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MASTER´S THESIS

Evaluating methods of avoiding redundant libraries in micro frontend based landscapes

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Eidesstattliche Erklärung

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Abstract

This transcript provides proof of possible solutions regarding redundant libraries in micro frontend landscapes. The data collected is based on an implemented prototype using the Luigi micro frontend framework. Different landscapes, with different technologies are implemented to represent a heterogenic landscape, which is considered to be representative for a micro frontend landscape.

The technologies in use are a Content Delivery Network, the Compound feature of Luigi in combination with Web Components and lastly the Webpack Module Federation, a rather new feature of Webpack which can serve as a foundation for micro frontend architectures. After implementation, data is collected and displayed, defining the performance metrics used for the evaluation. It is proven that each of the respective technologies has their own means to avoid redundant libraries in the micro frontend landscapes, be it either distinguishable resource URLs provided by the CDN, reusable Web Components or even shared dependency through the Module Federation. Each technology has its own approach of solving the issue at hand. Still, every method has limitation which are evaluated as well, such as the effort involved when using one of the corresponding technologies.

For CDN, it is shown that even though it is easy to implement and use in the project itself, a public CDN has certain restrictions. These include the absence of special libraries required for the project and the constant dependency on the availability of the CDN servers. Hosting your own CDN involves further costs and requires time for implementation and configuration, which in certain cases might not be affordable. Web Components implemented as Compounds in Luigi show great potential in avoiding redundancies to a certain degree, by providing reusable components registered in the browser. Additionally, this technology is framework-independent and compatible with almost all modern browsers, due to its standard status. It is shown how this technology provides a way to support multi-version landscapes via the scoping feature of the UI5 Web Components library. The Webpack Module Federation is considered to be a powerful tool to solve the issue of the redundancies in micro frontend landscapes. Not only can it serve to share central dependencies between its federalized modules, but also optimize shared dependencies in different versions. It is assumed that more features can be enabled through the Webpack bundler to optimize the landscape even further.

After showing how each respective technology avoids redundant libraries in a micro frontend landscape, the comparison is made and a conclusion is drawn. The use case and the requirements on the landscape define which technology should or could be used, since all technologies provide a solution for the issue in their own way.

Contents

1. Introduction

This chapter will explain the problem, motivation and goals of this transcript. It will also narrow down the thesis scope.

1.1   Motivation

The micro frontend technology has experienced a rise in popularity over the past 3 years. The occurrence of such a trend is no surprise, considering the fact that more and more applications are designed following the micro service architecture principles [1]. Micro frontends share a common interest with their assumed precursor. Generally, it can be stated that the market prefers smaller, independent, lightweight applications over monolithic giants with strong dependencies. Similar to micro services, micro frontends offer almost the same advantages to a development team: Independence of the respective micro frontend teams, shorter and decoupled developments cycles, smaller scope of maintenance, separations of concerns, reusable components available via defined APIs etc.[2] However, this concept has certain flaws which have to be considered when making the decision [3].

Depending on the type of the to-be-developed application, the concept of micro frontends is not always favored. One major point of criticism is the aspect of redundancies inside the landscape. Especially, since isolation is a core aspect of this architecture. The circumstance that each micro frontend is a separate project with its own runtime, developed by an independent team, causes this issue to occur. It allows the development teams to use their own preferred tech stack and enables the application itself to be reused in different landscapes. Nonetheless, that also means that isolated micro frontends are partially loading and using the same libraries during their runtime. This is causing an overhead on client and server side and therefore, correlates with the runtime costs of such a landscape and potentially an inferior user experience.[4][5]

Despite isolation being a key aspect of this architecture, it is still possible to avoid the related redundancies without disabling it.

1.2   Definition of redundancies

For the context of this transcript, the term *"redundancies"* or *"redundant libraries"* refers to same libraries or dependencies used by multiple micro frontend projects. It does not

mean the redundant code elements, like reoccurring methods inside the projects or same CSS classes.

A library is determined by its identifier or its name, e.g. `@luigi-project.` If the given library or dependency is imported, by multiple different micro frontends, it is considered to be redundant in the context of this thesis. The case of different versions of redundant libraries is considered too and is covered in subsequent chapters.

1.3 Goal

The goal of this thesis is to provide proof and evaluate methods to avoid redundancies during the runtime of a representative micro frontend landscape.

To achieve this, two prototypes are implemented using the Luigi micro frontend framework. The landscape itself is designed to be as representative as possible by using a heterogenic tech stack. Additionally, following methods are present to avoid redundantly loaded libraries:

- Content Delivery Network (CDN)
- Web Components (WCs) in Luigi Compound views
- Webpack Module Federation (WMF) framework

The implemented methods are evaluated under predefined metrics. The steps to collect the data for the metrics are explained too. Eventually, a conclusion is drawn based on the empirical data, accompanied by the subjective opinion of the author. It is explained how the usage and implementation of the respective technologies differs and which advantages each technology offers.

1.4 Scope of Work

To account for the limited time frame for this transcript, the following aspects are either not considered or referenced only on a theoretical level.

The development of a self-hosted CDN: An approximate cost assumption is made for such a project, without actual implementation.

Usage of the Webpack bundler outside the context of the Module Federation: Since this bundler offers many ways for configuration, the focus lies on those necessary for the WMF context.

Configuration for the Luigi framework of the implemented landscape: Each implemented prototype uses this framework for its micro frontend landscapes. Since showing all configurations would be to extensive, only a general overview is given.

Development of WCs: The general usage and functionality of this standard is explained.

Combinations of the implemented technologies: This aspect is not empirically considered in this transcript.

1.5   The collaborators

This thesis was written in collaboration with SAP Luigi project team. The SAP was originally founded in in 1972 as SAPD (system analysis program development), later became SAP AG in 2005 and in 2014 SAP SE. The Hybris company was originally founded in 1997, was later acquired by SAP in 2013, after moving its headquarter from Zug in Switzerland to Munich in Germany.[6] The Luigi project team is part of the SAP Hybris organization but the developed framework is an open-source product. The team and their product aim to improve the experiences of customers, developers and administrators who are using Luigi. Their open-source product was designed to make the transformation from monolithic architectures into micro frontend based landscapes as smooth as possible.

2. The Luigi framework

In this chapter, an overview of the used Luigi framework is given. Currently there are multiple different micro frontend frameworks available on the market, including but not limited to **Bit, SystemJS, Webpack 5 Module Federation, Piral, Single SPA** and **Luigi** [7]. For the implementation of the representative landscapes the Luigi framework was used. Therefore, a short introduction to Luigi is given here.

2.1 Luigi

Luigi is an open-source JavaScript framework for micro frontends, consisting of two main parts, the **Luigi Core** and the **Luigi Client**. It provides a basis to integrate micro frontends, also called **Nodes** in this context. Both parts serve different purposes within the micro frontend landscape.[8]

2.1.1 Core

The **Luigi Core** is the basis of the whole landscape. It defines the main app, which will serve as an entry point for the user. The possibilities for, applicable configurations of this part are the following:

- Navigation - enables navigation between micro frontends
- Authorization - enables authorization for the landscape
- Localization - providing translations to display its applications in multiple languages
- General settings - e.g. header display configurations, enable loading indicators for the micro frontends, etc.
- Luigi Core API - providing functions for the core app to interact with the framework and access its features

The core application inside the landscape is determined via the `luigi.config.js`. Any project containing it can fulfill this role, which is the only prerequisite. In the context of the framework, this app is later referred to as the **Core**. Following this principle, the project structure of the **Core** could look as shown in listing 2.1.[1]

---

[1]This example is taken directly from the implemented core project.

```
1   - react-core-mf
2     - [...]
3     - node_modules
4     - public
5       - [...]
6       - index.html
7       - luigi.config.js
8     - [...]
9     - src
```

LISTING 2.1: Project structure for a Luigi Core application including the
`luigi.config.js`

In the `luigi.config.js` itself the above mentioned possible configurations are defined [9].

2.1.2 Client

The Luigi Client serves as the connection between the framework and its micro frontends. In order to establish the connection, a micro frontend has to import and initialize the Client. This will grant the micro frontend access to the **LuigiClient** object during the runtime. The micro frontend can then interact with the framework to e.g. set a global state, add event listeners or enable navigation between other micro frontends in the landscape.

An import of the Luigi Client can be accomplished via different methods. The most straightforward approach is the direct import with a HTML script tag. Another option would be the import of the local package manager dependency.[10]

```
1   <!-- Via a HTML script tag -->
2   <script src="https://unpkg.com/@luigi-project/client@1.17.0/
      luigi-client.js">
3   </script>
4
5   <!-- Via a package manager -->
6   import LuigiClient from "@luigi-project/client";
```

LISTING 2.2: Import methods of the Luigi Client

2.2 Architecture

After the short introduction of the framework's core components, a general architecture of a landscape using Luigi is provided in figure 2.1.
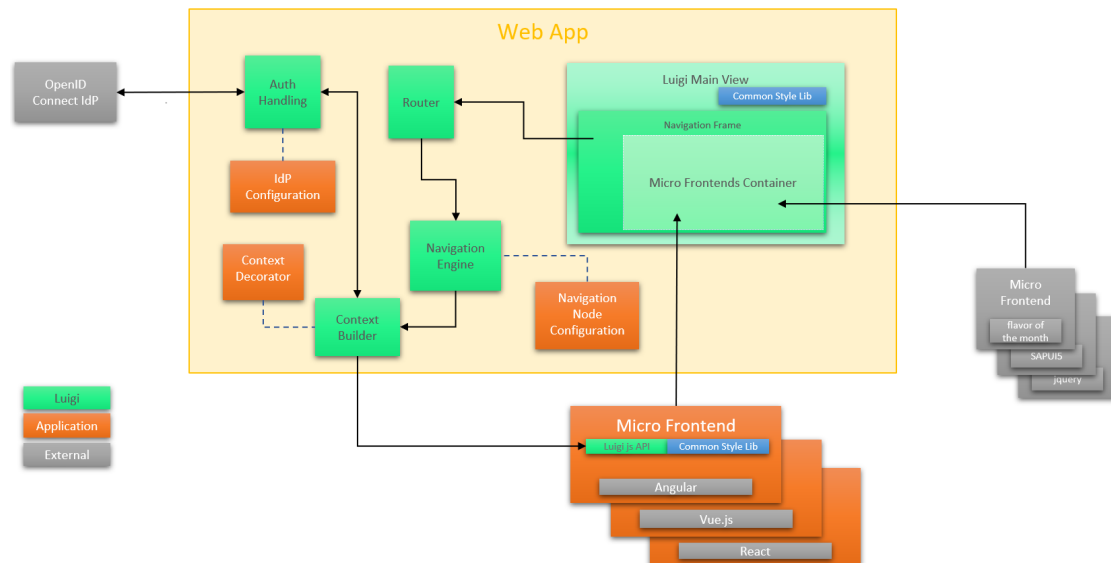
FIGURE 2.1: Architecture of the Luigi Framework [11]

As can be seen in figure 2.1, the displayed micro frontends in the Web App have a distinguished position in the Micro Frontends Container. The embedded projects can either be integrated via iFrames or as WCs. The provided dashboard (Navigation Frame), grants accesses to Luigi Core features, like the navigation or global search.

As described in the first chapter of this transcript, the issue in such a landscape are the redundantly imported libraries of the embedded micro frontends. The reason being that each node is an isolated application. For instance, navigating to the first micro frontend, followed by the second one, will load the bundled projects with their corresponding dependencies. In this case, the browser has no way to distinguish if a loaded resource is already present or not. The reason for that is the bundling of projects which makes the references indistinguishable to the browser. The following chapters will introduce technologies, which offer methods to resolve this issue.

3. Content Delivery Networks

One way of avoiding redundant libraries can be a central repository, where all resources are stored and can be requested via an API. Such a concept exists in the idea of Content Delivery Networks (CDNs). Since the resources are loaded via the CDN API, a dependency is available under a unique URL. Loading a dependency twice means the browser requests the resource from the same URL with the same parameters. Therefore, the browser can determine if the given resource is already present and decide to either load it from the CDN or from the browser cache, if it is already loaded.[12]

Nonetheless, a CDN has its limits which have to be considered. Costs can play a key role in the decision process. Even though free CDN services like **Unpkg.com** or **cdnjs** are valid options, the advantages of using these might differ depending on the business case. For instance, those services might solve the issue of redundant libraries in a micro frontend landscape, but do not necessarily improve the user experience of the application. Since the resources would be loaded from a cloud based service, the server location has significant influence on the latency of the requests. Therefore, depending from where the website is accessed, this circumstance could lead to a performance decrease when initially loading the page.[13]

Also the technological dependency on a public cloud based CDN has to be considered. Most cloud based services are scalable and replicable. However, a down time could lead to immense costs for a platform provider relying on a public CDN to deliver the platform resources. Besides, it is never guaranteed that certain dependencies are always available on the public CDN.

Another option is self-hosting a CDN and providing all required resources independently. A business would need to acquire hardware-resources (physically or via a hardware-as-a-service provider like Amazon Web Services), maintain the servers, fill the CDN with the necessary content and keep it up to date. However costs attached to this scenario can be immense and exclude this method due to cost inefficiency.[14]

This chapter will give further information about the CDN technology, how it functions and what further features it offers to optimize a micro frontends or websites performance.

3.1 Architecture

The basic architecture of a CDN can be split into three different building blocks.

Point of Presence (PoPs): Strategically located data centers around the world. Their function is to reduce the round trip time of requests. PoPs usually consist of several caching servers.

Caching servers: These servers are located in different PoPs and serve the function of caching resources from the origin server. That way website loading times and bandwidth allocations are reduced.

Hardware, like SSD/HDD and RAM: Located in the cache servers, the purpose of this building block is to provide the necessary storage and computing capacity. Better hardware means faster computing time, which then again improves the overall performance of the designated caching server.

Besides the above three building blocks, another one is crucial for the architecture of a CDN: The **origin server**. In a CDNs topology, the origin server can be compared to the center, or core. This is the server onto which the CDNs content is uploaded, synced with or distributed over the CDNs caching servers.[15]

An example for a basic CDN distribution is shown in figure 3.1.

FIGURE 3.1: Basic distribution of a CDN
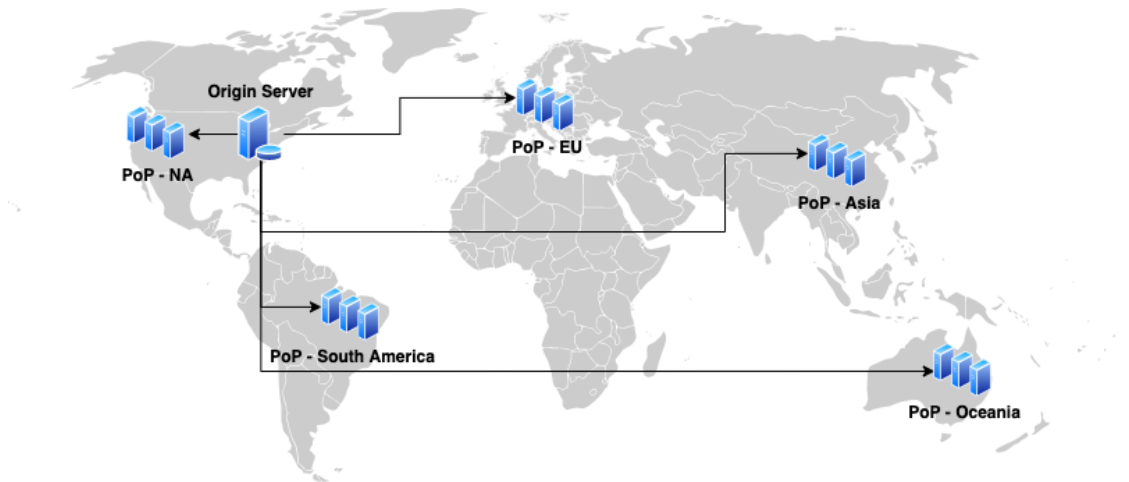
It has to be mentioned that the geographical distribution in figure 3.1 is simplified, for the sake of readability. In a real scenario, the cache servers of each PoP would themselves be distributed over different data centers on the continent. A client requesting resources from the CDN always communicates with the nearest possible cache server to their designated location.[13]

3.2 Design

For a CDN to fulfill its purpose, four requirements have to be met. These are not only technical requirements, like necessary hardware, but rather concerning the general design of the CDN. The four pillars of CDN design are:

Performance: First and foremost, the CDN has to provide a benefit when it comes to website performance. When the usage of a CDN increases the loading time of a website, the negative effect on user experience can cause financial harm to the host.[13]

Scalability: Since a cache server can serve multiple resources to different websites, it has to be able to handle traffic peaks. Without the aspect of scalability (either horizontal or vertical), this requirement cannot be met which would affect the CDNs performance.

Reliability: A website host has to rely on the CDN to deliver the websites resources. An outage on CDN side would cause the same effect to the relying websites, resulting in additional losses for the designated hosts. Therefore, most CDN providers commit to 99.9% availability in their service level agreements (SLAs).

Responsiveness: The aspect of responsiveness targets the issue of synchronization inside the CDN. A CDN has to be capable to react to changes and distribute those to its PoPs over the globe accordingly. Otherwise inconsistencies could occur on the websites relying on the CDN. This is ensured through an automated pull mechanism, via which edge servers pull changes from the origin server.[15]

Additionally to those four requirements, the topology of a CDN has to be considered. There are two options which can be used. Both would serve their purpose, but have different advantages as well as disadvantages.

The scattered CDN: This topology focuses on physical proximity. The PoPs are kept rather small in size, but are scattered around the world in greater frequency, thus providing as much proximity to their clients as possible. This topology excels in providing the CDN's resources into low-connectivity regions, since it is not highly dependent on wire infrastructure. When it comes to latency, it does not suffer as much due to the short distance between client and server. The trade-off with this topology is that it accrues more maintenance costs, since more PoPs are required to be maintained. Also, deploying new configurations can be connected to a lot of

effort, depending on the number of PoPs scattered across the CDN. Additionally, this number can also affect the RTT since every PoP inbetween the client and the server is a connection point.

The consolidated CDN: Contrary to the scattered CDN, this topology is designed to consolidate its resources at strategically located data centers. Since the PoPs are only located in those major data centers, the servers available to the PoPs are highly advanced and provide a lot of hardware capacity. Additionally, since the number of major data centers around the world is rather limited, the number of PoPs is reduced as well, compared to the scattered topology. Following the quality over quantity principle, a PoP in this topology can handle a greater amount of traffic compared to its counterpart, and is also more resilient, specifically when it comes to DDoS attacks. Also, due to the moderate number of PoPs, it is easier and faster for the operators of the CDN to deploy new configurations. Nonetheless, the trade-off for this topology is that, even though it can handle a high number of requests, its reach to low-connectivity regions is rather limited. This is due to the proximity difference between the servers and clients. Additionally, deploying a new PoP into this topology requires more effort, since the PoPs are rather complex.

The design decision is of course dependent on the business case for the CDN, as both topologies are intended to solve specific issues or challenges. [16]

3.3 Optimization

The CDN technology offers several ways of optimizing a websites performance and therefore, improving the user experience. In the following sections these optimizations will be showcased and explained.

3.3.1 Route optimization with Anycast

As previously mentioned, a CDN can be designed with different topologies which can affect its performance. Another factor which has to be considered in this equation is the routing itself. Basically, it does not matter if a cache server is located in close proximity to a client, if the requested resource is not present there. In this case, the client would have to be routed to different, cache servers located further away. To circumvent this, the Anycast routing is used in modern CDNs. This traffic routing algorithm is best explained in direct comparison with Unicast. Both serve the same purpose of routing requests to their designated destination, but they do it in different ways. Where with Unicast each

node has a unique address, Anycast advertises multiple nodes with the same address. For instance, in a Unicast orchestrated network the server address `10.10.0.1` would be only present once. Anycast, on the other hand, would advertise this exact address over multiple different servers around the globe. Thus, a request towards the address would reach its destination via the shortest path, given that the path will be identified and prioritized by devices that actually govern the flow of traffic. The shortest path itself is counted in hops. Hops represent the number of time a request changes hands between hosts.[17]

3.3.2 TLS Performance

The route optimization with Anycast, also improves the RTT when using the TLS/SSL protocol. Since this section does not focus on explaining the protocol, only a short description is given. SSL (Secure Socket Layer) or, as it now should be called, TLS (Transport Layer Security) is a protocol via which secure communications are ensured on the Internet. The communicating parties establish a connection via the following steps:

1. A so-called three-way handshake is done
2. The parties agree upon an encryption method
3. Mutual verification process is performed
4. Symmetric keys for encoding and decoding are generated

These steps are necessary to ensure secure communication and are a welcome trade-off for the benefits they provide.

A CDN can provide improvement to this overhead and decrease the RTT of a request. Through the aspect of route optimization and general proximity, the overall request distance is decreased. Therefore, the RTT is shortened as well. The steps are still processed, they just do not have to travel that long. Additionally, the SSL/TLS negotiation process is shorter, too.[18]

3.3.3 Frontend optimization

The term frontend optimization refers to the process of making a website more browser-friendly and reducing loading times. There are multiple ways to optimize a frontend. These will be explained under consideration of the role a CDN plays in them.

Reducing HTTP requests: When loading a website, the browser opens several HTTP connections, the number of which is actually limited by the browser. If a website requires more connections than a browser can open at the time, the browser has to start queuing the rest. This again leads to longer loading times and affects the user experience. A CDN improves on that by pre-pooling connections and ensuring they remain open throughout a session. Even though this does not reduce the actual number of requests, it does improve the response time for each one, making it so that every request can be processed faster. Additionally, HTTP/2 introduces the method of multiplexing. This allows a single TCP connection to transfer multiple different HTTP requests [19].

File compression: Not only do the number of requests or the proximity of the client to the server, affect the responsiveness of a website. The actual content has a major role in this aspect, too. Loading one single resource with a size of 1 GB takes a while, even if the server is close by. Reducing the size of this file or resource might increase the loading process. File compression like gzip is a method of doing exactly that. Most modern CDN providers offer automated file compression with gzip to reduce the actual content size delivered to the client.

Cache optimization: Via caching, static files are stored either on the client device or in the cache of a nearby cache server. Locally stored static files do not have to be loaded via the network and are available to the browser for rendering almost immediately. The only question remaining is how long does a resource have to be cached. This information is necessary to optimize the use of the client's cache. The caching time is usually defined in the cache header of the request. Modern CDNs offer cache control options, which help in defining rules for exactly that header. CDNs have also started to use machine learning techniques to follow and understand content usage patterns and automatically optimize caching policies.

Code minification: Similar to the file compression method, the process of code minification offers a way of reducing file sizes too. Whereas a developer writes code in a humanly readable way, with spaces and line breaks, a machine does not need this kind of formatting. By removing comments, spaces and line breaks, the size of a code file can be reduced by 30%. CDNs use methods like gzip, minify or a combination of these two to reduce the size of JavaScript, HTML or CSS files.

Image optimization: Images can be immense in size and require a long time to load. The best way to display an image on a website would be to cache it first and then load it from the cache to reduce actual loading time through the network. Another option could be to reduce the actual size of the image and thus the loading time. However, other than code files, images are already compressed when

loaded, therefore compressing them further to reduce file size might cause a loss of image quality. This is called lossy compression. If this trade-off is not an option, caching would be more effective. CDNs offer exactly that solution, caching images and providing them from the nearest source available to the client. If this does not suffice, CDNs also offer a progressive rendering option for images. On initially loading the page, the CDN would provide a lossy compressed version of the image quickly and then progressively replace it with higher-resolution variants. Alternatively, a website host could use vector or raster images. These are resolution independent, smaller in size and highly responsive.[20]

These methods in combination with the CDN technology provide a possible gain in user experience for a website host. [21]

3.4   Hosting a CDN

Even though the method of a self-hosted CDN was not implemented in the developed prototype, it has to be considered for the context of this thesis. Since the basic principle of a CDN was already explained, this section will focus on the financial aspect of the technology.

This topic will be showcased based on a hypothetical scenario. The numbers and metrics of this scenario are either assumed or taken directly from the implemented prototype.

The first requirements of the scenario are the following:

- A micro frontend landscape has to be developed.
- To reduce the runtime costs, the loading of redundant libraries should be avoided in the landscape.
- The libraries for the landscape were developed by the same team and are only available for internal use.

These circumstances ensure that only a self-hosted CDN is applicable. Next, the numbers and further requirements of the landscape are necessary. Those are required for the cost calculation of the CDN. It is mentioned if the numbers are actually *assumed/estimated* or *taken from the prototype.*

- How often the site is accessed per day - 50000 times (estimated)
- Avg. byte size per page load without caching on client side - 8983.5 KB (taken from the prototype)

- Avg. amount of GET requests to CDN per site load - 198 requests (taken from the prototype)
- The site is only accessed in North America

Based on those requirements, the following values are calculated for the monthly CDN usage of the described scenario landscape.

Let A be the amount of requests to the CDN per month:
$$A = 50000 \times 30 \times 198 = 297000000$$

Let B be the amount of bytes loaded per month:
$$B = 50000 \times 30 \times 8983.5 = 13475250000 \, \text{KB} = 13.47525 \, \text{TB}$$

Next, it will be calculated how much it would cost a company or department to pay for the CDN defined in this scenario.

There are multiple CDN solution providers on the market, including **Amazon Cloud-Front, Azure CDN, Google Cloud CDN**. [22] Since the pricing models of the mentioned providers differ, it is difficult to compare them directly. Applying the given scenario to the pricing calculator of the respective providers results in the following numbers.

- Amazon CloudFront - 1426.22 $ per month
- Google Cloud CDN - 1168.99 $ per month
- Azure CDN - 1123.90 $ per month

After averaging those values an *Avg.price* is calculated.

$$Avg.price = \frac{(1426.22 + 1168.99 + 1123,90)}{3} = 1239.70 \, \$$$

It has to be mentioned that these values were calculated using the basic packages offered by the providers. There are further features which can be added to the solutions, which of course would increase the sum. Additionally, other providers have different pricing models, some of which include pricing depending on the HTTP requests sent to the CDN. Others charge prices when resources are stored in several PoPs around the world. Also, locations play a key role, as different regions pay more for traffic then others and this value is provider-specific. Since it is not the goal to pick a provider here, but rather to provide a general overview of costs for such a solution, those additional features were not considered for the given scenario.

4. Web Components

Another option to address the issue of redundancies are WCs. Consisting of the following four standards, they provide reusable elements encapsulated in HTML tags.[23]

- Custom Elements
- Shadow DOM
- HTML Template
- ES Modules

The following sections will introduce the four standards of WCs with their functions and showcase what purpose they can serve for the context of this thesis.

4.1 Custom Elements

This standard of WCs provides an API via which new HTML tags can be defined and registered by the `CustomElementRegistry`. Since a single tag name can only be registered once, multiple registrations of the same element would lead to an exception, thereby making already registered tags reusable for the whole micro frontend landscape without reloading the code of the registered element.[24]
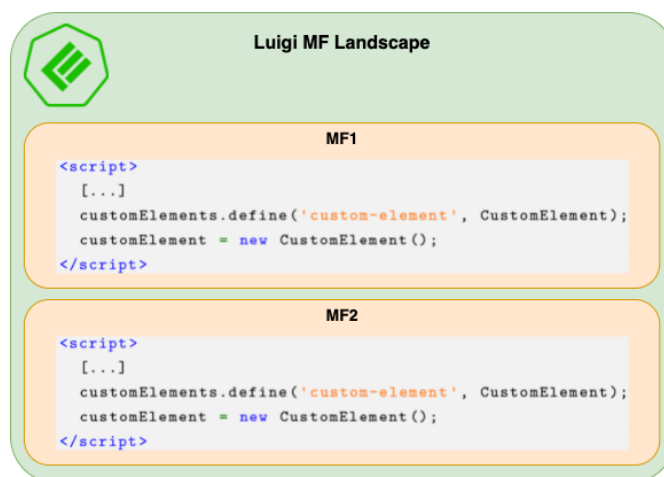

FIGURE 4.1: Simple micro frontend landscape using Web Components

Figure 4.1 shows a simple micro frontend landscape with Luigi using WCs. As displayed, both micro frontends are registering the same tag name `custom-element` using the `customElements` object. This object is a read-only property of the `Window` interface.

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The scenario shown will cause a `DOMException`, making it impossible to register the same tag twice.

The registration of WCs follows the *"first come, first serve"* principle: The first micro frontend to register a tag name defines this tag and cannot be overwritten without reloading the page [25]. Therefore, this standard is crucial for avoiding redundancies in micro frontend landscapes, by making it impossible to register same components with the same tag name.

4.2   Shadow DOM

The DOM (Document Object Model) represents the elements of a markup document in a tree-like structure, consisting of connected nodes. The commonly used markup language for websites is HTML [26]. The Shadow DOM is also a DOM, but is attached to the actual DOM of the document. Underneath it, elements can be defined in the same way as they are in the regular DOM. The difference becomes apparent during the rendering of the document, when a page is loaded. The Shadow DOM elements are rendered separately from the DOM it is attached to.[27]

To understand the relationship between the two connected DOMs, the following terms have to be explained.

Shadow host: The attachment of the Shadow DOM to the normal DOM happens via a node inside the normal DOM.

Shadow tree: Since the Shadow DOM is a DOM in itself, it consists of nodes in a tree-like structure.

Shadow boundary: The Shadow DOM capsules its Shadow tree and renders it separately from the actual DOM. This encapsulated area defines where the Shadow DOM begins and ends.

Shadow root: Just like a regular DOM, a Shadow DOM has a root from where it originates.

Figure 4.2 visualizes the relations between the newly introduced terms.

Through the isolation of the Shadow DOM's code, this standard offers a way to provide scoped HTML and CSS code to custom elements. As mentioned before, the nodes of the Shadow DOM are rendered separately. Therefore, styles, ids, names or even CSS classes
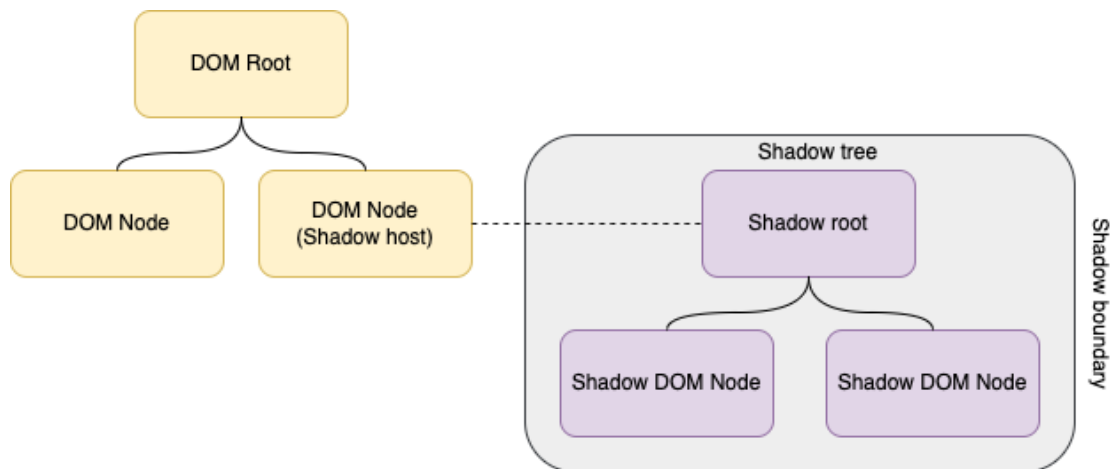
FIGURE 4.2: Shadow DOM architecture

and other configurations applied to a tag inside the Shadow DOM are not applied to the actual DOM.

The Shadow DOM, even though separated from the DOM, has an attribute via which it can be made accessible. By adding the `mode` attribute to the `this.attachShadow()` method, the visibility of the Shadow DOM to the document can be defined [27]. Possible values for the `mode` property are:

- **open**
- **closed**

This behavior is not meant to be used as a measure of security, since it can be overwritten. The Shadow DOM encapsulates every part of its DOM elements, that means HTML, CSS and JavaScript. The `document` object, available during runtime, remains the same for the regular DOM and for the Shadow DOM, though. Therefore, each configuration done in the Shadow DOM via scripts can be easily overwritten from any other script in the document, thus the mode can be changed even if initially set to `closed` [28]. For WCs, in particular, it is not recommended to use this mode at all, since it would make them less flexible for end users [29].

For the context of this thesis, the Shadow DOM standard offers means to individualize the registered WCs of a landscape. It can be used to apply customizations or add individual event listeners to specific components. This comes with a trade-off, though. The level of isolation increases through the encapsulation of code elements between the single components. This increase makes it difficult to guarantee that e.g. the same CSS class is not rendered in multiple different Shadow DOMs. Even though the redundancies would occur on code level and not on dependency level, they are redundancies nonetheless.

4.3   HTML Template

This standard offers a way to define reusable markup code. As a part of the HTML standard itself, the `template` tag is used to define templates. These are not rendered unless used by another element. The `slot` standard, serves a similar purpose as the `template` standard, but in a different way. Templates are defined HTML code snippets which can be cloned and inserted in other document elements or even elements rendered in the Shadow DOM. Slots, on the other hand, serve as placeholder for either default markup texts or other DOM elements. Therefore, a template is a rather static piece of reusable HTML code, compared to slots. Slots themselves are identified by their name, the content is inserted when the slot is addressed by its name. Listings 4.1 and 4.2 provide examples how exactly these two standards are used. [30]

```
1  <!-- Definition of the template -->
2  <template id="my-paragraph">
3    <p>My paragraph</p>
4  </template>
5
6  <!-- Usage of the template in an Web Component -->
7  customElements.define('my-paragraph',
8  class extends HTMLElement {
9    constructor() {
10     super();
11     let template = document.getElementById('my-paragraph');
12     let templateContent = template.content;
13
14     const shadowRoot = this.attachShadow({mode: 'open'})
15     .appendChild(templateContent.cloneNode(true));
16   }
17 });
```

Listing 4.1: Definition and usage of the `template` standard [30]

It is important to note that the defined template in the listing is not rendered unless somehow included in a DOM (either Shadow DOM or the regular DOM), via JavaScript.

```
1   <!-- Definition of the slot -->
2   <p>
3     <slot name="my-text">Default input</slot>
4   </p>
5
6   <!-- Usage of the slot in the markup document -->
7   <my-paragraph>
8     <ul slot="my-text">
9       <li>Some different input</li>
10      <li>In a list!</li>
11    </ul>
12  </my-paragraph>
```

LISTING 4.2: Definition and usage of the `slot` standard [30]

As it can be seen in listing 4.2, the `slot` definition has some default content defined. In the above case it is a simple text. When the slot is used, this content is overwritten by the content in the element which is calling the `slot` by its name. In that case, the content is replaced by some list items. Other than the templates, slots are always rendered if included in the markup via their respective names. The rendering of the content depends on whether the default content is overwritten or not.

Even though slots are an HTML standard, just as templates, their support for browsers is not always guaranteed. This is due to the fact that compared to templates, it is a rather new standard.

In combination, these two standards offer a way to define flexible, reusable markup code for WCs.[30]

When developing new WCs for a micro frontend landscape, this aspect can be used to reduce repetitive HTML code elements by serving them a template. Similar to the Shadow DOM, this feature could be used to apply more flexibility to the WCs by adding placeholders for customization. But, contrary to the Shadow DOM, this does not increase the level of isolation, since the rendered elements are not separated from the actual DOM. Redundant code snippets can be defined as reusable templates, thereby reducing the redundancies in the code itself.

4.4   ES Modules

The last standard is not referred to by every source, but according to [31], it is a stable part of the WCs standard, via which JavaScript modules can be defined and reused by

other documents. Thus the development of WCs can be done in a modular way, making every component available to other documents, using the `type="module"` attribute.

```
1  <!-- Import of the JS Module -->
2  <script type="module" src="awesome-explosion.js"></script>
3    [...]
4  <script type="module">
5    import 'awesome-explosion.js';
6    [...]
7    import {awesomeExplosion} from '@awesome-things/
       awesome-explosion';
8  </script>
9
10 <!-- Usage of the newly imported module -->
11 <awesome-explosion>
12   [...]
13 </awesome-explosion>
```

LISTING 4.3: Importing modular Java Script documents into another [31]

Listing 4.3 shows such an import. Assuming the `awesome-explosion.js` files contains the definition of an element called `awesome-explosion`, these lines enable the document to use this element.[31]

This feature is essential for the developed prototype, since via this aspect the components are made available to the landscape. The used WCs are served as ES Modules to the landscape and are imported similarly as shown in 4.3. Therefore, this aspect enables a component to be imported in multiple micro frontends as a module.

4.5 Additional considerations

There is a niche case which can be raised as an objection, concerning the WC technology. Since the registration and, therefore, the naming of elements is up to the developers, it can occur that two components are registered under the same tag name, but the elements themselves are different. In this case, it is up to the developers to use the standard properly.

Assuming a common micro frontend landscape where every micro frontend is developed by independent, isolated teams, using heterogenic frameworks, the mentioned issue might occur. Two teams use WCs and try to register different elements under the same tag name in the same landscape. This requires organizational interference on team level.

One way would be to define a namespace for every team when creating WCs e.g. Team 1 has the namespace `team-1`, causing a WC registered by the micro frontend of Team 1 to be named `team-1-tagname`. This could lead to redundancies, because there is no way of assuring that the `team-1-tagname` and `team-2-tagname` WCs are not the same.[32]

A better way might be to assign a common WCs library like **UI5 Web Components** [33]. That way, the registered elements are provided by the library and are limited to a set of unique registrable tags. If another micro frontend would try and register an already registered element of the library, a warning is thrown but no error occurs.

Most WC libraries also offer so-called scoping options. This feature is employed when versions of the used components differ between micro frontends. It enables the developers to customize their WCs and register them under different tags. With this feature, it is made possible to register components according to their respective versions, by adding a version-specific suffix. That, of course, might lead to redundancies again. But it also reduces the dependency of the developer teams to always use the latest version of the component library or the first registered element in the landscape. [34] [35]

5. Webpack Module Federation

A rather new technology on the market is the **Webpack 5 Module Federation (WMF)**. The Module Federation was part of Webpack's 5th version, released on October 10, 2020. It added features which improved its usage for developing micro frontends. This is achieved by modularizing self-compiled code parts and publishing them for integration by other modules. These published modules are called **remotes**, whereas the integrating modules are called **hosts**. **Hosts** refer to **remotes** under a configured name. This name is not actually known to the **host** during the compile time, but is first resolved at runtime. The self-compiled **remotes** can be anything, e.g. a micro frontend or some sort of utility script. This way, the Module Federation provides a way to avoid external or manual script loading and instead gives opportunities to automatically lazy load necessary code blocks during runtime.[36] The usage of the WMF is tied to the Webpack bundler, since the necessary configuration is done in the `webpack.config.js`. This restriction is applied to every **remote** in the WMF landscape, not only to the `host`.

WMF provides means to solve the issue of redundant libraries in micro frontend landscapes. In the following paragraphs, a short introduction of WMF is given, then the shared dependency feature is explained. It has to be mentioned, that WMF can be used in combination with most of the common UI frameworks. However, since the implementation for this thesis was done with Angular, the further examples and explanations will be Angular-based.

5.1 Enabling the Module Federation

Prior to introducing the usage of the Module Federation, it is necessary to introduce Webpack itself, as it is a mandatory feature for using the Module Federation. The documentations of popular UI frameworks, like React, VueJS or Angular, imply that Webpack is used by default, but this can be customized by a developer if needed [37][38][39].

To change the default configurations, the necessary `webpack.config.js` file has to be enabled first. In case of Angular, two dependencies have to be installed, using e.g. the Angular CLI. By enabling the Webpack configuration file, the features of the Module Federation are enabled, too. The command used for this is shown in 5.1.

```
1   ng add @angular - architects / module - federation  --project name --
      port port
```

LISTING 5.1: Angular CLI console command to enable Module Federation in an Angular project

These commands are necessary, since the CLI protects the Webpack configuration from access. The `@angular-architects/module-federation` package provides a custom builder, via which this access restriction is lifted. After installing this dependency in an Angular project, a `webpack.config.js` will appear on root level of the corresponding project. This dependency has to be added in each **remote** or **host** of the WMF landscape, to enable the Module Federation in those projects.[40]

After enabling, the necessary configuration can be applied to the `webpack.config.js` file. The **remotes** publish their modules and **hosts** consume them.

5.2 Shared dependency feature

The shared dependency feature of WMF is a way to solve the issue of redundant libraries in micro frontend landscapes. This feature is enabled and configured, as well as the rest of the WMF, via the `webpack.config.js`. When configuring the components of the landscape, it is possible to define a section where shared dependencies are described. These dependencies can be defined in different ways. For instance, it is possible to define a strict version of the dependency, which would result in the framework loading this specific version. Another option can be a less restricted dependency definition, which results in the framework loading of highest major version available. WMF is able to distinguish between major versions of the dependencies shared in its landscapes. If not configured otherwise, it automatically picks the highest major version and applies it to the sharing modules.

```
1   shared: share ({
2     "@angular / core": {
3       singleton: true ,
4       strictVersion: false ,
5       requiredVersion: '12.2.0'
6     },
7     "@angular / common": {
8       singleton: true ,
9       strictVersion: false ,
10      requiredVersion: '12.2.0'
11    },
12
```

```
13      "@fundamental-ngx/core": {
14        singleton: true,
15        strictVersion: false,
16        requiredVersion: '0.33.0-rc.214'
17      },
18      ...sharedMappings.getDescriptors()
19    })
```

LISTING 5.2: Example of sharing dependencies configured in the `webpack.config.js`

Listing 5.2 is an example of how libraries can be shared in a restrictive way. To provide a less restricted configuration, a simple array of the shared dependency names suffices. But to ensure a redundant free landscape, these restrictions are necessary. Each configuration property will be explained below.

singleton: This property defines if the dependency should be able to be loaded more than once in different versions or not. If set to `true`, WMF will automatically pick the highest available version of a major release of this dependency and distribute it to the **remotes**.[41]

strictVersion: This property defines if the dependency requires a specific version to work. If set to `true`, WMF will load the required version, even if another dependency mapping with the same name exists. This can lead to conflicts with the `singleton` property, if configured poorly.

requiredVersion: This property defines the required version of the dependency. When working with a package manager (e.g. NPM), this version has to be aligned with the locally installed version of the dependency. If the `strictVersion` property is set to `false`, this property defines the minimum version for the micro frontend.

It has to be mentioned that WMF is does not apply one dependency to all remotes if different major releases are configured for them. If a higher version of the same major release is available, it will only be loaded for the modules with the same major release configured. Modules with a lower or higher major release required, are not affected by it [42]. This aspect is explained further below.

Now, when it comes to sharing the dependencies inside the micro frontend landscape, each **remote** has to participate. That means each micro frontend has to define its required dependencies in their respective versions. Additionally, it has to be mentioned that the micro frontends themselves have to use dynamic imports when importing shared dependencies. Through the asynchronous behavior of the import, Webpack has time to pick the correct version of the dependency inside the landscape.[36] Analyzing this

statement in combination with the information taken from 5.2, it becomes obvious that multiple versions of the same framework can exist in a landscape.

5.3   Multi-version landscapes in WMF

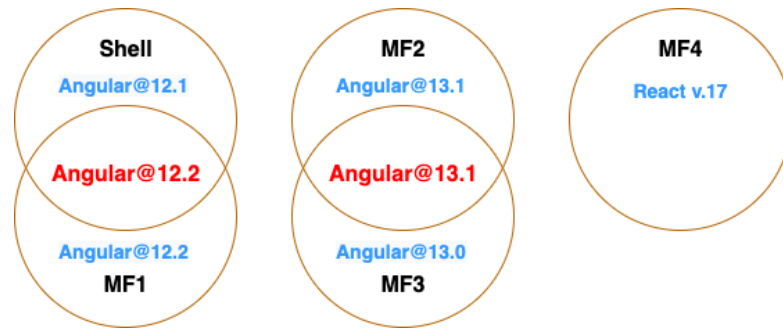Figure 5.1 illustrates the case, of how WMF handles a multi-version landscape.

FIGURE 5.1: Assignment of major release versions, of same dependencies in different versions, for micro frontends in a WMF micro frontend landscape

As it can be seen, WMF always picks the latest major release, assuming the respective micro frontends have a similar configuration as shown in listing 5.2 applied. If, for instance, **MF3** has the `strictVersion` property set to `true`, for a dependency, it would cause the loading of this library, too, even if it is already present in a different version.

There are side effects to sharing the same dependency over the whole micro frontend landscape. One of which is the increase in bundle sizes, since every **remote** bundles its local dependencies. WMF then, picks the ones to serve during the runtime of the landscape. This impact has an advantage, tough. Returning users can benefit from cached dependencies, since the same bundles are reused, loading the site.[42]

Therefore, WMF is able to reduce redundant libraries in micro frontend landscapes and additionally supports multi-version environments via the shared dependency feature.

6. Development of the prototypes

This chapter will provide an overview of the prototype landscapes and explain how the previously introduced technologies were used in them.

6.1   Definition of representation

Before the implementation is showcased, it is explained why and how representation is defined for the context of the thesis. Since not every micro frontend landscape is the same, a general definition is required before developing the prototypes. For clarification, the term prototype will be used a synonym for landscape and vice versa in the following context. To be considered representative, the prototypes had to fulfill most of the following requirements:

1. The landscape has to contain at least 6 micro frontends

2. The different micro frontends in the landscape have to load the same libraries/dependencies to cause redundancies

3. The tech stack of the landscape has to be heterogenic (not only one UI framework is used).

4. The embedded micro frontends have to be isolated projects

5. The landscape has to contain different versions of a dependency

6.2   Prototype overviews

This section will describe the developed prototypes and their respective designs. The whole environment is split over two prototypes, the first of which is the CDN/NPM prototype. The second prototype contains the Web Components/WMF landscapes.

6.2.1   Prototype 1 - CDN/NPM

The first prototype developed was the CDN/NPM landscape, totaling 8 micro frontends embedded as iFrames into a Luigi-Core-React application. Figure 6.1 visualizes this environment.
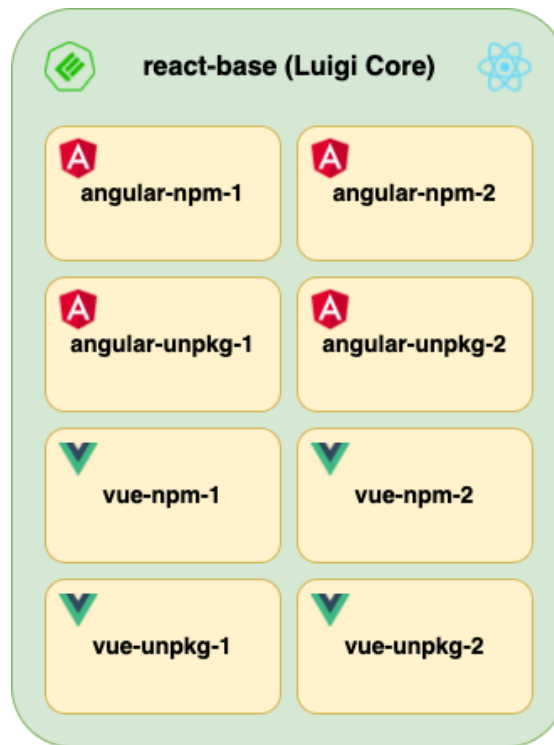
FIGURE 6.1: Overview of the CDN/NPM Luigi prototype

This prototype represents a Luigi micro frontend landscape, where each Luigi node is a single-page application (SPA). The 4 NPM apps embedded in the landscape were implemented for comparison. They are meant to show how the the CDN technology performs in direct comparison to a bundled application. In their core, each application contains the same UI-elements. Thus, it is made possible to compare them in terms of loading times and bytes loaded. The goals with this environment were to show:

- How redundancies occur in a micro frontend landscape.

- That the browser cannot distinguish between bundled resources, contrary to resources loaded from the CDN.

- What effect the UI framework has on the performance of the site, if any.

This landscape fulfills 4 out of the 5 requirements, missing the aspect of different versions. The reason behind this is that, even though it is possible to request different versions of a resource from the CDN, the CDN itself does not offer any means to resolve multiple versions inside the landscape. That means that the library is imported 2 times in different versions. That only increases the redundancies inside the landscape. Due to this predictability, this aspect was not considered for prototype 1.

6.2.2 Prototype 2 - Web Components/WMF

The second prototype developed was the WMF and Web Components landscape. It contains 36 micro frontends in total, which are split over 6 Luigi Nodes. Each Luigi Node, is therefore a compound of micro frontends. Figure 6.2 provides an overview of the Node landscape.
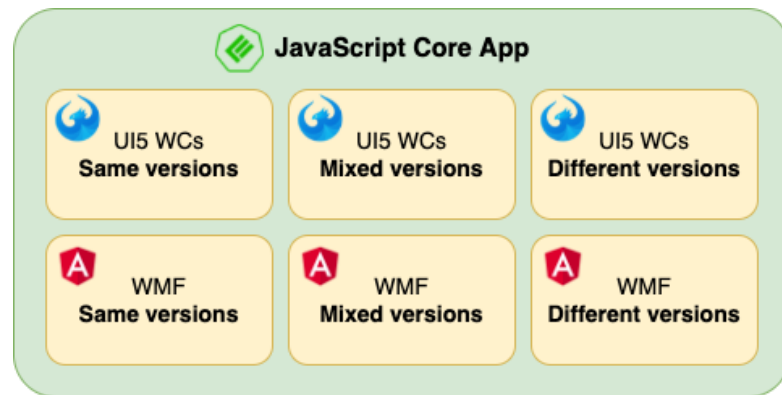
FIGURE 6.2: Overview of the Luigi Nodes in the WMF/Web Components environment

The 6 Nodes displayed in figure 6.2 contain 6 micro frontends each. Figure 6.3 provides an overview on how the micro frontends are arranged into a compound inside a Node.
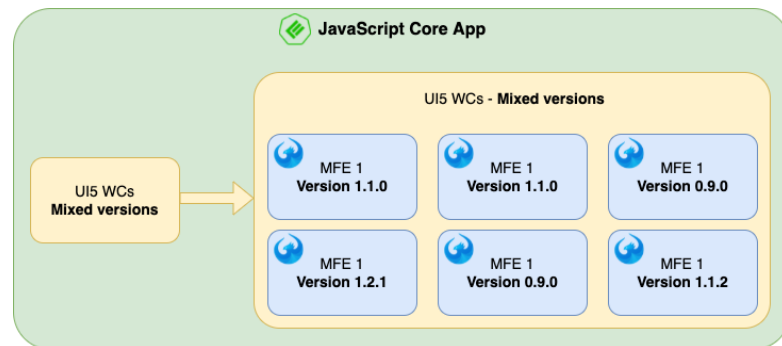
FIGURE 6.3: Example overview of a single Node inside the WMF/Web Components environment

Even though these two technologies are embedded in the same Luigi dashboard, they are referred to as separate landscapes, due to the technological differences. This prototype fulfills all 5 defined requirements for representation.

The following sections will shortly explain, how the micro frontends are embedded in the Luigi Nodes and showcase the mentioned technological differences.

6.2.2.1   Embedding a micro frontend into a compound in Luigi

The micro frontend compounds for the 3 Web Component Nodes are created through configurations made in the `luigi.config.js` [43] [44].

Contrary to WMF, these configurations allow to embed the referred compound components in so called `compoundItemContainer`. The arrangement and number of columns for the components inside the Node are defined in the `luigi.config.js`, too. Listing 6.1 shows the exact configuration for that.

```
Luigi.setConfig({
  navigation: {
    nodes: [{
      label: 'Home',
      pathSegment: 'home',
      icon: 'home',
      hideFromNav: true,
      globalNav: true,
      hideSideNav: true,
      defaultChildNode: 'mixedVersions',
      children: [
        // Mixed Versions
        {
          label: 'Luigi Compound mixed versions',
          pathSegment: 'mixedVersions',
          icon: 'activate',
          compound: {
            renderer: {
              use: {
                extends: 'grid',
                createCompoundItemContainer: (itemConfig,
                                             containerConfig,
                                             superRenderer) =>
              {
                const itemContainer = superRenderer
                .createCompoundItemContainer(itemConfig);
                if (!itemConfig.noPadding) {
                  itemContainer.style = itemContainer
                  .getAttribute('style') +
                  ' ; padding: 20px ; overflow: hidden';
                }
                return itemContainer;
              }
            },
```

```
35              config: {
36                columns: '1fr 1fr 1fr',
37                layouts: [{
38                  minWidth: 0,
39                  maxWidth: 1024,
40                  columns: '3fr',
41                  gap: 0
42                }]
43              }
44            },
45            children: [
46            // MFEs for this compound go here
47            {
48              webcomponent: true,
49              viewUrl: 'URL to the view to be embedded',
50              label: 'A label for the MFE',
51              layoutConfig: {
52                column: "auto"
53              }
54            },
55            ...
56            ]
57          }
58        },
```

LISTING 6.1: Configuration of Web Components Node for a compound view

Line 14 to 16 define the central Node navigation element for the Luigi dashboard. In line 17, it is defined that the content of this Node is a compound. The following line defines the `renderer` for the content and the tools for it are the attributes of the `use` property in line 19. Line 20 to 34 define the actual CSS attributes of the to be rendered container for the compound elements. The arrangement of the container is managed in the `config` property in line 35. In this scenario, the containers are arranged in 3 columns, each one taking 1 fraction of 1024 pixels. At line 45 the actual compound elements or micro frontends are defined as an array of JavaScript objects.

6.2.2.2   Embedding a micro frontend into a compound in WMF

Other than the Web Component Nodes, the WMF Nodes are actually embedded as iFrames into the Luigi dashboard. Therefore, the Luigi configuration for that landscape is similar to the CDN/NPM environements. Listing 6.2 shows how it was achieved.

```
1    Luigi.setConfig({
2      navigation: {
3        nodes: [{
4          label: 'Home',
5          pathSegment: 'home',
6          icon: 'home',
7          hideFromNav: true,
8          globalNav: true,
9          hideSideNav: true,
10         defaultChildNode: 'sameVersions',
11         children: [
12                {
13         pathSegment: 'wmfHostSame',
14         label: 'WMF Compound Same',
15         icon: 'technical-object',
16         viewUrl: 'https://angular-wmf-same-shell.surge.sh/',
17         loadingIndicator: {
18           enabled: false
19         }
20       },
21     ...
```

LISTING 6.2: Example configuration to embed a WMF micro frontend compound as a
Node in Luigi

As it can be seen, the integration is done via an URL. The same view displayed in
the dashboard can be found under the referred URL. This means, that to create a
compound view in WMF, the creation of the necessary container, the structure and the
actual arrangement of the micro frontends is managed by the host application of the
WMF environment and not Luigi. The code of this development is shown and explained
in section 6.5 of this chapter.

6.3   CDN - Unpkg.com

Chapter 3 introduced the concept of the CDN. A remote server provides the necessary
platform resources via an API, thus avoiding the necessity of bundling those resources.
To evaluate the impact of this technology on a micro frontend landscape, the first proto-
type was developed using the public cloud based CDN Unpkg.com. It is an open-source
project, built and maintained by Michael Jackson. It runs on the Cloudflare platform,
and auto-scalable servers are provided by Fly.io, which are located in 17 cities around
the world.[45]

An open API is available, through which resources can be requested. Via path and query parameters in the URL, necessary information like the dependency version can be provided.

The usage of the Unpkg.com-CDN is embedded in the code. Instead of loading the dependencies via the local `node_modules` directory, they are directly loaded using the CDN's API, the usage of which is displayed in listing 6.3.

```
1  <script src="https://unpkg.com/@ui5/webcomponents@1.0.0-rc.15/
     dist/StandardListItem.js?module" type="module"></script>
```

LISTING 6.3: Import of a dependecy using the unpkg API

This script tag is placed in the central `index.html`. The loaded resource can be read from the URL. The first part of the URL refers to the protocol and the host. The first path parameter is the NPM dependency name. In the case of 6.3, it is `@ui5`, followed by a subdirectory with its respective version annotated with an `@`. As it is described in the documentation, the Unpkg.com supports two query parameters [45]:

?meta: Added to the URL, to request meta data about the loaded package, in a JSON format

?module: Added to an Unpkg.com URL, to expand all import specifiers in JavaScript modules

If the import is handled via a script tag, as it is done in 6.3, the `type="module"` attribute has to be added, depending on the resource loaded. In the case of the given example, the resource is a JavaScript module type. To ensure this is parsed by the runtime as such, this attribute has to be added.[46]

6.4   Web Components - UI5 Web Components

The Web Component standard was partially used in the development of the second prototype. For development itself no UI application framework was used, which means all three compounds were developed using plain JavaScript. The actual components used in the micro frontends of the compounds were taken from a component library called UI5 Web Components. Each element in that library is, in fact, a Web Component [33]. Consisting of the picked elements, and under the usage of the scoping feature of the component library, the 3 compounds where created. The scoping feature, in particular, made it possible to scope the tags of the UI5 Web Components. This way, a multi-version landscape was simulated.[34]

```
1  import { LuigiElement, html }
2  from "@luigi-project/client/luigi-element.js";
3  import { setCustomElementsScopingSuffix }
4  from "@ui5/webcomponents-base/dist/CustomElementsScope.js";
5  setCustomElementsScopingSuffix("placeholder");
6  import "@ui5/webcomponents/dist/Dialog.js";
7  import "@ui5/webcomponents/dist/Button.js";
8  [...]
9  export default class extends LuigiElement {
10   constructor() {
11     super();
12     [...]
13     render() {
14       return html`
15       <div>
16         <div class="header">
17         <h2>Products table - Version: placeholder</h2>
18       </div>
19
20       <ui5-table-placeholder id="ui5-table"
21       ui5-table sticky-column-header>
22       <!-- Columns -->
23         <ui5-table-column-placeholder
24         slot="columns"
25         style="width: 4rem">
26           <span
27           style="line-height: 1.4rem">
28           Product
29           </span>
30         </ui5-table-column-placeholder>
31         [...]
32       </ui5-table-placeholder>
33       </div>`;
34     }
35   }
```

LISTING 6.4: Scoping feature used in the prototype

Listing 6.4 shows the exact usage of the scoping feature. The imported *setCustomElementsScopingSuffix* function is used to define a custom suffix, which is applied to all UI5 Web Component elements. Also, as it can be seen in the same listing, the suffix is set to *placeholder* using the imported method *setCustomElementsScopingSuffix("placeholder")*. This is done for the sake of the experiment itself. It was intended to

deploy 6 similar-looking micro frontends, using Web Components, into the Luigi landscape, to test how many redundancies occur. In addition, it was meant to be tested how different versions of the same elements could be registered. For example, without the scoping feature, a Web Component, e.g. the *Bar* element in version *1.0.1* and *1.1.0*, is registered under the same tag name. This causes a conflict, since the registered element might be required in the specific version by a micro frontend. By using the scoping feature, this conflict can be resolved. Through defining a general version suffix for the elements, they are registered under distinguishable tags in the browser. In case of the prototype, to create this exact scenario, one global tag suffix *placeholder* was picked and later replaced. The replacement itself happened during the bundling of the project. The RollUp bundler provided the necessary functionality for that. Inside the `rollup.config.js` several configurations were defined, which are shown in listing 6.5.

```javascript
import resolve from '@rollup/plugin-node-resolve';
import json from '@rollup/plugin-json';
import url from "@rollup/plugin-url";
import { terser } from "rollup-plugin-terser";
import replace from '@rollup/plugin-replace';
import { SameVersions } from './rollup_files/same_version';
import { DiffVersions } from './rollup_files/different_version';
import { MixedVersions } from './rollup_files/mixed_version';

let buildArray = [];

function aggregateConfigs() {
  for(let buildConfig of SameVersions) {
    buildArray.push(buildConfig);
  }

  for(let buildConfig of DiffVersions) {
    buildArray.push(buildConfig);
  }

  for(let buildConfig of MixedVersions) {
    buildArray.push(buildConfig);
  }
}

aggregateConfigs();

export default buildArray;
```

LISTING 6.5: Content of the `rollup.config.js`

The configuration of the bundler was split into several JavaScript files, to improve the readability of the file itself. The content of such a file can be seen in listing 6.6.

```
1  import resolve from '@rollup/plugin-node-resolve';
2  import json from '@rollup/plugin-json';
3  import url from "@rollup/plugin-url";
4  import { terser } from "rollup-plugin-terser";
5  import replace from '@rollup/plugin-replace';
6
7  export const MixedVersions = [
8  // 1
9  {
10    input: 'src/tableView.js',
11    output: {
12      file: 'dist/tableViewMixedVersions1.js',
13      format: 'es',
14      compact: true
15    },
16    plugins: [
17    replace({
18      'placeholder': '0-9-0',
19    }),
20    terser(),
21    resolve(),
22    json(),
23    url({
24      limit: 0,
25      include: [
26      /.*assets\/.*\.json/,
27      ],
28      emitFiles: true,
29      fileName: "[name].[hash][extname]",
30      publicPath: "\" + new URL(\".\", import.meta.url) + \"", //
      relative configuration for assets (TBD with UI5 Web Components
      team)
31    })
32    ]
33  },
34  // 2
35  {
36    input: 'src/tableView.js',
37    output: {
38      file: 'dist/tableViewMixedVersions2.js',
39      format: 'es',
```

```
40      compact: true
41    },
42    plugins: [
43    replace({
44      'placeholder': '1-1-0',
45    }),
46    terser(),
47    resolve(),
48    json(),
49    url({
50      limit: 0,
51      include: [
52      /.*assets\/.*\.json/,
53      ],
54      emitFiles: true,
55      fileName: "[name].[hash][extname]",
56      publicPath: "\" + new URL(\".\", import.meta.url) + \"", //
      relative configuration for assets (TBD with UI5 Web Components
      team)
57    })
58    ]
59 },
60 [...]
61 ]
```

LISTING 6.6: Configuration content for the `rollup.config.js`

The file which is bundled for each configuration and shown in listing 6.6 is always the same. This can be taken from the `input` property. The bundling result, though, is named differently, which can be read from the `output` property. The first bundle result is called `tableViewMixedVersions1.js`, the second `tableViewMixedVersions2.js` etc. The `replace` method, in e.g. line 17, of the first configuration object, replaces a string inside the input file. In the shown case, the string *placeholder* is first replaced with *0-9-0* and in line 43 with *1-1-0*. This results in elements being named differently inside those files. Thus, they are later registered under different tags in the browser. In this case, elements registered by the first bundled micro frontend are called, for example, `<ui5-bar-0-9-0>` and for the second then `<ui5-bar-1-1-0>`.

One file is bundled several times. Each resulting bundle, has a different name and replaces the placeholder string with a different string. This way, multiple micro frontends can be generated, which then again register the same elements under differently named tags. Therefore, those elements are treated as new elements.

6.5   Webpack Module Federation with Angular

The three implemented versions for the the WMF landscape are similar to one another, the only difference are the dependencies and their configured sharing. Listing 6.7 shows the configuration for the *sameVersions* Node.

```
[...]
module.exports = {
  [...]
  plugins: [
  new ModuleFederationPlugin({
    name: "shell",
    filename: "remoteEntry.js",
    shared: share({
      "@angular/core": {
        singleton: true,
        strictVersion: false,
        requiredVersion: '= 12.2.0'
      },
      "@angular/common": {
        singleton: true,
        strictVersion: false,
        requiredVersion: '= 12.2.0'
      },
      ...sharedMappings.getDescriptors()
    })

  }),
  sharedMappings.getPlugin()
  ]};
```

LISTING 6.7: Content of `webpack.config.js` of the shell of the sameVersions WMF project

As it is shown, the shared dependencies are defined in between lines 22 and 24. Line 18 and 19 define the name of the application in the landscape and the name of the file after bundling. For the above case, it has to be mentioned that the remotes are separate applications in their own runtime. Therefore, they have to be imported via the network, thus no `remote` property is configured in this file. To add the dynamically loaded remotes, a service had to be developed which imports the remotes at runtime [47]. This service is shown in listing 6.8.

```
1  [...]
2  @Injectable({ providedIn: 'root' })
3  export class LookupService {
4    lookup(): Promise<PluginOptions[]> {
5      return Promise.resolve([
6      {
7        remoteEntry: 'https://angular-wmf-same-mfe1.surge.sh/
    remoteEntry.js',
8        remoteName: 'mfe1',
9        exposedModule: './Mfe1',
10
11       displayName: 'Mfe1',
12       componentName: 'Mfe1Component'
13     },
14     [...]
15     ] as PluginOptions[]);
16   }
17 }
```

LISTING 6.8: Content of `lookup.service.ts` for remote module loading in shell applications

This service provides the information of the remotely loaded modules to a proxy plugin, which is responsible for the actual rendering of the components. This proxy plugin creates the container as a kind of placeholder for the remotes. [47]

```
1   [...]
2   @Component({
3     selector: 'plugin-proxy',
4     template: `
5     <ng-container #placeHolder></ng-container>
6     `
7   })
8   export class PluginProxyComponent implements OnChanges {
9     @ViewChild('placeHolder', { read: ViewContainerRef, static:
    true })
10    viewContainer: ViewContainerRef;
11
12    constructor(
13    private injector: Injector,
14    private cfr: ComponentFactoryResolver) { }
15
16    @Input() options: PluginOptions;
17
18
```

```
19      async ngOnChanges () {
20        this.viewContainer.clear ();
21
22        const Component = await loadRemoteModule(this.options)
23        .then (m => m[this.options.componentName]);
24
25        const factory = this.cfr.resolveComponentFactory(Component);
26        const compRef = this.viewContainer.createComponent(factory,
      null, this.injector);
27      }
28    }
```

LISTING 6.9: Content of `plugin-proxy.component.ts` for remote module loading in shell applications

Line 8 of listing 6.9 defines the `ng-container` with the identifier called `placeholder`. This identifier is used in the code below to select and actually fill the container with a remote module. The functionality is placed in one of Angulars Lifecycle hook methods `ngOnChanges`, which is triggered when changes to input properties occur [48]. In there, the container is first cleared, then a remote loading option is selected from the array of the `lookup.service.ts`. The following line creates an Angular component out of the loaded remote and inserts it into the placeholder container, using the imported dependencies. The type `PluginOptions`, was defined in an interface, exporting a type definition. The code for it is displayed in listing 6.10.

```
1  import { LoadRemoteModuleOptions } from '@angular -architects/
     module -federation';
2  export type PluginOptions = LoadRemoteModuleOptions & {
3    displayName: string;
4    componentName: string;
5  };
```

LISTING 6.10: Content of `plugin.ts` for remote module loading in shell applications

The previously imported `@angular-architects/module-federation` dependency offers an existing type interface for that use case. This type is extended by two more properties in line 4 and 5 of listing 6.10.

By configuring the above service and component, it is made possible to load federated modules via the network into the host application. The configuration for a federated module (aka remote) can be seen in listing 6.11.

```
1   [...]
2   module.exports = {
3     [...]
4     plugins: [
5     new ModuleFederationPlugin({
6       name: "mfe1",
7       filename: "remoteEntry.js",
8       exposes: {
9         './Mfe1': './src/app/mfe1.component.ts'
10      },
11      shared: share({
12        "@angular/core": {
13          singleton: true,
14          strictVersion: false,
15          requiredVersion: '<= 12.2.0'
16        },
17        "@angular/common": {
18          singleton: true,
19          strictVersion: false,
20          requiredVersion: '<= 12.2.0'
21        },
22        "@fundamental-ngx/core": {
23          singleton: true,
24          strictVersion: false,
25          requiredVersion: '0.33.0-rc.214'
26        },
27        ...sharedMappings.getDescriptors()
28      })
29    }),
30    sharedMappings.getPlugin()
31    ]};
```

LISTING 6.11: Content of `webpack.config.js` of the mfe1 remote app of the same versions WMF project

As mentioned in chapter 5, to share dependencies every remote has to participate. Therefore, similarities can be found in the sharing configurations of the remotes and hosts. Between line 7 and 11, the actual federation of the module is configured. The reference to the module is later bundled in a file with the name, defined in the `filename` property, in this case `remoteEntry.js`. This is the file which is automatically generated when the remote is compiled, and it serves as the entry point for the application when it is loaded by the host. Therefore, this is the file accessed via the server URL in the `lookup.service.ts` 6.8. As soon as the script is loaded via the service, the exposed

module paths and names become known to the host and can be used to load the module [36]. Thus the `expose` property contains a JavaScript object, which maps the path to the actual component. In the shown case, it is mapped to `./Mfe1`.

In section 6.2.2.2, it was shown how the developed WMF Nodes are embedded in the Luigi dashboard. The snippets in this section show how a compound of micro frontends is created using WMF. In direct comparison with the Luigi compounds, it becomes obvious, that WMF does not really offer support for heterogeneous landscapes. This is shown indirectly in the implemented prototype, but can be applied to any WMF landscape, too. The first indicator is the necessity of a separate service and plugin for the dynamic loading and rendering of the remotes.

Additionally, the only reason this prototype was implemented without conflicts, is because each remote is actually an Angular project/component. If, for instance, one project would be a Vue.js based remote, the integration of it would be connected to more obstacles. This can be showcased in lines 21 and 24 of the plugin proxy from listing 6.9, which is responsible for loading a remote component into the created container. The methods used in those lines expect an Angular component. If now a Vue.js remote would be loaded into, a conflict occurs.

Furthermore, routing inside a compound view of WMF requires further workarounds, even in a homogenic landscape. In the case of the implemented prototype, the routers of the Angular micro frontends are not shared with the other members of the compound. Therefore, a router would have to be either loaded via an API or a dynamic import by the other participants, or else routing between the micro frontends is impossible.

Lastly, enabling the `webpack.config.js` and, with it, the Module Federation, is different for every framework. In case of Angular, it was achieved via the installation of the mentioned dependencies.

7. Presentation of the results

In this chapter it will be explained how and which data was collected using the prototype, and which metrics were defined for comparison. Afterwards, the landscapes will be compared, using the defined metrics as KPIs. The conclusion based on the results will be given in chapter 8.

7.1 Basis of the experiment

This section will contain information about the environment in which the experiment was executed, how the data was collected and which metrics were defined based on the gathered data.

7.1.1 Testing hardware and environment

It has to be mentioned, that certain aspects of the environment were not maintained by the tester and are, therefore, out of scope for influence or configuration. Nonetheless, they are mentioned here for reproducibility. The following hardware and environment was used for testing:

1. **Laptop:** MacBook Pro (15-inch, 2017)

   - **Processor:** 2.9 GHz Quad-Core Intel Core i7
   - **Memory:** 16 GB 2133 MHz LPDDR3
   - **Graphics:** Radeon Pro 560 4 GB and Intel HD Graphics 630 1536 MB
   - **macOS Monetary - Version:** 12.2.1 (21D62)

2. **Browser, Network and Lighthouse:**

   - **Browser:** Google Chrome
   - **Version:** 99.0.4844.51 (Official Build) (x86_64)
   - **Chrome DevTools version:** Chrome 99
   - **Lighthouse version:** 100.0.0.0
   - **JavaScript version:** V8 9.9.115.8
   - **Network-Bandwidth:** 180-200 Mb/s

3. **Runtime environment for prototypes:** surge.sh [1]

---

[1] surge.sh is a platform for static web publishing for frontend developers via the command line.

4. **CDN:** Unpkg.com [2]

In addition to the specified hardware specs, version 1.18.1 of the `@luigi-project` was used. This dependency enables the Luigi framework and is, therefore, used in every implemented version of the prototype.

7.1.2 Testing process

Since multiple Nodes were implemented, a unified process was required to collect comparable data. The BPMN diagram 7.1 contains the process steps in detail.
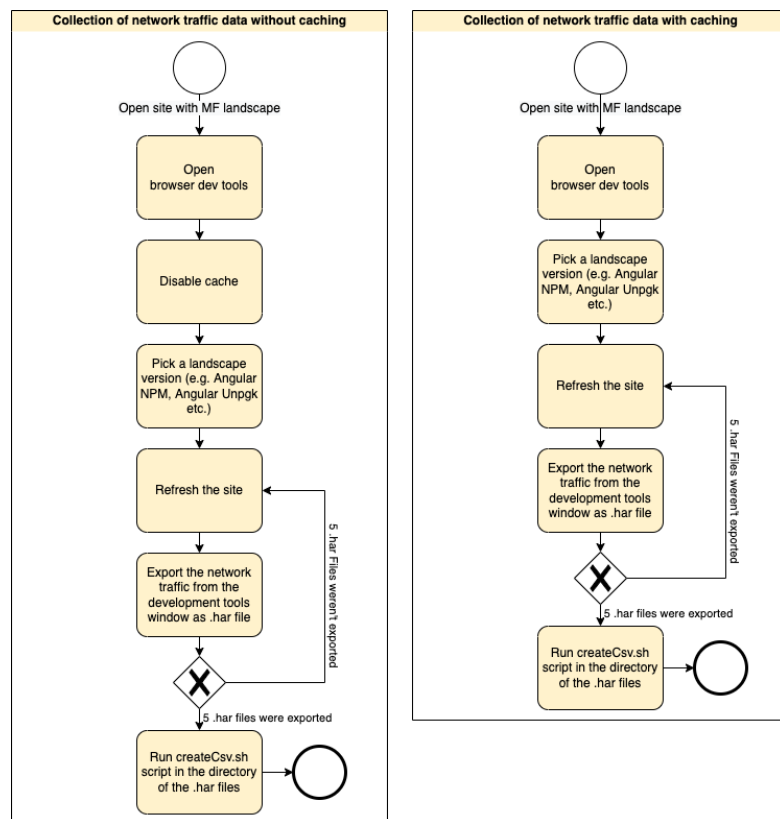
FIGURE 7.1: Data collection process for .har files

As it can be seen in 7.1, there were actually two processes executed to collect data. The first one had caching disabled, the second one enabled. The intention behind the first process was to collect data for an average initial loading time for the picked site, therefore, the resources must not be cached. The second process was used to gather information about caching behavior in general. Since each Node basically contains the same views, the browser should be able to pull already loaded resources from the cache, instead via the network. To showcase this behavior and prove the performance gain

---

[2]This part of the environment was explained in chapter 6

through caching, this data was gathered too. Each process was executed 5 times, therefore 10 HTTP Archive (`.har`) files were generated per Node. These `.har` files were then transformed into `.csv` files using a self-developed script, which can be found in the archive.

Additionally to the `.har` files, a website performance report was collected, using the Lighthouse tool embedded in the Google Chrome browser. Such a report provides information about the usage of the imported bytes by a web application, distinguished by resource URL.

In summary, for testing:

- 12 Nodes were developed.
- Each Node was loaded 10 times, 5 times with cache enabled and 5 times with cache disabled.
- Each loading of a Node is represented by a HTTP Archive file.
- The testing procedures were executed 120 times overall.
- 120 `.har` files were generated.
- These, were aggregated and transformed into 12 `.csv` files.
- These, were copied into one Excel file, where the data was analyzed.
- In addition, 12 Lighthouse reports where collected (one per Node) and added to the Excel.

The reason why this testing procedure was chosen, was due to the low variety in the parameters when a Node is loaded. First, it was tested if the parameters would vary when a Node is loaded up to 1000 times, which was found to be not the case. Due the constant resource sizes and stable network, not many fluctuations could be observed. Only when changes on technological level were made (e.g. usage of cache, network outage), fluctuations started to appear. But, other than that, it was observed that the results were stable. Therefore, it was decided that loading a Node 10 times would suffice for the experiment.

After the collection process, another self-developed script was used to aggregate all the gathered data into one single file. This file was later used to define and calculate the metrics, which are described next.

7.1.3 Defined metrics

The central file, containing all data, was split into separate sheets in which the metrics for each micro frontend were calculated. The parameters for calculation were:

connection: This is an ID for each opened TCP connection provided by the browser. It can be an indicator for the parallelity of the requests. Since the release of HTTP/2, several requests can be handled by a server via the same TCP connection, reducing the number for TCP handshakes. The application requesting the sources can not implement this HTTP/2 feature. It has to be enabled on server-side and by the browser, which is already the case for most modern browsers [19]. As of today, surge.sh, the web server platform onto which the prototypes are deployed, does not support HTTP/2.

loadedFromCache: This is a string value with three possible characteristics, *not loaded from cache, disk* or *memory*, whereas *disk* and *memory* are semantically the same for the context of this thesis. This value explains from where the resource was loaded. Either via the network from a server or from the local cache. It indicates the caching behavior of bundled resources, in comparison with resources loaded from a unified URL (e.g. a CDN).

startedDateTime: This is a timestamp given to each request, marking its starting time in a DateTime format. This value can serve as an indicator for parallelity, since multiple TCP connections can be opened at the same time.

requestUrl: This is a string value, containing the request URL used by the browser to load the resource. This value mainly categorizes the calculation results, since neither *connection* nor *pageRef* are valid options to distinguish the loaded resources of a website.

responseContentSize: This number value is the byte size of the loaded resource.

timeInMs: This value represents the RTT of the request in milliseconds.

Further were parameters, available in the `.har` files, but those could not be used for the calculation, since those were either to application-specific or had no significance for the goal of this thesis. Based on the given metrics from the `.har` files, the following KPIs were calculated.

Avg. content size: Numerical value calculated by averaging the **responseContentSize** values of all the websites resources.

Avg. time in MS loaded values: Numerical value, calculated by averaging the **timeInMs** values of all the websites resources.

Occurrences connection duplicates: Numerical value to represent parallelity, by counting the number of duplicate/multiple occurring **connection** values.

Connection IDs: List of all **connection** characteristics for the website.

Connection IDs occurrence: Number of times the **connection** occurred during the loading of the website.

Parallel start time: Numerical value, calculated by counting reoccurring **started-DateTime** values.

Avg. response content size per loading type: Numerical value, calculated by averaging the **responseContentSize**, differentiated by the characteristics of the **loadedFromCache** property.

URLs loaded: List of all unique **requestUrl** values.

Avg. response time per URL loaded in MS: Numerical value, representing the average loading time of each loaded resource URL of the website.

Avg. response size per URL loaded: Numerical value, representing the average loading byte size of each resource URL.

Avg. response size per URL loaded via network: Numerical value, calculated by averaging the **responseContentSize** differentiated by the **requestUrl** for all resources with the **loadedFromCache** value of *not loaded from cache*. For the test scenarios with cache disabled, this value equals the **Avg. Response Size per URL loaded** KPI.

Avg. response size per URL loaded from disk: Numerical value, calculated by averaging the **responseContentSize** differentiated by the **requestUrl**, for all resources with the **loadedFromCache** value of *disk*.

Avg. response size per URL loaded from memory: Numerical value, calculated by averaging the **responseContentSize** differentiated by the **requestUrl**, for all resources with the **loadedFromCache** value of *memory*.

The main indicators for whether a technology successfully reduces redundant libraries in a micro frontend landscapes were the **Avg. time in MS loaded values** and **Avg. content size**.

Avg. content size was chosen as a main indicator, due to its significance. The reduction in loaded libraries, should be represented in the overall loaded byte size. Therefore, this metric is object for optimization.

Avg. time in MS loaded values was chosen as the second main indicator, since it is asserted that the loading time correlates with the bytes loaded by a micro frontend. It

can be argued, that this value also correlates strongly with the bandwidth of the testing environment. However, it still was chosen, since it is a metric for optimization. The goal of reducing redundancies in a micro frontend landscape is considered to be achieved, when the number of loaded bytes and the loading time of a website are decreased. If a technology avoids redundant libraries in a micro frontend landscape, but increases the loading time of that landscape, the result is insufficient for the purpose of this transcript.

Therefore, the goal was to optimize these two KPIs. If, by using a technology, these two values decreased, it was considered to be a first success. But, for the general evaluation, further aspects were put into consideration. KPIs for those aspects, such as e.g. the complexity of the implemented technology, were hard to measure. A metric like this must not be ignored for the context of this transcript, since the benefit of a technology highly depends on it. Thus, the subjective estimation and impression of the used technologies by the author is part of the conclusion in chapter 8.

Statistical values, like the median of loading times or loaded bytes, were calculated, but not included in the conclusion, since the meaningfulness of those values was not applicable for the goal. The package size does affect loading time of a resources, that is a matter of fact. But since the packages are application-specific, no general statement can be drawn from the median of this parameters. The goal was to showcase that through the use of one of the three technologies, the loading times and loaded bytes are reduced in general, not to show what package was not loaded or loaded faster.

In the following sections, the results of the introduced metrics for each landscape are showcased. The tables shown, are separated whether, the data was collected with caching enabled or disabled. In addition, to the shown metrics, the graphs and Excel tables for the landscapes are referred to in the archive. A table of contents of the archive is available in appendix A.

7.2 CDN/NPM KPI results

This section will introduce the KPI results of the CDN/NPM prototype. It is split into 2 subsections for a better comparison of the two technologies.

7.2.1 Implementation with NPM

Table 7.1 contains the results for the implemented Nodes with a regular bundler and a package manager, namely NPM. Certain metrics are not added to the table for readability (cf. 7.1.3), but those, as well as a graphical representation, can be found in

archive.

TABLE 7.1: Table of numerical KPI results for the NPM Nodes with caching disabled

Metric	Angular NPM	Vue NPM
URLs loaded count	14	13
Avg. response content size per loading type	*not loaded from cache:* 129529.13 *memory:* 0, *disk:* 0	*not loaded from cache:* 156131.63 *memory:* 0, *disk:* 0
Parallel start time	33	45
Connection IDs occurence	*none established:* 10, *207393:* 10	*241394:* 10
Connection IDs count	62	71
Connection duplicates	20	10
Loaded values & occurrences	*not loaded from cache:* 80, *memory:* 0, *disk:* 0	*not loaded from cache:* 80, *memory:* 0, *disk:* 0
Avg. time in MS	162.22	5323.54
Avg. content size	129529.13	156131.63

The results shown in table 7.1 were collected without caching enabled. This explains for instance, why no resources were loaded from cache and therefore, why the values for the *memory* or *disk* characteristics are missing. The main takeaway from these results is an average initial loading time for the Nodes, which differs depending on the framework. It can also be seen that even though fewer resources are loaded via URLs by the Vue.js Nodes, they have a longer loading time compared to the Angular ones.

TABLE 7.2: Table of numerical KPI results for the NPM Nodes with caching enabled

Metric	Angular NPM	Vue NPM
URLs loaded count	14	13
Avg. response content size per loading type	*not loaded from cache:* 166856, *memory:* 17548.5, *disk:* 17548.5	*not loaded from cache:* 145646.67, *memory:* 0, *disk:* 187586.5
Parallel start time	32	39
Connection IDs occurence	*none established:*20	*none established:*20
Connection IDs count	61	61
Connection duplicates	20	20
Loaded values & occurrences	*not loaded from cache:* 60, *memory:* 6, *disk:* 14	*not loaded from cache:* 60, *memory:* 0, *disk:* 20
Avg. time in MS	150.90	1890.6
Avg. content size	129529.13	156131.63

The results of table 7.2 show the effect caching has on the performance of a site. The average loading time of the site decreases, as do the opened TCP connections.

Both environments were implemented using a regular bundler. Therefore, it cannot be ensured that redundant libraries were not loaded.

7.2.2 Implementation with Unpkg.com

Table 7.3 contains the results for the implemented Nodes with a use of a public CDN, namely Unpkg.com. Certain metrics are not added to the table for readability, but those, as well as a graphical representation, can be found in archive.

TABLE 7.3: Table of numerical KPI results for the Nodes using the Unpkg.com CDN with caching disabled

Metric	Angular Unpkg	Vue Unpkg
URLs loaded count	171	165
Avg. response content size per loading type	*not loaded from cache:* 9768.62, *memory:* 0, *disk:* 0	*not loaded from cache:* 8205.19, *memory:* 0, *disk:* 0
Parallel start time	871	989
Connection IDs occurence	*223736:* 20, *223722:* 1574, *none established:*10	*241394:* 20, *249654:* 1560
Connection IDs count	53	42
Connection duplicates	1604	1580
Loaded values & occurrences	*not loaded from cache:* 1654, *memory:* 0, *disk:* 0	*not loaded from cache:* 1620, *memory:* 0, *disk:* 0
Avg. time in MS	97.23	194.01
Avg. content size	9768.62	8205.19

The data shown in table 7.3 has again been collected without caching enabled. An approximate estimation for the initial loading times can be drawn from this. It becomes apparent that the Vue.js environment takes longer to load for less content. A similar behavior was observed in the NPM implementations. Nonetheless, it is an improvement in performance compared to the NPM counterparts for both Nodes. The trade-off of this technology is that single component resources, like a button or a table, had to be imported via script tags one by one, thus the increase in loaded URLs. This also explains the reduction in **Avg. content size**. The CDN Nodes only request the necessary resources, such as buttons, tables or lists, and avoid loading the whole component libraries.

TABLE 7.4: Table of numerical KPI results for the Nodes using the Unpkg.com CDN with caching enabled

Metric	Angular Unpkg	Vue Unpkg
URLs loaded count	171	165
Avg. response content size per loading type	*not loaded from cache:* 63972.08, *memory:* 208838, *disk:* 7166.1	*not loaded from cache:* 28143.2, *memory:* 0, *disk:* 7570.22
Parallel start time	1111	1069
Connection IDs occurence	*none established:* 1590, *223722:* 15	*none established:* 1570, *249654:* 10
Connection IDs count	52	42
Connection duplicates	1605	1580
Loaded values & occurrences	*not loaded from cache:* 65, *memory:* 3, *disk:* 1587	*not loaded from cache:* 50, *memory:* 0, *disk:* 1570
Avg. time in MS	58.73	87.1
Avg. content size	9762.72	8205.19

A similar development can be observed in table 7.4. Firstly, with caching enabled, the number of loaded resources from cache increases significantly. Secondly, the average loading times decrease, and lastly, the Angular environments show shorter average loading times, despite more resources being requested via URL by them.

7.3 Web Components and WMF landscapes

As described in chapter 6, these environments exist in different versions. They were designed that way to showcase how the used technologies handle multi-version landscapes and how they affect the performance. Table 7.5 shows the KPIs of those environments.

TABLE 7.5: Table of numerical KPI results, for the Nodes implemented with Web Components and WMF as compounds, with caching disabled

Metric	Web Components	WMF
URLs loaded count	27	118
Avg. response content size per loading type	*not loaded from cache:* 213266.74, *memory:* 0, *disk:* 0	*not loaded from cache:* 507168.76, *memory:* 0, *disk:* 0
Parallel start time	29	109
Connection IDs occurence	*78725:* 15, *78890:* 15	*728247:* 3, *none established:* 14
Connection IDs count	546	42

Table 7.5: continued from previous page

Metric	Web Components	WMF
Connection duplicates	30	20
Loaded values & occurrences	*not loaded from cache:* 135, *memory:* 30, *disk:* 0	*not loaded from cache:* 563, *memory:* 0, *disk:* 0
Avg. time in MS	2454.95	552.7
Avg. content size	213266.74	507168.76

As the data in table 7.5 shows, the initial loading time for the Web Component environments is significantly lower compared to the WMF counterpart. Also the number of URLs loaded differs. This is due to the fact that WMF has to be used in combination with the Webpack 5 bundler. Therefore, certain resources might be loaded several times, if not configured as shared dependencies in the Module Federation. Table 7.6 showcases the same landscapes, but with caching enabled.

TABLE 7.6: Table of numerical KPI results, for the Nodes implemented with Web Components and WMF as compounds, with caching enabled

Metric	Web Components	WMF
URLs loaded count	27	109
Avg. response content size per loading type	*not loaded from cache:* 215385.36, *memory:* 167973, *disk:* 588082	*not loaded from cache:* 525243.08, *memory:* 0, *disk:* 1959
Parallel start time	35	105
Connection IDs occurence	*none established:*4, *78890:* 15, *78725:* 11	*none established:*15
Connection IDs count	104	537
Connection duplicates	30	15
Loaded values & occurrences	*not loaded from cache:* 107, *memory:* 20, *disk:* 4	*not loaded from cache:* 536, *memory:* 0, *disk:* 15
Avg. time in MS	897.62	356.53
Avg. content size	219526.89	510997.6

The general results appear to be similar for both cases of caching en- or disabled. The only KPI in favor of Web Components is the average content size loaded. Additionally, compared to the Web Component Nodes the WMF Nodes cache little to none resources.

To add further parameters into the decision making process for the final conclusion, the Lighthouse tool was used. Through it, more information about the prototypes was gathered. The next section will showcase and explain how the analysis was done.

7.4 Lighthouse analysis

For the Lighthouse analysis, it was put into consideration that the reports are application-specific. But since the prototypes are considered to be representative, it is assumed that similar results can be expected in general from other micro frontend landscapes. Exception are not excluded from this assumption.

The given data was gathered based on the previously introduced prototypes and their Nodes. It contains the analysis of the imported resources and how much of the corresponding imports were not used by the application, measured in bytes. First, a tabular view is provided, followed by the corresponding graph.

TABLE 7.7: Table of the average imported and unused bytes of the prototypes, collected via the Lighthouse tool

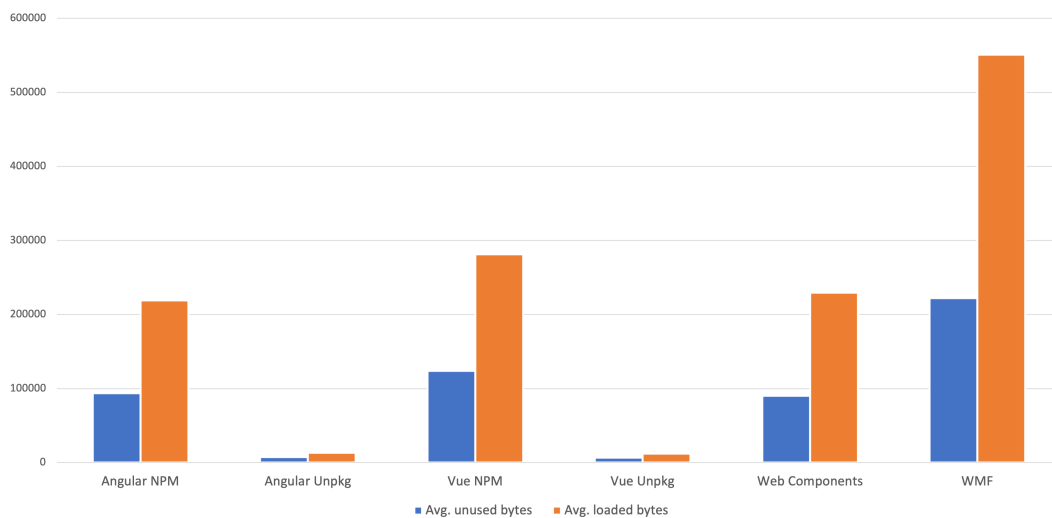| Landscape	Avg. imported bytes	Avg. unused bytes	Avg. unused bytes in %
Angular NPM	219257.14	93671.43	42.72
Angular Unpkg	13126.84	7425.87	56.57
Vue NPM	281262.33	123902	44.05
Vue Unpkg	12057.91	6844.21	56.76
Web Components	229483.67	90265.19	39.33
WMF	551111.19	222113.73	40.31

FIGURE 7.2: Unused and imported bytes per landscape

The data in table 7.7 and figure 7.2 is highly application-dependent. As these landscapes are considered to be generally representative, a display in efficiency can be drawn from the charts. The Unpkg CDN Nodes show a high ratio of unused bytes. However, it has to be taken into account that the overall imported sum of bytes is lower compared to the NPM counterparts, since only the required resources were requested from the CDN. For the WMF Nodes, it can be argued that due to the bundling with Webpack, a lot of bytes were imported and only a few of them were not used. This can be explained by how the Module Federation was configured for this prototype. To simulate a multi-version landscape, a rather restrictive WMF configuration was required. Therefore, the majority of the bundled dependencies is actually used by the modules in those landscapes. Web Components have the lowest unused bytes ratio of all the Nodes. This might be due to the fact that no UI framework was used for development. Therefore, no unnecessary framework features are present in this landscape.

The following chapter will draw conclusions based on the displayed data. Detailed tables, code examples and further information can be found in the archive.

8.   Conclusion

This chapter will conclude and evaluate the results shown in chapter 7. For the evaluation of the results, the introduced KPIs will be used, either as examples or references. Lastly, a final recommendation will be made, under which circumstances or for which use case the used technologies should best be employed.

8.1   Evaluation of the landscapes

This section will evaluate the results for each implemented Node and compare it to its respective counterpart. This section is split into two subsections, one for each prototype.

8.1.1   NPM/CDN prototype

The Angular and Vue Nodes implemented were the following:

- Angular NPM 1
- Angular NPM 2
- Angular Unpkg 1
- Angular Unpkg 2
- Vue NPM 1
- Vue NPM 2
- Vue Unpkg 1
- Vue Unpkg 2

The naming refers to the technology used to load or access the required resources for the apps. Unpkg.com, as mentioned before, is a public cloud CDN. The idea behind those implementations is to prove that not only the CDN technology affects the performance of a micro frontend, but also the used frameworks. When, comparing the numbers of those two landscapes, it becomes obvious that the Angular Nodes load more resources (counted by the URLs loaded KPI) in a shorter loading time for all implementations. Also, looking at the initial loading times calculated through the loading procedure where caching was disabled, Angular performed better compared to Vue.js for all implementations.

It has to be mentioned that the actual goal of this implementation was to compare the technology of the CDN, not the used frameworks. It still shows, that the framework has an affect on the performance of a micro frontend, though.

The following conclusions can be drawn by comparing the numbers of the NPM implementations and the ones using Unpkg.com:

1. The number of requested URLs is significantly increased when a CDN is used.

2. Even though approximately ten times the number of URLs is requested by the CDN landscapes, the initial loading time decreases by ~60 ms for the Angular Unpkg landscapes. For Vue it is even more.

3. The cache usage of the CDN landscapes significantly increases. This information is taken from the number of *none established* ID occurrences. For each connection not established, a resource is loaded from the cache, resulting in the faster loading times when cache is enabled.

4. A similar result is present in the loaded bytes from connection type. Compared to the NPM implementations, the Unpkg environments load significantly more bytes from *disk* or *memory*. This behavior was anticipated in the CDN implementations, since it is one of the desired features of this technology. Every resource has a designated URL it is loaded from, thus the browser can distinguish if it is already present or not.

5. Additionally, the average loaded content size of the Unpkg apps is lower, since only specific resources are requested from the CDN. Therefore, big bundles with unused features are generally not present.

6. Graph 7.2 shows that approximately half of the imported bytes were not used according to the Lighthouse report. However, the absolute number of loaded bytes is significantly lower, compared with the NPM environments.

7. When comparing the variances of the loading times, the Unpkg implementations show a lower value. Reasons for that could either be, the proximity of the CDN server, the bandwidth or the smaller sizes of the loaded resources.

In retrospective, the KPIs **loading time in MS, resource sizes in bytes** and **amount of cached resources** of the Unpkg.com implementations follow the expected patterns. Additionally, looking at the variance, the Unpkg environments show a less variant loading time for all applications compared with the NPM implementations. One behavior was not expected though: It was assumed that the initial loading time of a CDN landscape would be significantly higher. The reason behind that assumption was the effect of the network latency, since the resources are loaded from a remote server, and not from an integrated bundle inside the project itself. Nonetheless, in case of the prototype this behavior could not be confirmed, as even the initial loading times for the Unpkg

apps were lower compared to the NPM apps. This could be due to the efficiently picked resources. Instead of importing whole bundles of libraries, only necessary components or resources were added as imports in the Unpkg Nodes, thus the loaded byte size of those are so low.

On the topic of *"efficiently picked resources"*, another KPI which should be considered for all landscapes, is the effort connected to using a corresponding technology. This metric is hard to measure, though, since it is highly influenced by the individual using the technology. A developer who is familiar with Webpack, for instance, would have less trouble using the Module Federation. Therefore, this metric is not easily quantifiable. Still, in the context of this thesis, the author will try and provide a subjective opinion based on his experiences with the implementations he has done as generally as possible.

In case of the CDN, the effort of implementation was comparably low. From a developer's point of view it is even less effort, since no libraries have to be maintained in a central resource or package manager file (namely `package.json`). Nonetheless, it has to be considered what type of CDN is used. In case of the prototype implementation, it was a public cloud CDN which already had all the required resources available. For a self-hosted CDN, this might not always be the case. Also when deciding to host a CDN maintenance, development and deployment costs have to be put into account. This was explained in chapter 2. In summary, the CDN technology is a comparably easy way to avoid redundancies in a micro frontend landscape. It is still connected to certain obstacles, when the use case is highly specific, and requires certain customizations on CDN side. Also, multi-version landscapes are not supported by a CDN. That means that redundancies still can occur if the same resource is imported under different version tags. This use case is not directly covered by a CDN. If the resource itself has some sort of scoping feature, a support can be provided (e.g. Custom Scopes by UI5 Web Components), but this is not part of the CDN. The other technologies offer more support on that part, as described in the next section.

8.1.2   Web Component/WMF landscapes

The functionality of the WC and WMF landscapes to avoid redundant libraries was explained in chapters 4 and 5. Therefore, this section will focus on the direct comparison of these two environments. Since these two landscapes also include the aspect of heterogenic, multi-version micro frontends, this fact is considered in the comparison. Starting with values introduced in chapter 6, the first thing to attract attention should be the difference in the average loading times of the landscapes. For the caching disabled scenarios, the WMF landscape requires almost a fifth of the time compared to

the compound landscapes. With caching enabled, the difference is only a third, but still significant. Additionally, the bytes loaded by the landscapes differ. WMF loads almost twice the number of bytes compared to the WC environments in a shorter period on average and it does that barely using the cache, when it is enabled. Whereas the WC environment loaded approximately 756055 bytes on average from memory, the WMF only imported 1959 bytes on average from the cache. Therefore, based in this comparison, the WMF seems to come out on top.

Still, further aspects have to be considered when using those technologies. The first is the multi-version handling. WCs offer means to register different versions of a component, e.g. by adding a suffix to its tag name. In case of the prototype, the UI5 Web Components library provided such a feature. A self-developed component can implement a similar functionality. This would again be connected to more effort developing Web Components for a compound landscape in Luigi, but it is not entirely impossible. When using an existing component library, this feature might already be present, as it is the case for the UI5 Web Components. Since each other version of a component is registered under a different tag, with a version suffix attached to it, the result might lead to redundancies again. That means a component called e.g. `ui5-table` would be registered and imported twice into the same landscape under different names. Thus, even though the different versions are handled in a distinguishable way, the redundancies would increase.

The Module Federation offers a different feature for solving this issue. By sharing certain dependencies and with a definition of a required version, redundancies are not entirely eliminated in a multi-version WMF landscape, but handled more elegantly. During the data collection of this landscape, a phenomenon appeared which seems to be intended by the Module Federation's developers. Shared dependencies, like for instance `@angular-common - v1.1.2`, are always loaded via the network, even if caching is enabled, but never in full size. On initial loading, this dependency would be approximately 1.2 MB in size, but when reloading the page with cache enabled, it is loaded again but with 412 KB in size. This behavior appeared for all shared dependencies in the WMF landscape. It is enabled via the Module Federation itself, since the shared dependencies are lazy loaded as chunks.[49]

Again it seems that the WMF is superior in that regard compared to WCs. Still, one aspect has not been considered yet: The effort of using the technologies. As mentioned in the previous section, this is no actual KPI but rather a subjective opinion of the author. When compared directly, the effort of implementing or developing micro frontends was higher by far when using WMF compared to Web Components. Even taking into account that a component library was used, the Module Federation still required more expertise

with the Webpack bundler. The possibilities with WMF are versatile, but difficult to use by a layman unfamiliar with the necessary bundler. The documentation offers good hints and explanations for options and syntax inside the configuration, but it is documented in a more general way, and if the developer wants to use it in combination with a Webpack based framework like Angular or Vue.js, the whole operation becomes more experimental. In the case of Angular, a separate dependency is required to publish the hidden `webpack.config.js` via which the Module Federation is enabled in the first place. And this configuration has to be done for every module or remote, federated in the landscape. Applied to a real life scenario, this might become a bigger obstacle, as it was in case of the prototype. Independent, isolated teams might work on the same micro frontend landscape, using different UI frameworks for their remote modules. Not only would the bundle sizes of the heterogenic landscape increase, since every shared dependency has to be bundled and published in the landscape, but the routing inside the landscape might become a challenge itself. In case of Angular, the inner routers do not recognize route changes. One router would have to import another application's router manually, in order to be able to communicate route changes.[49]

Web Components, on the other hand, are based on standards. The result and assigning process are the same. Different UI frameworks provide features to register developed components as Web Components (e.g. Angular Elements). Thus, the developer can work framework-independent within a familiar environment and expect the same result as another developer working with the tools of their choice. Additionally, Web Components are not bound to certain technology stacks - unlike the WMF which requires the Webpack bundler to enable it. Therefore, Web Components have less limitations and more stability due to their standardization.

In summary, both technologies can solve the issue of avoiding redundant libraries, but when it comes to handle multi-version landscapes, WMF offers more elegant ways compared to Web Components. On the other hand, using the WMF limits the developer to a certain technology stack and is not always easy or effortless implemented depending on the UI framework in use. Also, as of now certain obstacles are present in the WMF which require workarounds [49]. On that regard, Web Components offer easier ways for implementation due to their standardized aspects.

8.2 Final recommendations

The previous sections contain general summaries for each respective technology, based on either empirical data, official sources or subjective experience. The following descriptions will provide final recommendations when and how best to use the introduced and

implemented technologies, based on the conclusions made in this transcript.

Content Delivery Networks: CDNs offer an easy way to reduce redundancies in micro frontend landscapes by centralizing the landscape's resources to one point. From a developer-perspective, only the method of importing the resources changes. Therefore, this is the easiest and fastest way of achieving the goal to avoid redundant libraries in micro frontend landscapes. Nonetheless, what it offers in simplicity, it lacks in flexibility. Multi-version support is not always present and can not be entirely solved by this technology. Also, a public CDN might not always have the necessary resources required by the landscape and hosting a CDN is connected to high maintenance and developing costs (depending on its size). Therefore, if the use case describes a homogenic micro frontend landscape, one without different versions, CDN is the way to go. If different versions of the same resource are required, there are more elegant ways than this technology.

Web Components: As a web standard, it is a safe way to avoid redundancies - maybe not in libraries, but rather in the used components themselves. By providing reusable components to the browser which are not affected by the isolation of micro frontends, this technology reduces the amount of used components in the landscape. Additionally, existing WC libraries provide features to scope different versions of its components to handle multiple versions inside the landscape. With its standardized aspect, it also does not limit the developer to certain technology stacks and is compatible with most common UI frameworks. Some of these even offer features to create WCs from their projects like Angular Elements. If the use case requires a lot of reusable components with as few redundancies as possible, WCs offer the best way to provide that service.

Webpack Module Federation: A rather new technology compared to the other two, WMF promises to excel in where the other two are lacking. It can federalize any piece of pre-compiled code and serve it to the landscape. This module or remote is then embedded into a host application. The remote itself can either be a UI component, a module or a utility service, thus providing a flexible way of sharing code inside its landscapes. The possibilities of using this technology are vast. But, this offer comes for a price: One has to use the Webpack bundler and for certain features or issues, workarounds are required. Subsequently, it can be said that this technology, if used correctly, is applicable to almost any use case, as long as it involves a homogenic landscape[1].

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[1]This was explained in section 6.5 of chapter 6.

As a closing word for the recommendation: When the main goal is to avoid redundant libraries in a micro frontend landscape, each of the introduced technologies offers means to do that. But each comes with its own trade-off. Also, when picking one of the above choices, side effects and benefits have to be considered. Therefore, the final recommendation is highly dependent on the use case and requirements for the landscape to be developed.

9. Prospect

The time available for the research, data collection and the actual writing was limited and, therefore, this transcript is scoped to a certain degree. Nonetheless, the statements in this document are not final and further possibilities can be explored in that field. The combinational effect of the researched technologies: For instance, a WC-based micro frontend landscape, in which the resources for the components are provided by a CDN. Also, the WMF topic was only analyzed in the context of the UI framework Angular. Even though this is a valid option, the Module Federation can be used in combination with other frameworks, too. This is definitely a field which should be looked into. Especially when taking into account how it was shown that a chosen framework can affect the performance of a micro frontend. Another field which was not dealt with, is the development and the hosting of a CDN. Even though an approximate assumption was made concerning the effort connected to such a project, this is by no means empirical data. Therefore, since the developed landscape relies on the Unpkg.com API to request the CDN resources, it would be an interesting experiment to see if and how an own CDN could improve or optimize the performance metrics for similar landscapes. Furthermore, it should also be inspected if a regular bundler environment with e.g. NPM could perform as good or even better as the other technologies, if a tree shaking algorithm is used [50]. Lastly, the Surge web server, used for the deployment of the landscapes, is connected to certain limitations too, namely the missing HTTP/2 server configuration. Thus, it would make sense to deploy those landscapes over different web servers, just to see if the changes on server-side improve the performances in the given context.

Even though the use cases covered by the prototypes are asserted to be representative, they still offer room for improvements and optimizations. Thus, when the given research is applied to a real life scenario, special conditions or requirements have to be considered when making a decision in that context. Therefore, it is mentioned in chapter 7 that the gain or benefit of each respective technology is highly dependent on the individual use case.

Nonetheless, the evidence provided in this transcript is applicable for a development team, either as a source of advice, a documentation for best practices or as a basis for design decisions. The goal set for this thesis can be considered to be achieved and exceeded, since it was showcased that the used technologies provide a solution for the issue of redundant libraries in micro frontend landscapes, and how they do it. Additionally, it was also evaluated under which circumstances those technologies

are applicable under consideration of their own individual attributes. Based on this research, the mentioned aspects of the technologies can be explored and improved upon.

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Glossary

API	**A**pplication **P**rogramming **I**nterface
CDN	**C**ontent **D**elivery **N**etwork
CLI	**C**ommand **L**ine **I**nterface
CSS	**C**ascading **S**tyle **S**heets
DOM	**D**ocument **O**bject **M**odell
ES	**E**cma **S**cript
HTML	**H**yper **T**ext **M**arkup **L**anguage
HTTP	**H**yper **T**ext **T**ransfer **P**rotocol
KPI	**K**ey **P**erformance **I**ndicator
PoP	**P**oint **o**f **P**resence
RTT	**R**ound **T**rip **T**ime
SSL	**S**ecure **S**ockets **L**ayer
TCP	**T**ransport **C**ontrol **P**rotocol
TLS	**T**ransport **L**ayer **S**ecurity
UI	**U**ser **I**nterface
URL	**U**niform **R**esource **L**ocator
WC	**W**eb **C**omponent
WMF	**W**ebpack **M**odule **F**ederation

A. Table of contents for the archive

A.1 Folder Data

Contains all data collected via the data collection process of chapter 7.

A.1.1 analysisExcel.xlsm

Central excel containing all calculation, graphs and data gathered via the testing process.

A.1.2 centralJson.csv

Aggregated `.json` file, of all Lighthouse reports.

A.1.3 createAllCsv.sh

Shell script, used to run a cascading process for the shell scripts in the sub-folders. Via this script, the generation of **analysisExcel.xlsm** and **centralJson.csv** is triggered.

A.1.4 Folder angular-npm-data

Folder containing all the data for the Angular NPM landscapes. The data is available as `.har`, `.json` as well as **.csv** files. The files themselves are split into, whether the data was collected with cache enabled or disabled. Additionally, aggregated files for that landscapes are present, as well as a shell script to trigger the creations of every file in the folder.

A.1.5 Folder angular-unpkg-data

Folder containing all the data for the Angular Unpkg landscapes. The data is available as `.har`, `.json` as well as **.csv** files. The files themselves are split into, whether the data was collected with cache enabled or disabled. Additionally, aggregated files for

that landscapes are present, as well as a shell script to trigger the creations of every file in the folder.

A.1.6   Folder vue-npm-data

Folder containing all the data for the Vue NPM landscapes. The data is available as `.har`, `.json` as well as **.csv** files. The files themselves are split into, whether the data was collected with cache enabled or disabled. Additionally, aggregated files for that landscapes are present, as well as a shell script to trigger the creations of every file in the folder.

A.1.7   Folder vue-unpkg-data

Folder containing all the data for the Vue Unpkg landscapes. The data is available as `.har`, `.json` as well as **.csv** files. The files themselves are split into, whether the data was collected with cache enabled or disabled. Additionally, aggregated files for that landscapes are present, as well as a shell script to trigger the creations of every file in the folder.

A.1.8   Folder compound-views-vanilla-data

Folder containing all the data for the WC landscapes. The data is available as `.har`, `.json` as well as **.csv** files. The files themselves are split into, whether the data was collected with cache enabled or disabled. Additionally, aggregated files for that landscapes are present, as well as a script to trigger the creations of every file in the folder.

A.1.9   Folder wmf-views-data

Folder containing all the data for the WMF landscapes. The data is available as `.har`, `.json` as well as **.csv** files. The files themselves are split into, whether the data was collected with cache enabled or disabled. Additionally, aggregated files for that landscapes are present, as well as a shell script to trigger the creations of every file in the folder.

A.2 Folder Master_Development

Containing all the developed prototype projects for this thesis.

A.2.1 Folder master_thesis_dev

Contains the project for the CDN/NPM landscapes and their respective React Core application.

A.2.2 Folder master_thesis_dev_compound

Contains the projects for the WC compounds landscapes.

A.2.3 Folder master_thesis_dev_wmf

Contains the projects for the WMF compounds landscapes.

A.2.4 Folder master_thesis_express_app

An express app, was developed in the early stages of the thesis and later abandoned, since a local data source was picked.

A.3 Folder Self-developed-Scripts

Contains all self-developed scripts for generating the `.csv` from the `.har` and `.json` files.

A.3.1 Folder centralJson2Csv

Generates the centralJson.csv file in the archive. It is a JavaScript script, which adds a command to the console, which is later executed via the shell scripts in the Data directory.

A.3.2 Folder har2csv

Generates a single `.csv` file based on single `.har` file. It is a JavaScript script, which adds a command to the console, which is later executed via the shell scripts in the Data directories.

A.3.3 Folder hars2csvs

Generates a single `.csv` file based on all `.har` files in the given directory. It is a JavaScript script, which adds a command to the console, which is later executed via the shell script in the Data directories to generate the central `.csv` files for each data directory.

A.3.4 Folder json2Csv

Generates a single `.csv` file based on single `.json` file. It is a JavaScript script, which adds a command to the console, which is later executed via the shell scripts in the Data directories.

A.3.5 Folder jsons2Csvs

Generates a single `.csv` file based on all `.json` files in the given directory. It is a JavaScript script, which adds a command to the console, which is later executed via the shell script in the Data directories to generate the central `.csv` files for each data directory.