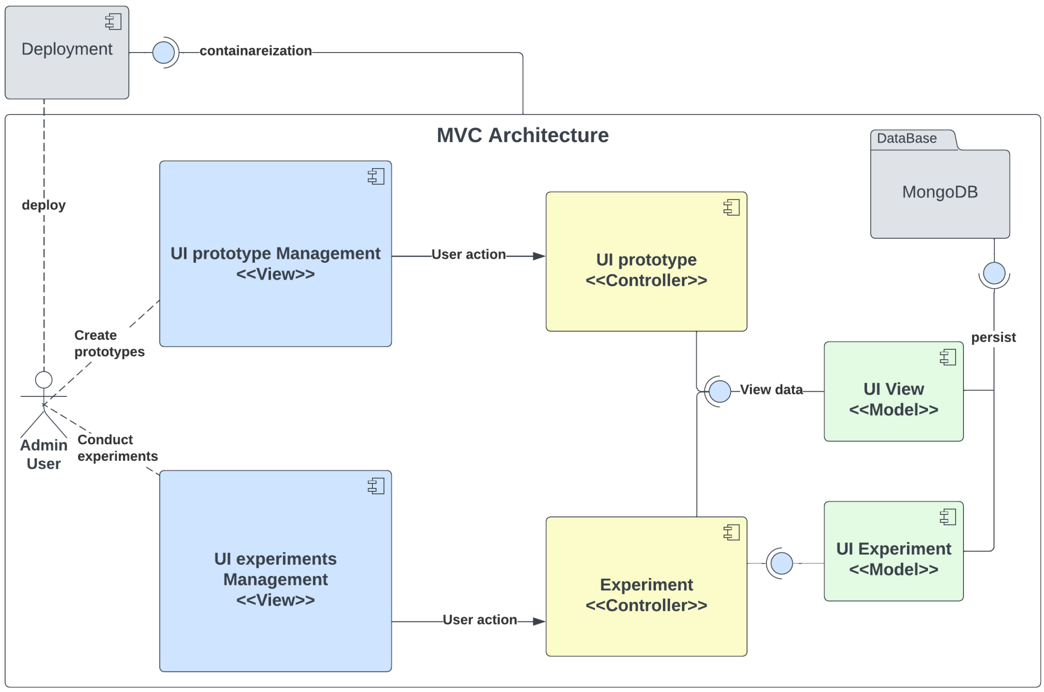


Fig. 4.1 MVC Architecture of our UI Prototyping tool

ponents of the UI prototyping tool and how they interact with each other during the execution of the tool. We chose the MVC architecture for this tool because it separates the application logic into three interconnected components. The model component represents the data and the business logic of the application. The view component represents the application's UI, and the controller component handles the user input and updates the model and the view. The separation of these components allows for easier application maintenance, scalability, and modifiability.

As shown in figure 4.1, the *UI prototype management* and the *UI experiments management* are the two main views of the tool. The *UI prototype management* view manages the prototyping process, while the *UI experiments management* view manages split tests and task-based usability tests. The *UI View* model is connected to the prototyping view, and the *UI experiment* model is used for split tests. The *UI prototyping* and *Experiment* controllers are the main controllers for handling user input and updating the models and views accordingly. For the database, we use a NoSQL database that provides flexibility and scalability for applications with changing data requirements.

The *admin* user is responsible for prototyping and creating user experiments and scenarios. The *admin* user can access all the tool's features and create, edit, and delete prototypes and experiments. Finally, for deployment, we have one component that includes all the files and dependencies required to run the application. This component contains the server-side code, the client-side code, and the necessary libraries and dependencies. The deployment component is responsible for packaging the application and deploying it to the target environment.

In summary, the software architecture for our UI prototyping tool is designed using the MVC architecture, with the details explained in the next sections. Similarly, the role of the *admin*, the user responsible for prototyping and creating user experiments and scenarios, is also explained in the next section in detail.

4.3 UI Prototype Management

In our solution approach, we must have features for creating various UI prototypes. Therefore, using this component, we allow the admin users to create UI prototypes as shown in the figure 4.2. It consists of various sub-components for constructing UI elements, data models, and analyzing results.

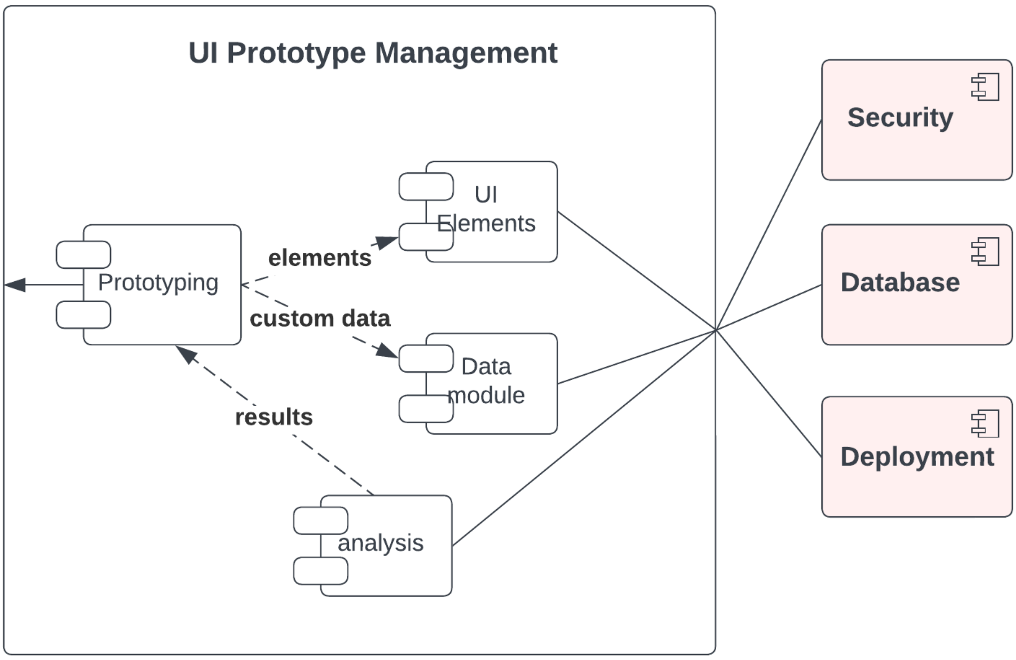


Fig. 4.2 Details of UI Prototyping Management connecting to a Database

UI Elements The prototype management features a comprehensive set of UI elements designed to be reusable and easy to customize. The UI Elements component represents various predefined UI elements used during the prototyping. These components can be added to a screen using a simple drag-and-drop interface, allowing users to create interactive prototypes with minimal effort quickly. Each of our UI elements includes a range of properties that can be customized to meet the user's specific needs. These properties include size, color, font, and behavior properties. Providing these options allows users to create prototypes that accurately represent their vision without being limited by the tool's capabilities. Some UI elements we have developed include buttons, select elements, text boxes, image render, and the input element. Each component is designed to be intuitive and easy to use while providing enough functionality to allow users to create complex interactions.

Data Models The prototype management includes a data model component allowing users to create and manage data sets for their prototypes easily. With this component, users can create data models, which are then stored in a database and can be accessed and manipulated using a model. Creating a data model is straightforward: users import the CSV file and then create a model for the particular data set they want to use in their prototype. Once the model is created, users can iterate through the data in various forms, such as a table or a grid, and visualize how the data will be displayed in their final product. One of the key benefits of our data model component is how easily it can be modified and updated. Users can change the data directly within the model using a table, allowing them to quickly iterate on their prototypes without constantly importing new data sets. This makes it easy to test different scenarios and refine the user experience. Similarly, by importing real-world data sets, users can create prototypes that more closely resemble the final product, which can be valuable for testing and validation.

Analysis The prototype management includes an analysis component that enables users to combine and aggregate the results of qualitative and quantitative analyses. By combining these different types of research, users can gain a more comprehensive understanding of how their prototype is performing and make data-driven decisions about how to iterate and improve it. One of the key features of our analysis component is its ability to transfer the results of the winner variant back to the prototyping component. It allows users to quickly iterate on their designs based on the insights gained from the analysis, ensuring that the final product is optimized for user engagement and satisfaction.

In summary, implementing a prototyping management component simplifies the UI prototyping, helps improve the effectiveness of the UI, allowing to add UI elements, and data models and improves the prototype.

4.4 UI Experimentation management

In our solution approach, we must have features for creating various UI variants and conducting experiments of A/B testing. Therefore, as shown in figure 4.3, using this component, we allow the admin users to create experiments on the UI as defined in the UI prototype. It consists of various sub-components for constructing UI variants, assigning participants to experiments, managing participants' tasks, including qualitative questions, and collecting quantitative feedback.

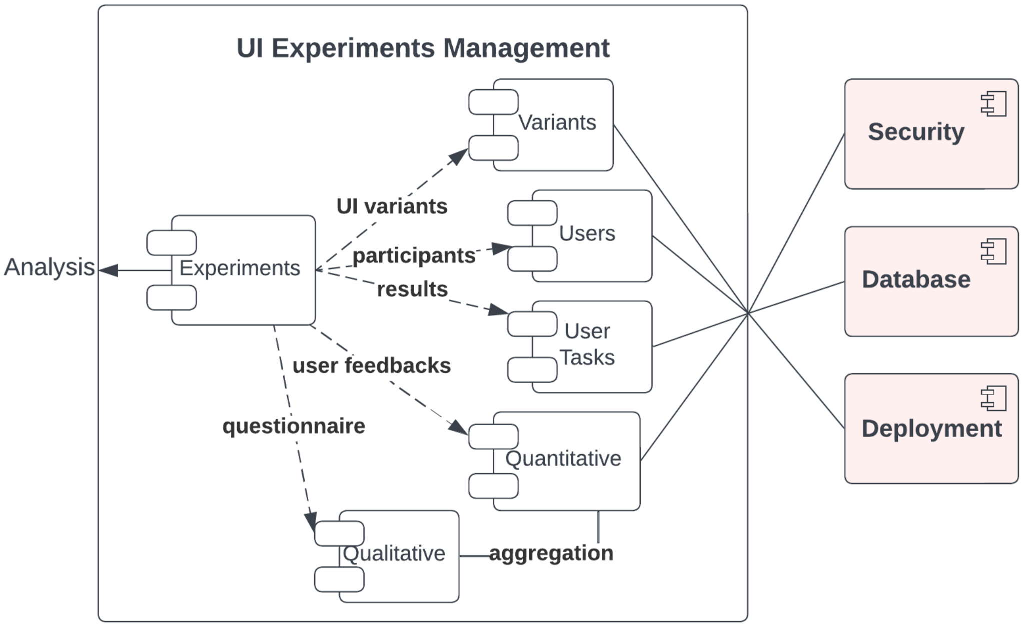


Fig. 4.3 Details of UI Experiment Management connecting to a Database

Constructing UI Variants The UI Variants component represents the different variations of a UI that are used in A/B testing. Here, we compare two or more UI variations or variants to determine which performs better regarding user engagement and conversion rates. Firstly, the admin user is responsible for creating an experiment and its other variants. Then we modify the UI prototype for each variant to have some differences and uniqueness. Hence, using our interactive prototyping tool, the admin user should be able to design each variant accurately. In the end, we have a unique prototype for each UI variant.

Participants Assignments An important aspect while experimenting or A/B Testing is the users' participation. The admin user is responsible for assigning the participants to their variants. Therefore, we need to specify the percentage of participants allocated to an experiment variant during an experiment. For our solution approach, we use the between-group study such that different participants test each UI variant so that each person is only exposed to a single variant.

Task Management We need to assign them certain user tasks to get quantitative feedback from the participants. It means the admin user must create certain tasks before the start of the experiment. Our solution approach has a *Tasks* component that provides a feature for creating user tasks for every UI experiment. These tasks are built and maintained in our tool by the admin user and are useful while collecting user feedback. So, the participants carry out the tasks, and our tool would collect their interaction details (e.g., time taken to finish the task, the path taken by the participant, number of unsuccessful attempts).

Qualitative Questions The experiment management includes a qualitative component that allows users to gather participant feedback through a qualitative questionnaire. This component complements the quantitative component and provides users with a more holistic view of how users interact with their prototype. The qualitative questionnaire can be easily added to the prototype, and users can choose from various question types, including open-ended and scale-based questions. It allows users to gather rich and detailed feedback from participants about their experience with the prototype.

Quantitative analysis The experiment management includes a quantitative component that allows users to collect data from user tasks, such as user clicks, user paths, and time taken. By gathering this data, users can better understand how users interact with their prototypes and identify areas for improvement. Once the data has been gathered, the quantitative component calculates the mean for each metric. It provides users with an average value that they can use to compare different variations of their prototype and identify which one performs the best. Users can make data-driven decisions about their prototype using the mean and quickly iterate based on user feedback.

Analyze Results Every experiment needs to visualize its results, and the visualization component is responsible for providing this feature of analyzing the results of the A/B testing to determine which UI variant performs better. This component compares the user engagement and conversion rates for each variant (e.g., time to finish the task, unsuccessful attempts, etc.) and identifies the factors contributing to the performance differences. Once we receive the details of the winner variant from this component, the tool sends these details to the original UI prototyping management to iterate and refine the UI variants based on the experiment's results.

In summary, implementing an experiments management component simplifies the A/B testing, helps improve the effectiveness of the UI, and allows you to manage and track the different interface variations.

4.5 Persistence

In our solution approach, we must have features for persisting the data in our database. Therefore, as shown in figure 4.4, using this component, we store the data from the models from our MVC architecture. It consists of a *Persistence infrastructure* for providing various features like *database connection*, and *data persistence*.

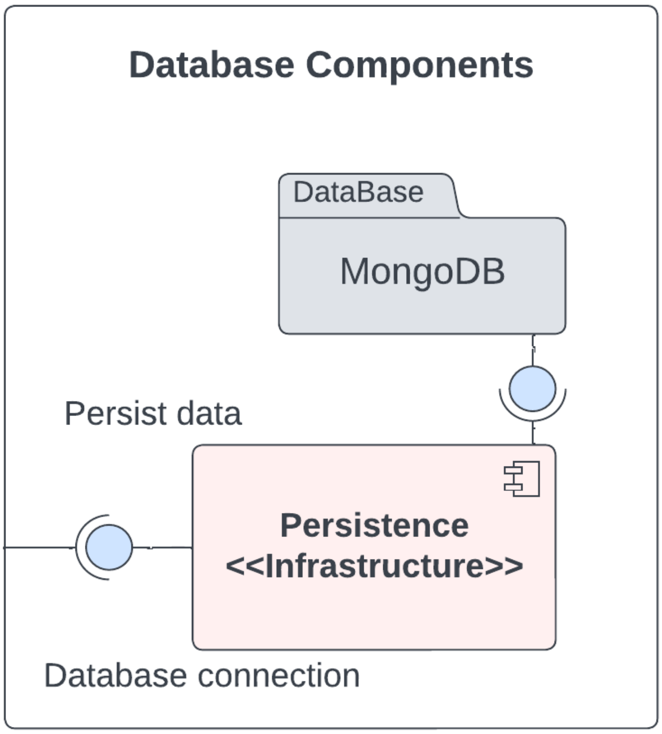


Fig. 4.4 Details of Database Management

Persistence infrastructure A persistence infrastructure is necessary for our software to manage a system's data storage and retrieval. When a model needs to store data for later use or retrieve data that has been previously stored, a persistence infrastructure can provide the necessary functionality to accomplish this.

Database connection Our persistence infrastructure provides database connectivity for a non-relational database by using a MongoDB driver or library to interact with the database. We install and configure MongoDB on the appropriate servers or cloud-based environments[1]. Then we select a proper driver or library, configure the connection details, and use the driver

[1] Cloud-based environment: https://cloud.mongodb.com/

or library to interact with the database in the components of the system[2]. Utilizing the driver or library, we interact with the non-relational database in the components of the system. It typically involves defining data models, creating, reading, updating, and deleting documents or records, and querying the database using the appropriate syntax and commands.

Data persistance After setting up the necessary drivers or libraries to connect to the MongoDB instance from the components in the system, we define the necessary CRUD (create, read, update, delete) operations for the data models. These include methods for inserting, updating, deleting, and retrieving data from the database. It also provides the necessary validation and error handling for the data models and CRUD operations.

In summary, when implementing a persistence infrastructure for a non-relational database like MongoDB, we developed the structure and functionality of the database and designed the persistence layer accordingly. Therefore, the system can store and retrieve data in an efficient, scalable, and reliable way.

[2]How to connect to cloud-based deployed MongoDB instance: https://www.mongodb.com/docs/atlas/connect-to-database-deployment/

4.6 Deployment Infrastructure

A deployment infrastructure is necessary for ensuring that the system is deployed and running in a secure, scalable, and reliable way. A deployment infrastructure is responsible for managing the deployment of components, ensuring that they are running on the appropriate servers or cloud-based environments, and monitoring their performance. We use a no-code platform and microservice architecture to simplify deployment infrastructure implementation. It allows for the creation of deployment pipelines and automates many of the processes involved in deploying components.

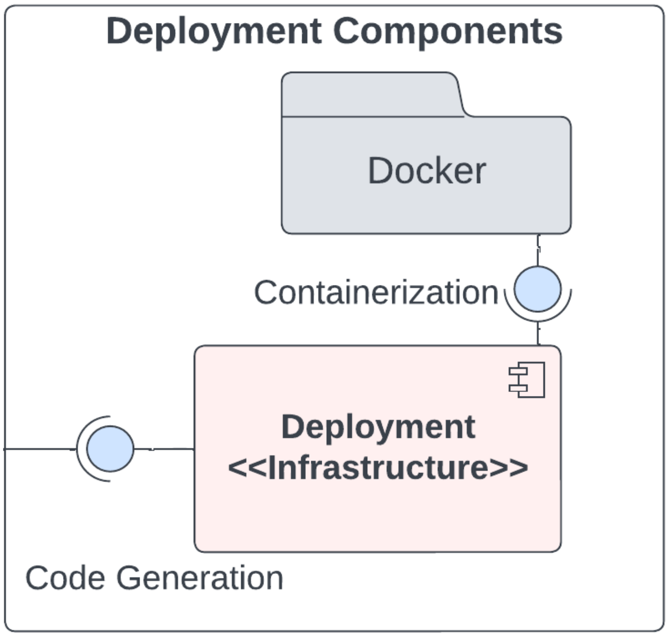


Fig. 4.5 Details of Deployment components

Code Generation We use a no-code approach using code generation to simplify the implementation of our deployment infrastructure by automating many of the tasks involved in deploying the system. So, we define a set of rules and templates for automatic code generation and generate some reusable components as defined by the UI prototyping management. These components' implementation uses templates containing its code (e.g., for a button element defined in the UI prototype, a template is generated containing all its properties and logic). Then, the code generator takes input data, including configuration files, database schemas, and models of system components and their interactions. Finally, the code will be generated using the templates and rules defined in the previous steps, and we will containerize the generated code.

Containerization Containerization plays an even more important role in using a microservice architecture. It must support the deployment of many independent microservices that may be deployed across multiple servers or databases. From our component diagram, we first identify the system's microservices and their dependencies, such as database components, UI prototyping management, and UI experimentation management. It helps determine how the microservices should be deployed and how they should communicate. Next, we create Docker images for each microservice and its dependencies. Then, we define docker-compose files[3] in yaml[4] (see Appendix A) that describe how the docker containers should be deployed and connected. Finally, we build the *docker images* and deploy them as *docker containers*.

In summary, implementing a deployment infrastructure for a microservice architecture can simplify the deployment and management of microservices, making it easier to build and maintain complex systems.

[3] A Docker Compose file is a YAML file that specifies the microservices, their dependencies, and how they should be deployed and connected.

[4] YAML format for files: https://www.redhat.com/en/topics/automation/what-is-yaml

4.7 Security Infrastructure

Security infrastructure is essential to protect the system from unauthorized access and attacks. By implementing security measures, such as access control, we limit access to sensitive information and functions to only authorized users. Similarly, authentication is one of the fundamental security mechanisms used to verify the identity of users. Our security infrastructure, therefore, provides access control and some authentication mechanisms.

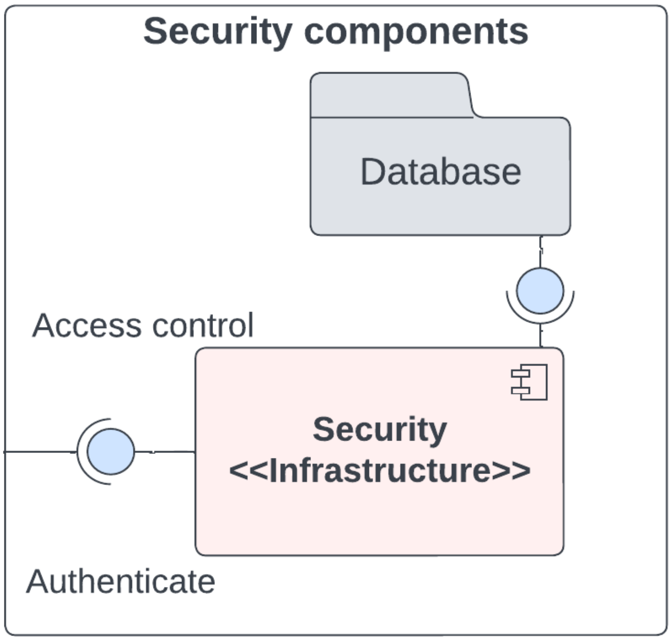


Fig. 4.6 Details of Security components

Access control Access control involves defining policies and rules determining who can access resources under what circumstances. Therefore we implement access control mechanisms using role-based access control (RBAC) and then allowing or denying access based on those roles or groups. So, we first identify the roles or groups requiring system access, including participants, administrators, and other users[5]. Then we define the access rights (e.g., the UI prototyping management should only be accessible to the admin users). Finally, we implement a mechanism that checks the user roles and then accesses the data or services accordingly.

Authentication mechanisms Authentication involves verifying the identity of users and ensuring that they have the appropriate permissions to access the system. We provide an

[5] This may include different stakeholders like designers, product managers, developers, etc.

authentication mechanism using a password and username. It ensures that only authorized users can access our tool. Moreover, we define some validators for password strength to make sure the passwords are strong.

In summary, implementing a security infrastructure providing access control and authentication mechanisms for our tool can help prevent unauthorized access and protect sensitive data from being compromised.

Chapter 5

Solution Implementation

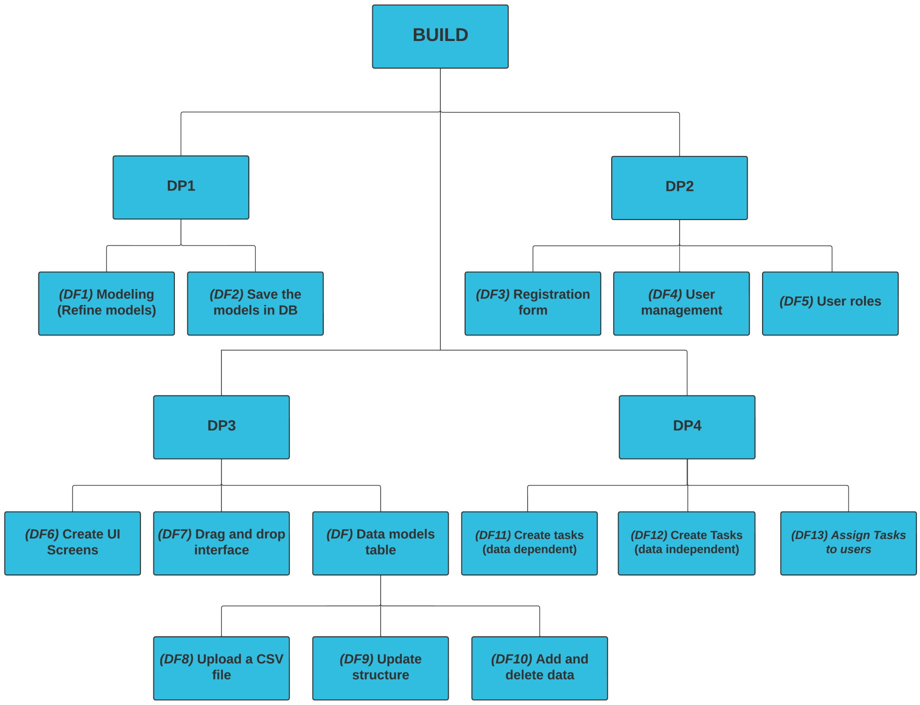
In the previous chapter, we displayed an overview design of our approach. Consequently, the solution implementation chapter of this thesis presents the details of how the proposed system was developed and implemented. Firstly, we define some Design Features (DF) (see section 5.1) that focus on designing and developing new artifacts, methods, or systems. Next, the description of the technology stack and development tools is explained (see section 5.2). The chapter includes a detailed explanation of the critical features and functionality of the system and the processes used in frontend implementation (see section 5.3), database implementation (see section 5.5) backend implementation (see section 5.4), and the software tool (see section 5.6). Through this chapter, readers will understand how we brought the proposed solution to reality and its potential for real-world applications.

5.1 Tool Design Features (DFs)

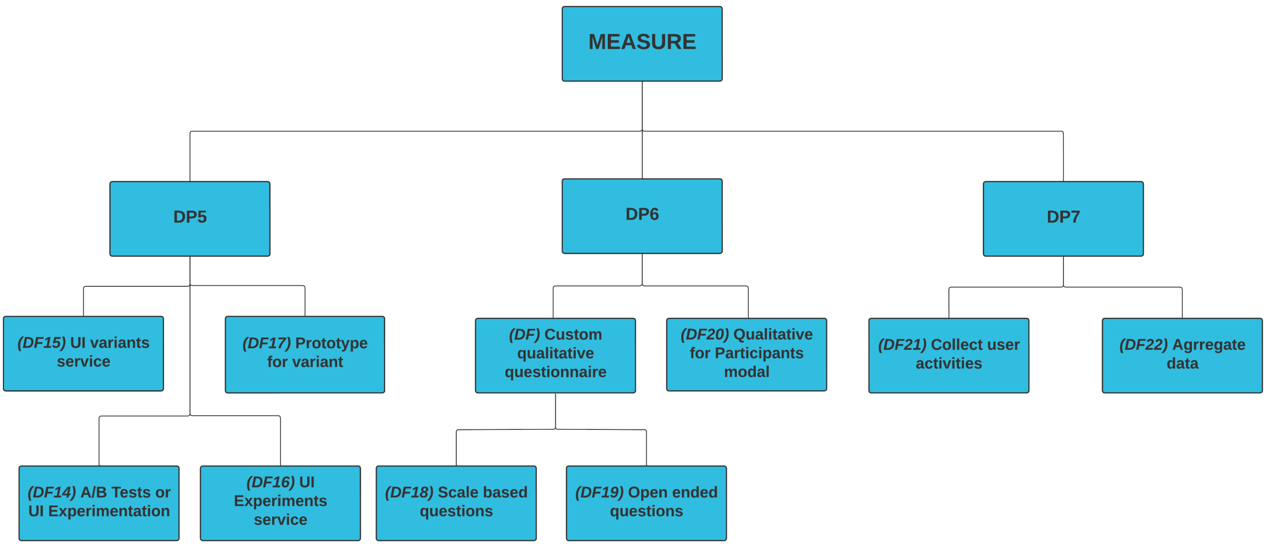
DSR aims to produce a tangible outcome, such as a new software tool, a process improvement, or a theoretical framework. It often involves multiple cycles of design, evaluation, and redesign, allowing for constant improvement of the artifact. Since we perform the *first* iteration of the cycle, we derive the features of our software tool using the DFs. In this section, we translate each DPs (we defined in chapter 3) into a set of DFs that we can directly implement into the tool or solution approach and we describe the DFs for each of the derived DPs. As shown in the figure 5.1, we see that the DFs are divided according to the *LEAN* development cycle.

Build: In the *Build* phase of the *LEAN* development cycle, based on the **DP1: Modeling**, the solution approach provides features for creating the models (*DF1*) useful for persisting data in the database and updating them (*DF2*) with the results of the experiments. It helps to create our prototypes in a model-based approach and improve our prototypes by improving the models throughout the LEAN development cycle. With the **DP2: User Variety**, the key features of our solution approach for the UI prototyping tool will include registration for diverse users using a registration form (*DF3*) and user management, i.e., features that enable team members to create and manage user accounts (*DF4*), assign different levels of access and permissions (*DF5*). The *User module* maintains all these features and also the user authentication, authorization, and user profile management. And then based on the **DP3: Flexible UI Elements**, the privileged user prototypes using the features of our solution approach, which includes the creation of different screens (*DF6*) and reusable UI elements using a drag and drop interface (*DF7*). The tool also provides a feature to add custom data i.e., creating data models by uploading a CSV file (*DF8*), revising structures of data model table (*DF9*), adding and deleting data from the table (*DF10*). Next, based on the **DP4: User tasks Refinement**, the privileged user creates *User Tasks* for the users using the features of our solution approach, which includes creating tasks for users depending on the data model (*DF11*) and independent of data models (*DF12*), and assign the task to the experiments (*DF13*).

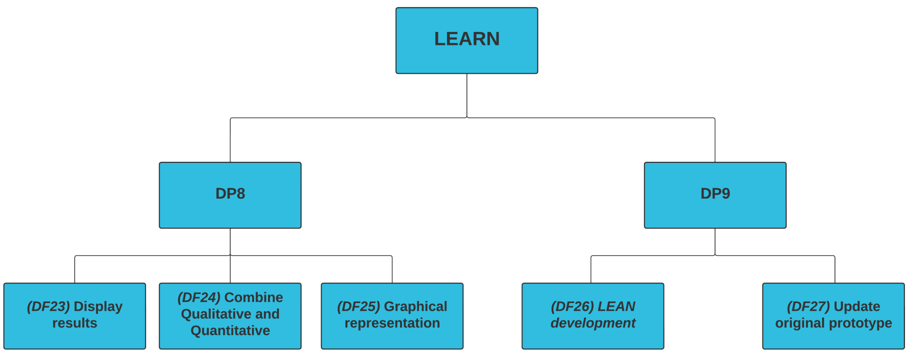
Measure: In the *Measure* phase of the *LEAN* development cycle, based on the **DP5: Split Tests**, the privileged user would be able to create A/B tests or UI experimentation (*DF14*) using the features of our solution approach, which includes creating and modifying the experiments (*DF15*), creating and updating the UI variants (*DF16*), and modifying the variants' prototypes such that each variant has a unique view (*DF17*). Next, based on the **DP6: Qualitative Analysis**, the privileged user would be able to do qualitative analysis on the users using the features of our solution approach, which includes creating the custom qualitative questionnaire with options in the answering formats like *Scale based*, i.e., the users will have to choose from options 1 to 10 (*DF18*) and open-ended questions, i.e., the users will have the freedom to answer whatever they think (*DF19*). And, the users will answer these questions after finishing the tasks with a modal appearing with different questions (*DF20*). Similarly, based on the **DP7: Quantitative Analysis**, the privileged user creates quantitative analysis on the users using the features of our solution approach, which includes collecting the task data feedback, i.e., collecting the time taken to finish the task, number of unsuccessful attempts, the path taken by the users to complete the task, etc. (*DF21*), and aggregating these feedback data (*DF22*).



(a) A hierarchical diagram of DFs from *Build* phase



(b) A hierarchical diagram of DFs from *Measure* phase



(c) A hierarchical diagram of DFs from *Learn* phase

Fig. 5.1 Hierarchical structure of DFs

Learn: In the *Learn* phase of the *LEAN* development cycle, based on the **DP8: Diversity in Analysis**, the privileged user compares the statistics using the features of our solution approach, which includes showing the results of the experiment (*DF23*), combining qualitative and quantitative analysis of each variant (*DF24*), and a graphical view to see the results (*DF25*). Finally, based on the **DP9: Continuous Design**, the solution approach would provide features including LEAN development cycle (*DF26*). The privileged user should be able to update the original prototype with the results from the experiment (*DF27*) for continuous improvement.

Overall, the design features section in DSR delivers a comprehensive overview of the solution tool to address the identified problem or research question. Moreover, this section describes the DFs for our Proof-Of-Concept (POC) solution tool.

5.2 Technologies Used

We have created a software tool that allows us to test the features (DFs) and underlying principles of the developed DFs with actual users. To test our solution approach, we developed a rapid prototyping tool for the first cycle of our DSR.

The implementation of our *UI Prototyping Tool with Experimentation (UPTE)* platform uses various technologies. Our UI prototyping tool was developed using Angular[1], Loopback[2], and MongoDB[3]. Angular is a JavaScript framework used for building web-based applications. It provides comprehensive tools for creating dynamic and responsive UI components and handling user interactions. With angular, we are using several other UI components which are available on Node package manager (npm)[4].

Loopback is a Node.js[5] framework used for building RESTful APIs. It provides an intuitive interface for creating API endpoints and managing data persistence. Loopback's support for various data sources, including relational and NoSQL databases, makes it a versatile choice for web applications. We connect our database using the data managers provided by the loopback framework. The framework's ability to generate API documentation and testing tools simplifies our development process.

MongoDB is a NoSQL document-oriented database used for storing unstructured data. We store our prototyping tool's data using a JSON[6] format in an unstructured manner. It provides a scalable and flexible solution for managing volumes of data. MongoDB's support for automatic sharding and replication ensures high availability and fault tolerance. The database's dynamic schema and rich query language make it easy to adapt to changing data requirements.

By leveraging these technologies, our UI prototyping tool delivered a powerful and user-friendly interface while ensuring efficient data retrieval and storage. Based on these technologies, we build a microservice architecture explained in the next section so that our DPs and DFs can be easily implemented.

[1] A framework of javascript: https://angular.io/
[2] A framework of the NodeJS https://loopback.io/
[3] A non-relational database https://www.mongodb.com/
[4] NPM: https://www.npmjs.com/
[5] NodeJS: https://nodejs.org/en/
[6] What is JSON: https://developer.mozilla.org/en-US/docs/Glossary/JSON

5.3 Frontend Implementation

This section discusses the front-end implementation of our software tool. As discussed in the previous section, we developed the UI using *Angular*, a popular front-end framework. Angular provides a comprehensive architecture (see figure 5.2[7]) that includes components, templates, event binding, property binding, directives, and injectors. Angular's architecture is organized into modules containing specific functions designed to achieve particular goals. These modules can be imported and exported between different Angular applications. In each application, a root module is launched at the start of the application and imports other modules to add additional functionality.

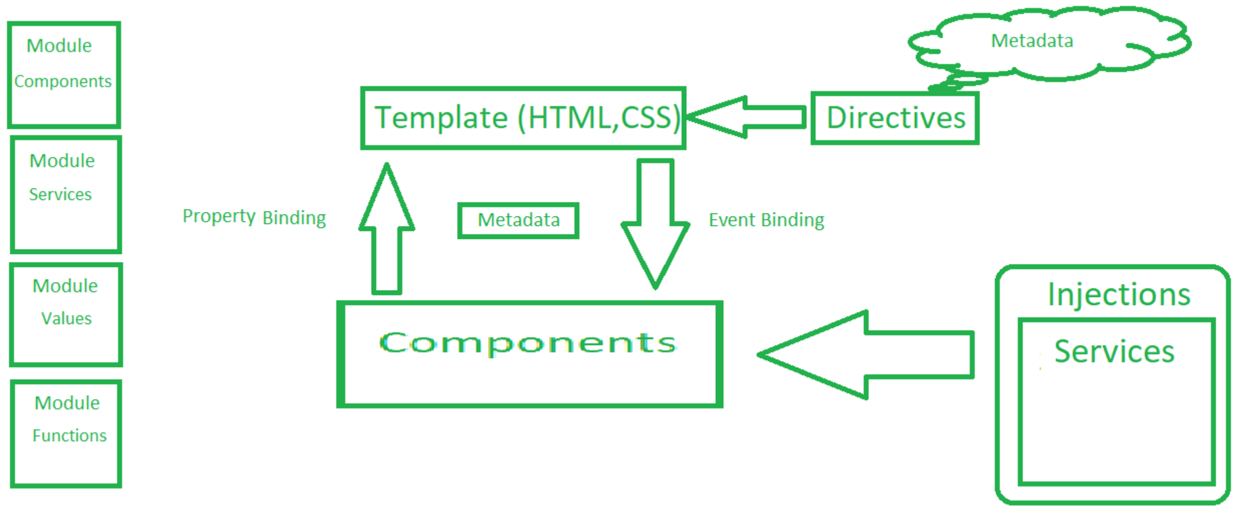


Fig. 5.2 Angular Architecture

In our implementation, the angular application has a root entry point, a module file (see Listing 5.1), containing all the necessary imports to function properly. Within our NgModule, we have imported various user-developed modules and third-party modules like *MatInputModule*, *NgxMatFileInputModule*, and *DragDropModule* for UI elements. By importing these modules, we can utilize their functions and features within our application to enhance its overall functionality and user experience. One key benefit of using *Angular Material Design*[8] is providing a library of pre-built UI components that follow Material Design guidelines, such as buttons, forms, and navigation menus. It saves time designing and developing UI elements from scratch and instead focuses on customizing them to fit our

[7] Fig taken from: https://www.geeksforgeeks.org/angular-7-architecture/
[8] Website for Angular material design: https://v7.material.angular.io/

needs. *Nginx File Input*[9] is another third-party module we have imported into our application. This module allows users to upload files directly from their local device, enabling us to save them to our server for future use. Finally, the *Drag and Drop module*[10] allows users to easily rearrange elements on the UI by dragging and dropping them to their desired location. Utilizing this module can provide a more interactive and dynamic user experience for prototyping.

```
// Components
import { LoginComponent } from './components/login/login';
...
// Modules
import { DragDropModule } from '@angular/cdk/drag-drop';
import { AppRoutingModule } from '../app-routing.module';
import { NgxMatFileInputModule } from '@angular-material-components/
    file-input';
// Material design
import { MatSidenavModule } from '@angular/material/sidenav';
...

@NgModule({
    declarations: [
        LoginComponent,
        ...
    ],
    imports: [
        DragDropModule,
        AppRoutingModule,
        NgxMatFileInputModule,
        MatSidenavModule,
        ...
    ],
    exports: [
        LoginComponent,
        ...
    ]
})
export class AllComponentModule { }
```

Listing 5.1 all-component.module.ts

[9] Website for Angular Material File Input https://www.npmjs.com/package/@angular-material-components/file-input

[10] Website for the Angular material Drag and drop https://v7.material.angular.io/cdk/drag-drop/api

Our implementation focuses on the MVC architecture, which contains services and directives to talk to the server and some middleware to add a user token to every request to authenticate the user. In the next section, we explain how we implemented the *UI Prototyping component*. In our tool, we have implemented *left-panel*, *middle-panel*, and *right-panel* components, dividing our screen. Then, we use the *observer pattern*[11] for the interaction between these components and various services to interact with the server.

```
import { NestedTreeControl } from '@angular/cdk/tree';
import { Component, OnInit } from '@angular/core';
...
@Component({
    templateUrl: './left-panel.component.html',
    ...
})
export class LeftPanelComponent implements OnInit {
    // Define variables ...
    constructor(private shared: CommunicationService, private
        viewService: ViewsService, ...) { }

    async ngOnInit() {
        // get master view from server
        let master: View = await firstValueFrom(this.viewService.
            getMasterView())
    }

    // CRUD of view
    addView(isMaster: boolean = false, node: View = new View()) {
        let master: View = this.dataSource.data[0]
        master.children.push(View.getView(false, name))
        this.dataSource = new MatTreeNestedDataSource<View>()
    }
    ...

    // Emit events and the other panels/components capture them
    addElement(elementName: string) {
        this.shared.setAddUIElement(elementName)
    }

}
```

Listing 5.2 left-panel.component.ts

[11]Website for Observer pattern: https://refactoring.guru/design-patterns/observer

Left panel The left-panel component contains a list of UI elements that can be added to the screen. It allows users to navigate and manipulate the elements on the screen easily, improving the UX. In our implementation (see Listing 5.2), firstly, we added a `@Component` directive to the component's TypeScript file to specify the location of its template file, CSS file and selector. Next, we added a function that fetches the master view, if present in the database, and assigns it to a variable in the component's code. This function is called during the initialization of the component called `ngOninit`. We also included functionality for CRUD operations for the views or UI screens in the prototyping phase. It includes adding, editing, deleting, and viewing views or UI screens. Finally, we had several functions that emit events to other panels or components that are listening to these events. It allows for communication and coordination between different parts of the application. Similarly, the template of the left panel contains a tree structure that displays the views and their children. This structure allows users to easily navigate through different UI screens and select the one they want to work on. The left panel template also contains various UI elements that the user can add to the UI screen in the middle panel. We have grouped them into different categories based on functionality, such as form elements, buttons, text elements, etc. Each category can be expanded or collapsed to make it easier to find the desired element.

Middle Panel In our implementation, firstly, in the constructor, the middle panel component (see Listing 5.3) creates a renderer to listen to mouse and keyboard events. This component subscribes to the required events that are emitted by other components. For example, it listens to adding UI elements from the left panel component. After the event is subscribed it adds the required UI element to the screen using the `addUIElement()` method and the provided information. It then uses the *Drag API* to make the element draggable within the virtual screen and adds various listeners. When the element is moved and placed at a certain position, the draggable interface provides the element's position, which is then added to the data structure of the current element. This component also provides CRUD functionality for the UI elements, i.e. to add, update, remove elements. For instance, it adds listeners for the keyboard events, such as delete or backspace key press, and removes the element from the screen when the event is triggered. Similarly, we implemented a template for the middle panel component that allows the user to build the prototype visually. The template is designed to provide a virtual screen for the user to place UI elements. It contains a box that defines the dimensions of the screen and displays the name of the current view that is being edited. The user can place UI elements within the box by dragging and dropping them onto the screen. These elements are provided by the left panel component and can be customized using the properties panel component on the right. The middle panel component subscribes to events emitted by the left and right panel components, allowing it to update the screen in real-time.

```
@Component({...})
export class MiddlePanelComponent implements OnInit {
    // Define variables
    @ViewChild('cardContent') el!: ElementRef
    ...
    constructor(private rf:RendererFactory2,private drag:DragDrop) {
        this.renderer = this.rf.createRenderer(null, null);
    }
    async ngOnInit() {
        // Subscribe to events e.g. add UI element
        await firstValueFrom(this.shared.getAddUIElement())
        this.addUIElement()
    }
    addUIElement() {
        // Define Component
        let component: ComponentContainer = new ComponentContainer()
        component.name = this.toAddElement
        ...
        // Make it draggable
        let dragRef: DragRef = this.drag.createDrag(
           recaptchaContainer).withBoundaryElement(this.el)
        // Add Element, push to array, add listener
        const text = this.renderer.createText(this.toAddElement)
        this.elementsOnCanVas.push(component)
        this.addListener(recaptchaContainer, component)
        this.getPosition(dragRef, component.id)
        ...
    }
    async getPosition(dragRef: DragRef, id: string) {
        const val = await firstValueFrom(dragRef.ended)
        toAdd.cssProperty.dropPoint = dragRef.getFreeDragPosition()
    }
    async addListener(elm: Element, el: ComponentContainer) {
        // Delete the element
        const event = await this.renderer.listen(elm, 'keydown')
        if (event.key == 'Delete' || event.key == 'Backspace') {
            elm.remove() ...
        }
    }
}
```

Listing 5.3 middle-panel.component.ts

Right Panel In our implementation, the right panel component serves as a property editor for the selected UI element in the middle panel. It contains various functions which are explained using the Listing 5.4. It listens to events emitted by the left panel and middle panel components to update the selected element's properties. It also listens to events to edit the canvas or screen and to delete the element from the canvas. The right panel contains various input fields and dropdowns to edit the properties of the selected UI element, such as color, text, font, size, etc. When the user selects an element on the canvas, the right panel updates with the properties of that element. Similarly, when a new UI element is added to the canvas, the right panel displays the default properties for that element. Additionally, the right panel contains a function for adding new interactions to the UI element, such as `onClick` event. This function allows the user to define a JavaScript function that will be executed when the UI element is clicked. The function can be added to the element's properties in the right panel and saved to the database along with the other properties. Moreover, the template of the right panel component displays the properties of a selected UI element. It is dynamically updated based on events emitted by the middle panel component. When the middle panel emits an event to update the selected element, the right panel template displays the properties of that element. Similarly, when the middle panel emits an event to update the canvas or screen, the right panel template updates the properties displayed on the screen. Overall, the right panel template is designed to provide real-time updates to the properties of the UI element based on user actions and events.

```
@Component({...})
export class RightPanelComponent implements OnInit {
    // Define variables
    ...
    constructor(...) { }

    ngOnInit() {
        // Functions for subscribing to various events
        this.updateSelectedElement()
        this.getProperties()
        this.updateCanvasView()
        this.updateDeletionUIElement()
    }
    async updateCanvasView() {
        this.element =
        await firstValueFrom(this.shared.getCanvasView())
        this.elementName = this.element.name
        if (this.element.type == ContainerType.VIEW) {
            this.element.cssProperty = new CSSProperty().json
            this.element.cssProperty.height = '200'
        }
    }

    addNewInteraction() {
        const interaction: OnClickInteraction =
        new OnClickInteraction();
        interaction.id = uuidv4();
        this.element.interactions = [interaction]
    }
}
```

Listing 5.4 right-panel.component.ts

5.4 Backend Implementation

This section discusses the back-end implementation of our software tool. As discussed in the previous section, we developed the backend server using *Loopback* which is a popular open-source Node.js framework. We implemented the backend following the MVC architecture pattern. According to the loopback 4 architecture (see figure 5.3 [12]), the backend implementation contains controllers, services, repositories, models, data sources, authentication middleware, and many more. But for our tool, we focus on these few components of Loopback 4. The controllers are responsible for handling incoming requests and returning responses to the client. Services contain the application's business logic and interact with repositories to perform CRUD operations on the data. Repositories provide an interface to the data source for data storage and retrieval. Models define the data schema and are used by controllers, services, and repositories to interact with the data source. Data sources describe the connection details to the database where the data is stored. In our case, we use MongoDB configurations. Additionally, authentication middleware was implemented to secure the application by verifying the user's identity and providing access control to specific resources. Thus, the backend implementation provides a robust and scalable architecture to handle the application's data management and authentication needs.

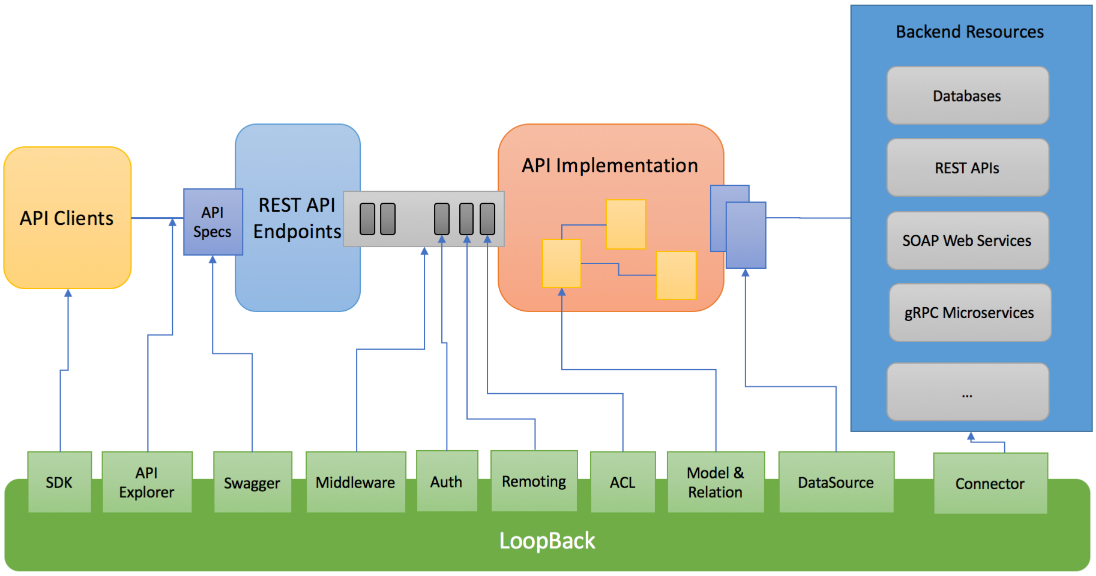


Fig. 5.3 Loopback 4 Architecture

[12]Website of Loopback 4 architecture: https://loopback.io/pages/en/lb4/imgs/loopback-overview.png

MoongoDb Datasource In the backend implementation using LoopBack 4, we used a MongoDB database as the data source for our application. LoopBack 4 provides an easy way to create and configure data sources using its Command-Line Interface (CLI). We used the CLI to generate a MongoDB data source for our application by running the command `lb4 datasource`. It generated a data source file (see Listing 5.5) with the necessary configuration for connecting to our MongoDB instance. We customized the data source configuration to include the database name and other options, such as the connection string, username, and password in an env variable `DB_CONNECTION`.

```
// imports
const config = {
  name: 'mongo',
  connector: 'mongodb',
  url: process.env.DB_CONNECTION,
  useNewUrlParser: true
};
// Observe application's life cycle to disconnect datasource when
   application is stopped
@lifeCycleObserver('datasource')
export class MongoDataSource extends juggler.DataSource
  implements LifeCycleObserver {
  static dataSourceName = 'mongo';
  static readonly defaultConfig = config;

  constructor(@inject('datasources.config.mongo', {optional: true})
       dsConfig: object = config) {
    super(dsConfig);
  }
}
```

Listing 5.5 lb-4-mongo.datasource.ts

REST Controller Using Loopback 4, we created RESTful APIs for our application. The REST controller was generated using the LoopBack CLI tool, which provided a boilerplate code structure for creating REST endpoints. To connect the REST controller to our application's business logic, we connected it to the repository and services. It allowed us to define the operations that could be performed on the model and provide implementation details. We also implemented APIs for file uploads (see the Listing 5.6), specifically images, necessary for our prototyping tool. We created a function called `fileUpload`, which takes in a `@requestBody` containing the file to be uploaded. This function used the Nginx File input module to process file upload. Once the file is uploaded, we save it to our server folder.

```
// imports ...
export class FileUploadController {
    constructor(...) {}

    @post('/files/{key}', {
        responses: {...},
    })
    async fileUpload(
        @requestBody.file()
        request: Request,
        @inject(RestBindings.Http.RESPONSE) response: Response,
        @param.path.string('key') key: string,
    ): Promise<object> {
        this.handler(request, response, async (err: unknown) => {
        this.uploadCsv(files["files"][0]["path"], key)
        })
    }

    private uploadCsv(file: File) {
        ...
    }
}
```

Listing 5.6 file-upload.controller.ts

Model for data In our implementation, we used the CLI to generate our data model. A data model in Loopback is essentially an entity representing a collection of data or a resource. It can have various properties that define its schema, such as the data type, validation rules, default values, etc. In our implementation, we defined our data model with various properties (as shown in Listing 5.7) like `id` of type *string*, textttkey of type *string* an *array* of `data` and some other properties. We also defined validation rules and default values for some of these properties. Overall, a model in Loopback 4 provides a structured way of organizing and storing data in our application.

Other components We implemented a *Middleware* using the `@authenticate('jwt')` decorator to secure the API endpoints and authenticate the user. This decorator validates the JWT token sent in the request header and authenticates the user based on the token's validity. If the token is valid, the user can access the endpoint; otherwise, a 401 unauthorized error is returned. *OpenAPI* is a specification that allows developers to define, create, and consume RESTful APIs. We used the Loopback OpenAPI specification to generate API documentation for our application. The OpenAPI specification defines the API's endpoints, parameters, request and response bodies, and authentication requirements. The specification generates interactive documentation, client libraries, and code snippets to help developers integrate with the API. We configured the OpenAPI specification by defining the application's metadata, security schemes, and endpoints in the Loopback configuration file. Finally, we used a predefined docker file generated from the Loopback CLI to deploy the application. The file specified the base image, environment variables, exposed ports, and dependencies required to run the application. The docker file contained all the necessary instructions to build and run the application in a containerized environment.

```
@model({ settings: { strict: false } })
export class DataModel extends Entity {
    @property({
        type: 'string',
        id: true,
        generated: true
    })
    id?: string;

    @property({
        type: 'string'
    })
    key?: string;

    @property({
        type: 'array',
        itemType: 'object',
        required: false,
        default: []
    })
    data: any;

    [prop: string]: any;

    constructor(data?: Partial<DataModel>) {
        super(data);
    }
}
```

Listing 5.7 data.model.ts

5.5 Database Schema

5.6 Software Tool

Chapter 6

Evaluation

Chapter 7

Related Work

7.1 State of the Art Research

7.2 Comparison

Software Approach (SA)

3. Do not use 'ditto' signs or any other such convention to repeat a previous value. In many circumstances, a blank will serve just as well. If it won't, then repeat the value.

Comparison between different tools										
Tool	**DR1**	**DR2**	**DR3**	**DR4**	**DR5**	**DR6**	**DR7**	**DR8**	**DR9**	**DR10**
SA1	2	3	4	5	6	7	8	9	10	11
SA2	2	3	4	5	6	7	8	9	10	11
SA3	2	3	4	5	6	7	8	9	10	11
Legend	No Fulfillment (○)			Partial Fulfilment (◑)			Complete Fulfilment (●)			

Table 7.1 Table comparing different SAs against DRs

Chapter 8

Conclusion

8.1 Conclusion

8.2 Future Work

References

[1] William L. Kuechler and Vijay K. Vaishnavi. On theory development in design science research: anatomy of a research project. *European Journal of Information Systems*, 17:489–504, 2008.

[2] Faheem Ahmed, Luiz Fernando Capretz, and Piers Campbell. Evaluating the demand for soft skills in software development. *IT Professional*, 14(1):44–49, 2012.

[3] David J Teece. Business models, business strategy and innovation. *Long range planning*, 43(2-3):172–194, 2010.

[4] Alan M. Davis. Software prototyping. volume 40 of *Advances in Computers*, pages 39–63. Elsevier, 1995.

[5] Steve Blank. Why the lean start-up changes everything. https://hbr.org/2013/05/why-the-lean-start-up-changes-everything, May 2013.

[6] Eveliina Lindgren and Jürgen Münch. Raising the odds of success: the current state of experimentation in product development. *Information and Software Technology*, 77:80–91, September 2016.

[7] Aleksander Fabijan, Pavel Dmitriev, Helena Holmström Olsson, and Jan Bosch. The benefits of controlled experimentation at scale. In *2017 43rd Euromicro Conference on Software Engineering and Advanced Applications (SEAA)*, pages 18–26, 2017.

[8] Kathryn Whitenton. But you tested with only 5 users!: Responding to skepticism about findings from small studies. https://www.nngroup.com/articles/responding-skepticism-small-usability-tests/, 2019.

[9] Brian L. Smith, William T. Scherer, Trisha A. Hauser, and Byungkyu Brian Park. Data–driven methodology for signal timing plan development: A computational approach. *Computer-Aided Civil and Infrastructure Engineering*, 17, 2002.

[10] Shirley Gregor, David Jones, et al. The anatomy of a design theory. Association for Information Systems, 2007.

[11] Alan R Hevner, Salvatore T March, Jinsoo Park, and Sudha Ram. Design science in information systems research. *MIS quarterly*, pages 75–105, 2004.

[12] Jane Webster and Richard T Watson. Analyzing the past to prepare for the future: Writing a literature review. *MIS quarterly*, pages xiii–xxiii, 2002.

[13] Jasmin Jahić, Thomas Kuhn, Matthias Jung, and Norbert Wehn. Supervised testing of concurrent software in embedded systems. In *2017 International Conference on Embedded Computer Systems: Architectures, Modeling, and Simulation (SAMOS)*, pages 233–238, 2017.

[14] Faezeh Khorram, Jean-Marie Mottu, and Gerson Sunyé. Challenges and opportunities in low-code testing. In *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings*, MODELS '20, New York, NY, USA, 2020. Association for Computing Machinery.

[15] Jordi Cabot. Positioning of the low-code movement within the field of model-driven engineering. In *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings*, MODELS '20, New York, NY, USA, 2020. Association for Computing Machinery.

[16] Mark A Hart. The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses eric ries. new york: Crown business, 2011. 320 pages. us$26.00. *Journal of Product Innovation Management*, 29(3):508–509, 2012.

[17] John D Gould and Clayton Lewis. Designing for usability: key principles and what designers think. *Communications of the ACM*, 28(3):300–311, 1985.

[18] Carlye A Lauff, Daniel Knight, Daria Kotys-Schwartz, and Mark E Rentschler. The role of prototypes in communication between stakeholders. *Design Studies*, 66:1–34, 2020.

[19] Jim Rudd, Ken Stern, and Scott Isensee. Low vs. high-fidelity prototyping debate. *interactions*, 3(1):76–85, 1996.

[20] Reinhard Sefelin, Manfred Tscheligi, and Verena Giller. Paper prototyping-what is it good for? a comparison of paper-and computer-based low-fidelity prototyping. In *CHI'03 extended abstracts on Human factors in computing systems*, pages 778–779, 2003.

[21] UXPin. What is a prototype. 2022.

[22] Mark van Harmelen. Exploratory user interface design using scenarios and prototypes. In *Proceedings of the Conference of the British Computer Society, Human-Computer Interaction Specialist Group on People and Computers V*, pages 191–201, 1989.

[23] Paweł Weichbroth and Marcin Sikorski. User interface prototyping. techniques, methods and tools. *Studia Ekonomiczne*, (234):184–198, 2015.

[24] Figma high-fidelity prototype. https://www.figma.com/community/file/988854619809579450.

[25] Jenny Preece, Yvonne Rogers, Helen Sharp, David Benyon, Simon Holland, and Tom Carey. *Human-computer interaction*. Addison-Wesley Longman Ltd., 1994.

[26] Ken Schwaber. *Agile project management with Scrum*. Microsoft press, 2004.

[27] Pedro Szekely. User interface prototyping: Tools and techniques. In *Workshop on Software Engineering and Human-Computer Interaction*, pages 76–92. Springer, 1994.

[28] G. F. Hoffnagle and W. E. Beregi. Automating the software development process. *IBM Systems Journal*, 24(2):102–120, 1985.

[29] Ender Sahinaslan, Onder Sahinaslan, and Mehmet Sabancıoglu. Low-code application platform in meeting increasing software demands quickly: Setxrm. In *AIP Conference Proceedings*, volume 2334, page 070007. AIP Publishing LLC, 2021.

[30] Alexander C Bock and Ulrich Frank. Low-code platform. *Business & Information Systems Engineering*, 63(6):733–740, 2021.

[31] Austin Miller. Low code vs no code explained. https://blogs.bmc.com/low-code-vs-no-code/?print-posts=pdf, 2021.

[32] Raquel Sanchis and Raúl Poler. Enterprise resilience assessment—a quantitative approach. *Sustainability*, 11(16):4327, 2019.

[33] Jordi Cabot. Positioning of the low-code movement within the field of model-driven engineering. In *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings*, MODELS ’20, New York, NY, USA, 2020. Association for Computing Machinery.

[34] Vagisha Arora. What are the three steps of low-code app development? https://www.planetcrust.com/what-are-the-three-steps-of-low-code-app-development, 2022.

[35] Christoforos Zolotas, Kyriakos C Chatzidimitriou, and Andreas L Symeonidis. Restsec: a low-code platform for generating secure by design enterprise services. *Enterprise Information Systems*, 12(8-9):1007–1033, 2018.

[36] Omg, meta-object facility. http://www.omg.org/mof/.

[37] Frédéric Jouault and Jean Bézivin. Km3: a dsl for metamodel specification. In *International Conference on Formal Methods for Open Object-Based Distributed Systems*, pages 171–185. Springer, 2006.

[38] Iyad Zikra. Implementing the unifying meta-model for enterprise modeling and model-driven development: An experience report. In *IFIP Working Conference on The Practice of Enterprise Modeling*, pages 172–187. Springer, 2012.

[39] Mariana Bexiga, Stoyan Garbatov, and João Costa Seco. Closing the gap between designers and developers in a low code ecosystem. In *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings*, pages 1–10, 2020.

[40] Pierre A Akiki, Arosha K Bandara, and Yijun Yu. Adaptive model-driven user interface development systems. *ACM Computing Surveys (CSUR)*, 47(1):1–33, 2014.

[41] Frank Doesburg, Fokie Cnossen, Willem Dieperink, Wouter Bult, Anne Marie de Smet, Daan J Touw, and Maarten W Nijsten. Improved usability of a multi-infusion setup using a centralized control interface: A task-based usability test. *PloS one*, 12(8):e0183104, 2017.

[42] Marieke McCloskey. Turn user goals into task scenarios for usability testing. https://www.nngroup.com/articles/task-scenarios-usability-testing/, 2014.

[43] Miklos Philips. Evolving ux: experimental product design with a cxo. https://uxdesign.cc/evolving-ux-experimental-product-design-with-a-cxo-2c0865db80cc, 2020.

[44] Effie Lai-Chong Law, Virpi Roto, Marc Hassenzahl, Arnold POS Vermeeren, and Joke Kort. Understanding, scoping and defining user experience: a survey approach. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 719–728, 2009.

[45] Rasmus Ros and Per Runeson. Continuous experimentation and a/b testing: a mapping study. In *2018 IEEE/ACM 4th International Workshop on Rapid Continuous Software Engineering (RCoSE)*, pages 35–41. IEEE, 2018.

[46] Brian Fitzgerald and Klaas-Jan Stol. Continuous software engineering: A roadmap and agenda. *Journal of Systems and Software*, 123:176–189, 2017.

[47] Mary Poppendieck and Michael A Cusumano. Lean software development: A tutorial. *IEEE software*, 29(5):26–32, 2012.

[48] Freddy Ballé and Michael Ballé. Lean development. http://www.lean.enst.fr/wiki/pub/Lean/LesPublications/LeanDevBalleBalle.pdf, 2005.

[49] Nicolas Navet, Loïc Fejoz, Lionel Havet, and Altmeyer Sebastian. Lean model-driven development through model-interpretation: the cpal design flow. In *8th European Congress on Embedded Real Time Software and Systems (ERTS 2016)*, 2016.

[50] Forrest W Young. Quantitative analysis of qualitative data. *Psychometrika*, 46(4):357–388, 1981.

[51] Helena Holmström Olsson and Jan Bosch. Towards continuous customer validation: A conceptual model for combining qualitative customer feedback with quantitative customer observation. In *International Conference of Software Business*, pages 154–166. Springer, 2015.

[52] Eric Ries. *The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses*. Currency, 2011.

[53] Vidroha Debroy, Senecca Miller, and Lance Brimble. Building lean continuous integration and delivery pipelines by applying devops principles: a case study at varidesk. In *Proceedings of the 2018 26th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering*, pages 851–856, 2018.

[54] Sandra EP Silva, Robisom D Calado, Messias B Silva, and MA Nascimento. Lean startup applied in healthcare: A viable methodology for continuous improvement in the development of new products and services. *IFAC Proceedings Volumes*, 46(24):295–299, 2013.

[55] Tanja Suomalainen, Raija Kuusela, and Maarit Tihinen. Continuous planning: an important aspect of agile and lean development. *International Journal of Agile Systems and Management*, 8(2):132–162, 2015.

[56] Katrin Burmeister and Christian Schade. Are entrepreneurs' decisions more biased? an experimental investigation of the susceptibility to status quo bias. *Journal of business Venturing*, 22(3):340–362, 2007.

[57] Robert Waszkowski. Low-code platform for automating business processes in manufacturing. *IFAC-PapersOnLine*, 52(10):376–381, 2019. 13th IFAC Workshop on Intelligent Manufacturing Systems IMS 2019.

[58] Kari Kuutti, Katja Battarbee, Simo Sade, T Mattelmaki, Turkka Keinonen, Topias Teirikko, and A-M Tornberg. Virtual prototypes in usability testing. In *Proceedings of the 34th Annual Hawaii International Conference on System Sciences*, pages 7–pp. IEEE, 2001.

[59] Karen M Staller. Confusing questions in qualitative inquiry: Research, interview, and analysis, 2022.

[60] Philipp Mayring. Qualitative content analysis: theoretical foundation, basic procedures and software solution. 2014.

[61] Urvashi Kokate, Kristen Shinohara, and Garreth W Tigwell. Exploring accessibility features and plug-ins for digital prototyping tools. 2022.

Acronyms

API Application Programming Interfaces

CE Continuous Experimentation

CLI Command-Line Interface

CRUD Create Read Update Delete

CSV Comma Separated Value

DB Database

DBMS Database Management System

DF Design Features

DML Data Modeling Language

DP Design Principles

DR Design Requirements

DS Data Structure

DSL Domain Specific Language

DSR Design Science Research

GUI Graphical User Interface

HTML Hypertext Markup Language

IT Information Technology

LCDP Low-Code Development Platform

MBSE Model-Based Software Engineering

MDD Model Driven Development

MDSE Model Driven Software Engineering

MOF Model Object Facility

MQTT Message Queue Telemetry Transport

MVC Model-View-Controller

MVP Minimum Viable Product

NCDP No-Code Development Platform

OMG Object Management Group

POC Proof-Of-Concept

REST Representational State Transfer

SA Software Approach

SE Software Engineering

UAT User Acceptance testing

UCD User-Centered Design

UI User Interface

UML Unified Modeling Language

UX User Experience

Appendix A

How to install our Application

Our UI Prototyping tool (as shown in figure A.1) utilizes AngularCLI[1], MongoDB[2], and NodeJS[3] in conjunction with a microcontroller architecture that employs docker containers. To use the tool, you will need to download and install these technologies beforehand. NodeJS serves as a runtime environment for executing JavaScript code and comes with the Node Package Manager (NPM), which can be used to include external JavaScript code packages in the software. Moreover, you need to install Loopback[4] which is a framework for NodeJS. AngularCLI, on the other hand, is a command-line interface (CLI) used to develop and maintain Angular applications. Additionally, MongoDB drivers can be installed or can also be the cloud version of MongoDB. Lastly, for cloning the repository, you can install the Git[5].

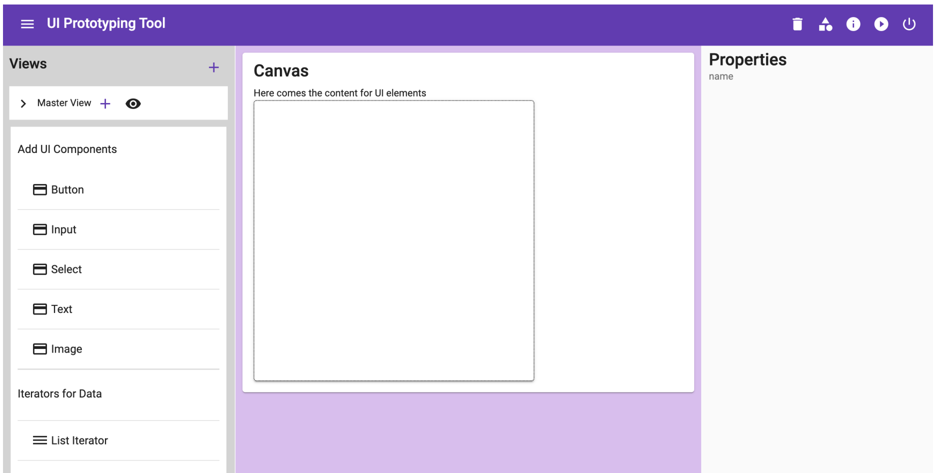


Fig. A.1 Index page of our UI Prototyping tool

[1]Website of AngularCLI: https://angular.io/cli
[2]Website of MongoDB: https://www.mongodb.com/
[3]Website of NodeJS: https://nodejs.org/en/
[4]Website of Loopback: https://loopback.io/doc/en/lb4/Getting-started.html

Based on these prerequisites, there are additional instructions for installing the tool.

```yaml
version: "3.9"
services:

  ui-prototyping:
    container_name: ui-prototyping-app-docker
    build: ./ui-prototyping-tool/
    restart: unless-stopped
    ports:
      - 8083:8083
    networks:
      - myNetwork

  ui-prototyping-no-code-app:
    container_name: ui-prototyping-no-code-app-docker
    build: ./no-code-built-app/
    restart: unless-stopped
    ports:
      - 8084:8084
    networks:
      - myNetwork

  ui-prototyping-server:
    container_name: ui-prototyping-server-docker
    build: ./ui-prototyping-server/
    ports:
      - 3001:3001
    networks:
      - myNetwork

  nginx:
    container_name: nginx-final-docker
    restart: unless-stopped
    build: .
    ports:
      - 80:80
      - 443:443
    networks:
      - myNetwork
    volumes:
      - ./certbot/conf:/etc/letsencrypt
      - ./certbot/www:/var/www/certbot
    depends_on:
      - server
```

(a) A configuration file for docker-compose file

```nginx
upstream ui-prototyping {
    server ui-prototyping-app-docker:8083;
}

upstream no-code-app {
    server ui-prototyping-no-code-app-docker:8084;
}

upstream ui-prototyping-api {
    server ui-prototyping-server-docker:3001;
}

server {

    listen 80 default_server;
    listen [::]:80 default_server;

    server_name _;

    location / {
        proxy_pass http://ui-prototyping/;
        proxy_redirect     off;
    }

    location /no-code-app/ {
        proxy_pass http://no-code-app/;
        proxy_redirect     off;
    }

    location /ui-prototyping/api/ {
        proxy_pass http://ui-prototyping-api/;
        proxy_redirect     off;
    }

    error_page  404              /404.html;


    error_page   500 502 503 504  /50x.html;
    location = /50x.html {
        root   /usr/share/nginx/html;
    }
}
```

(b) Nginx Configuration for our tool

Fig. A.2 Configuration settings

Tool configuration steps:

1. **Install Docker:** To begin with, you need to install Docker on your computer. You can download it from the official website[6] based on your operating system.

[5] Website of Git installation: https://git-scm.com/downloads
[6] Website of Docker Installation: https://www.docker.com/

2. **Clone Repository:** Get the latest version of the tool from GitLab repository[7]. We use GitLab which is hosted by the University of Paderborn.
   (a) Clone the GitLab repository directly from GitLab[8].
   (b) You can fork the repository[9]
3. **Start docker daemon:** Start the docker engine or the service for running the docker containers[10].
4. **Run Application:** Run the script file (`./restart-docker.sh`) which is available to run the docker containers. This also runs the `docker-compose.yml` file internally. You can update the file if you want to change the ports or add TLS signatures (see figure A.2a).
5. **Check on Browser:** Use the UI Prototyping tool to develop the UI prototypes, create experiments and improve the prototype by opening `http://localhost/` in your web browser.

[7]Link for repo: https://git.cs.uni-paderborn.de/rakshitb/thesis
[8]Website for cloning repository instructions: https://docs.gitlab.com/ee/gitlab-basics/start-using-git.html
[9]Website for forking a repository: https://docs.gitlab.com/ee/user/project/repository/forking_workflow.html
[10]How to start docker deamon: https://docs.docker.com/config/daemon/start/

Appendix B

Literature Review Summary

In this thesis, a non-systematic literature review was conducted to explore the current state of UI prototyping tools and develop the DRs for our DSR. Several research papers were reviewed, along with an examination of some renowned UI prototyping tools. The review focused on the features and capabilities of these tools and any potential limitations or drawbacks. Through this process, valuable insights were gained into the strengths and weaknesses of existing UI prototyping tools, which can inform the development of more effective tools in the future. This section below contains a table containing the papers (see section B) we reviewed and the tools (see section B) we tested.

Software tools

In this section, we briefly discuss some of the tools and how they helped us formulate the DRs. Our non-systematic literature review identified ten tools that could help us with our solution approach (see table B.1). Among these, we found five UI prototyping tools that could be useful in designing and refining the user interface of our solution. These tools included Axure, Figma, Proto.io, InVision, and Adobe XD. Additionally, we identified five split testing tools that could be helpful in testing and improving the effectiveness of our solution. These split testing tools included Optimizely, VWO, Google Optimize, Freshmarketer, and Zoho PageSense. By incorporating these tools into our solution approach, we hope to create a user-friendly and effective solution that meets the needs of our users.

Literature and State of the Art (SOAT) technologies

Our non-systematic literature review led us to state-of-the-art research in several key areas relevant to our solution approach (see table B.2). We identified research on UI prototyping,

Software Tools			
#	**Name**	**Type**	**View**
1	Figma	UI Prototyping Tool	Link
2	InVision	UI Prototyping Tool	Link
3	Axure	UI Prototyping Tool	Link
4	Adobe XD	UI Prototyping Tool	Link
5	Proto.io	UI Prototyping Tool	Link
6	Google Optimize	Split Testing Tool	Link
7	VWO	Split Testing Tool	Link
8	Convertize	Split Testing Tool	Link
9	Freshmarketer	Split Testing Tool	Link
10	Zoho PageSense	Split Testing Tool	Link

Table B.1 Table for different UI prototyping and A/B testing tools

which can help us design and refine our solution's user interface to meet our users' needs. We also found research on low-code/no-code development, which can help us to build our solution quickly and efficiently. Additionally, we explored model-based software engineering, which can provide us with a structured approach to software development. We also discovered research on continuous experimentation, which can help us to test and improve our solution over time. Task-based usability testing was another key area of research we explored, which can help us to ensure that our solution is easy to use and meets the needs of our users. Finally, we looked into the LEAN development cycle, which can help us build our solution iteratively and incrementally while minimizing waste and maximizing user value. By incorporating the insights from these research areas into our solution approach, we hope to create a robust and effective solution that meets the needs of our users.

Literature and State Of The Art Research			
#	**Name**	**Type**	**View**
1	Rapid software prototyping	UI Prototyping	Link
2	Automating the software development process	UI Prototyping	Link
3	User interface prototyping	UI Prototyping	Link
4	Exploratory user interface design using scenarios and prototypes	UI Prototyping	Link
5	Low-code application platform	LCDP	Link
6	Low Code vs No Code	LCDP / NCDP	Link
7	No-code platform	NCDP	Link
8	Adaptive model-driven user interface development systems	MBSE	Link
9	OMG, Meta-Object facility	MBSE	Link
10	Turn User Goals into Task Scenarios for Usability Testing	Task Based Usability Testing	Link
11	But You Tested with Only 5 Users!	Task Based Usability Testing	Link
12	Continuous experimentation and A/B testing: a mapping study	Split Testing	Link
13	Evolving UX: experimental product design with a CXO	Split Testing	Link
14	Why the lean start-up changes everything?	LEAN	Link
15	Lean software development: A tutorial	LEAN	Link
16	Continuous planning: an important aspect of agile and lean development	LEAN	Link

Table B.2 Table for different State Of The Art research

Appendix C

User Responses