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STUDMAP 3.0 - AN INTEROPERABLE WEB-BASED PLATFORM FOR GEOSPATIAL DATA OFFERS IN ACADEMIC LIFE

Ștefana Cioban

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NOVA IMS Information Management School
Universitat Jaume I
Westfälische Wilhelms-Universität Münster

STUDMAP 3.0 - AN INTEROPERABLE WEB-BASED PLATFORM FOR GEOSPATIAL DATA OFFERS IN ACADEMIC LIFE

Dissertation supervised by

Prof. Doutor Vitor Manuel Pereira Duarte dos Santos, Information Management School, NOVA Lisbon

Dr. Torsten Prinz, Institute for Geoinformatics, WWU Münster

Dr. Andrés Muñoz, Geotech Institute, UJI, Castelló

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ABSTRACT

Geographic Information Systems has now entered the realm of web and yields for feasible solutions to balance the technology offers with the users' needs to share, access and explore the massive amounts of geodata available. Challenges occur when moving forward from old 2D platforms towards innovative and integrated webGIS systems that align functionality with the necessity to grant a complete understanding of the surrounding reality. 3D space responds to this but, however, stands only at the beginning of its era and cannot yet reach the development of 2D web integration. Research is now aiming at possible webGIS solutions to adapt to the special structure imposed by 3D data. In this context, this thesis focuses on designing an architecture for 2D and 3D geospatial data integration on a student-oriented web platform. This concept was further delivered and validated through a real case scenario – Studmap 3.0, a webGIS platform to serve the students of the University of Muenster in their academical life. The portal currently grants availability of geospatial data and web services of regional interest in a smart GIS environment that allows access and comparison of official services with own data. The implementation of Studmap 3.0 aided in the continuous improvement of the proposed architecture model and developed under a design science research cycle that reached its end once the final approval of its users was attained via a usability evaluation. Final strengths and drawbacks of the proposed architecture were ultimately identified together with an expert usability evaluation and a lab-based usability test of the resulting portal interface suitability for academic use. The results fall under the acceptable range with an 83.75 score for the System Usability Scale standardized questions when addressed to experts and a score of 83.87 when addressed to students. For the open-ended questions, the interface received an overall positive critique. A summary of future participants' opinion on the benefits, drawbacks and proposed improvements was also delivered. Peers interested in similar concepts can use both this model and its final remarks as a reference for their work.

KEYWORDS

webGIS, geodata, 3D, web portal

ACRONYMS

2D – Two Dimensional

3D – Three Dimensional

API – Application Program Interface

db – Database

DBMS – Database Management System

DEM – Digital Elevation Models

ds – Data Store

DSM – Digital Surface Models

EPSG – European Petroleum Survey Group

ESRI – Environmental Systems Research Institute

GIS – Geographic Information System

GPS – Global Positioning System

HTTP – Hypertext Transfer Protocol

HTTPS – Hypertext Transfer Protocol Secure

ISO – International Standards Organization

I3S – Indexed 3D Scene Layers

JSON – JavaScript Object Notation

LAS – Log-ASCII-Standard

LiDAR – Light Detection and Ranging

NRW – North Rhine-Westphalia

OGC – Open Geospatial Consortium

REST – Representational State Transfer

RDBMS – Relational Database Management System

SQL – Standardized Query Language

SDK – Software Development Kit

SLPK – Scene Layer Package

SUS – System Usability Scale

UAS – Unmanned Aerial Systems

UAV – Unmanned Aerial Vehicle

URL – Uniform Resource Locators

WAB – Web Appbuilder

WCS – Web Coverage Service

WFS – Web Feature Service

WMS – Web Map Service

WMTS – Web Map Tiling Service

WWU – University of Münster (Westfälische Wilhelms-Universität)

XML – Extensible Markup Language

INDEX OF TEXT

INDEX OF FIGURES

INDEX OF TABLES

1. INTRODUCTION

This chapter raises the awareness of a problem in the Geospatial Technologies realm, namely the need for a client-server architecture for an interoperable webGIS platform for the integration of geospatial data to serve students for educational purposes. The problem's background and the research motivation are first introduced, followed by the aim and the main objectives of this thesis.

1.1 BACKGROUND

The information age we are living in stretches the limits of Geographic Information Science. We are now facing an increasing demand for integrated solutions to handle geospatial data due to an increasing number of users, a heavy load of geodata generated daily and a limited number of resources to cope with them. In academia, such serious problems are now making the call for innovative ways for students to effectively share and handle data, address it to a particular problem and refer to it when needed. In this way, conventional Geographic Information Systems (GIS) are being pushed towards the web and yield more sophisticated approaches to integrate data into new web dedicated systems.

Moreover, these new directions in GIS are moving from conventional 2D to innovative 3D data integration on the web as aligned with the offers of the latest technologies and the positive impact of 3D space on how the user understands the surrounding space. However, this process is still facing the problem of discrepancy between the development of the two data types as a 3D data structure imposes a greater complexity that still lays behind the current web availability of 2D data.

1.2 MOTIVATION

To synchronize with the current tendencies in GIS and geodata offers across the web, students crosscutting with this realm now require a smart, 3D-friendly web environment to respond to their practical needs: to allow the access of public and official data and to upload and share own data with the others. In this scenario, the motivation of this thesis steps in the lack of scientific solutions to balance both 2D and 3D functionality in an integrated webGIS system dedicated to academical use.

The proposed approach in this paper offers a new architecture for complex 2D and 3D data and web services integration to a common web platform to grant GIS functionality for academical use. The platform is intended to ultimately allow students to download, exploit and upload datasets of regional interest in a webGIS environment. This approach has further been evaluated and validated by a case study platform, Studmap 3.0 based on a design science research process. Studmap 3.0 is hence intended to replace the currently unfunctional and outdated geoportal, Studmap 1.4 with a new application of the concept of a smart architecture. The implemented architecture will serve as a good reference tool for all peers interested in similar problems regarding complex 3D data integration and web-based services importation on a GIS Server.

Hence, this thesis comes as an answer to three main needs for the situation argued above:

- The need to find the optimal client-server architecture based on a design science research process to implement an integrated GIS web platform;
- The need to validate the architecture through a real implementation of a new GIS platform according to the theoretical model that would replace its outdated version;
- The need to find the strengths and limitations of the architecture and to provide a useful resource for peers interested in similar issues.

As Gaghegan (2018) was stating, *"we should not expect a third party to take responsibility for validating and delivering our ideas into a GISystem that is focused on research"*. Researchers in the GIS field is delivering innovative ideas to promote progress usually in written forms such as journal publications. However, these ideas tend to remain only written and not applied to real-world practices. The present research, therefore, responds to this call as it ultimately resulted in a practical approach. The new architecture has been implemented and validated and resulted in a platform designed to support students in real life altogether with a framework that can always be adapted according to specific needs and improved upon feedback.

1.3 AIMS AND OBJECTIVES

This research aims to contribute for a better understanding of the complexity of the geodatabase integration of data coming from different sources and new web services of regional interest to serve the students' current needs. To attain this, we propose, implement and validate a viable client-server architecture for the complex 2D and 3D data and web services integration to a GIS Server. The aim will be achievable throughout a series of technical and personal objectives. In terms of technical objectives:

1. Proposing a conceptual client-server architecture for a webGIS platform that offers a smart data concept and functionality aligned to the current needs of the students to have it ready for evaluation;

2. Implementation and evaluation of the proposed architecture through a case study to prove the new conceptional setup and to generate conclusions for future optimization, to generate the thesis' final assumptions;

As for the personal objectives:

3. Writing on the master thesis and presentation, to have it finished for the thesis defense;

4. Completing five courses on ESRI's online learning platform, to develop the skills for the technical requirements of publishing the GIS web-services;

2. THEORETICAL BACKGROUND

The focus of this chapter is the research and description of the existing GIS integration solutions offered by researchers up to the present.

2.1 GEOSPATIAL CONTEXT AND WEBGIS

As the name implies, geospatial data are information specific to the position on the globe where the data were collected, distinguished by two main types: raster and vector, depending on their structure. A discrete regular grid of cells representative for each spatial location is specific for raster data, while vector consists of mathematical functions materialized by geometric shapes (Shekhar, Xiong, & Zhou, 2018).

New tendencies of GIS integration with Internet technologies enable geospatial data to move towards a new accessibility and interoperability culmination. The accessibility aims to grant the public access of geospatial data through the so-called webGIS, offering interactive and real-time integration and transmission of both data and GIS tools to a worldwide audience (Agrawal & Gupta, 2017). On the other hand, interoperability refers to the geospatial data resource synthesis to offer a better organization and understanding of geographic information (Cannata, Antonovic, Molinari, & Pozzoni, 2015).

WebGIS, which is sometimes referred to as web mapping, represents the integration of GIS on the web to allow the efficiently sharing of the geospatial data among its users around the world. With the rise of technological development nowadays, we situate ourselves in the transition between Web 1.0 and Web 3.0. WebGIS is continuously adapting to this growth of the web, altogether with its subsequent architecture to comply with the current needs and technologies. Agrawal & Gupta (2017) offer an insight into how webGIS has evolved from simple web mapping websites to the current complex webGIS architectures, giving a comparison between different types of architectures. They conclude that any webGIS structure is primary depending on the user's necessities.

Veenendaal, Brovelli, Li, & Ivánová (2017) make a distinction between the two concepts, web mapping, and webGIS, providing an overview of the terms and terminology around them. They argue that mapping and GIS have started to migrate towards the online environment altogether, suffering a huge impact from the fast developments of the web, which in turn has caused confusion between the two. We now take advantage of these developments which give us an easy interaction with the maps that allow a stronger collaboration with GIS. Developing web services allow these communications and give access to geospatial data in the online environment as components with an application programming interface.

However, such developments come with different drawbacks. There are a series of limitations that can impact GIS nowadays regarding the computational shortcomings and community. Gaghegan (2018) gives a listing of the issues of GIS science and suggestions on how to overcome them.

Altogether with the expansion of webGIS, recent research has started to emphasize the importance of its functionality and to offer different frameworks to review and assess it. New directions now focus on the data, users and functionality of the system (Veenendaal, Brovelli, & Li, 2017). Hence, the front-end mapping functionalities, and the back-end database management system should work together to offer the end user the amount of information and flexibility addressed by its purpose. Kong, Zhang, & Stonebraker (2015) propose that the functionality of a webGIS system can be assessed using eight common GIS functions: basemap availability, legend customization, map elements, map products, information query, location search, reporting, and spatial analysis.

To ultimately evaluate the users' appreciation of a webGIS platform, standard meeting criteria for usability (International Organization for Standardization, 2018) should emerge to a design an evaluation methodology dedicated to its domain-specific context. An evaluation addressed real users of the platform where they are given specific tasks is encouraged by the literature (Kong, Zhang, & Stonebraker, 2015) and should result in qualitative feedback for the further improvements of the webGIS design.

2.2 BIG 3D DATA AND GEOSPATIAL SCIENCES

Big data refers to the abundance of digital data collected throughout different sources: Earth Sciences, Internet of Things, Social sciences, Astronomy, Business or Industry (Yang, Huang, Li, Liu, & Hu, 2017). Nowadays, we confront with a "flood of digital data", directly or indirectly involving information about space. Altogether with the processing advancements and data availability, big data forces geospatial sciences to turn to a new perspective. This comes with both advantages and challenges as it yields for great changes in the way the data are understood, stored, handled and delivered (Yang, Huang, Li, Liu, & Hu, 2017).

Shekhar, Xiong, & Zhou (2018) estimate an increase in the number of digital earth sensors in the following 5 years which is approximated to 50 billion. Not only does this boom impact the volumes of geocoded data, but it also brings a new challenge to the table: managing the temporal dimension. This forces the processing capabilities to turn to new data distribution methods to adapt to the computing capacity of a single or a set of machines. Horizontal scaling is preferred to vertical systems in terms of rapidly computing large amounts of data. However, their performance is still disputed, and the focus turns to find` the distributed computing solutions to handle both the quality of the big data processing and the security of the data in terms of control and privacy (Shekhar, Xiong, & Zhou, 2018).

2.2.1 3D geospatial data

Tendencies in the geospatial realm nowadays focus around the capturing and applications of one specific type of big data: 3D data. 3D data gives GIS a real-world image of the surroundings in terms of visualization. This data normally derives either from aerial captures with the help of LiDAR (Light Detection and Ranging) or UAS (Unmanned Aerial Systems) techniques, or from terrestrial LiDAR capturing systems, represented by TLS (Terrestrial Laser Scanning). These approaches are used to grant people a better understanding of the main characteristics of the environment. However, due to the size of the dataset and the resources required by it, the geodatabases are facing a real management issue (Shekhar, Xiong, & Zhou, 2018).

LiDAR is one of the most common sources of qualitative 3D products such as classified point clouds, digital elevation and surface models (DEMs and DSMs). Li, Hodgson, & Li (2018) bring a review of the recent literature regarding LiDAR and point cloud processing. Similarly, Walsh, Page, McKnight, Yao, & Morrissey (2015) offer an insight into the applications of LiDAR generated geodata, altogether with a review of the most recent applications in the research area. These researches now address the integration of terrain analysis with software engineering in order to offer an appropriate solution for a web-based GIS.

2.2.2 3D geospatial data management

3D world benefits of massive amounts of 3D geodata available which come into different forms: 3D textured or untextured city models, surface or terrain models derived from triangular irregular networks (TINs) or 3D point clouds which usually consist of billions of points. WebGIS developers seek for solutions to distribute these large volumes of data throughout integrated platforms to serve for the consumption and delivery of 3D data around the world (ESRI, 2016b).

Data model serves as a solution to better manage massive 3D geocoded data as part of a spatial database management system (DBMS). The aim is to distribute the data as records stored in the rows of an integrated system that would easily allow the query of the data and hence, a better analysis of the information (Shekhar, Xiong, & Zhou, 2018).

Even if big data distributed in a database offers an easy manipulation of the data on the web, this structure imposes a series of challenges (Shekhar, Xiong, & Zhou, 2018). Storing space and disk size is one of the main. For instance, LiDAR produces billions of points into massive volumes beyond the storing limit and computing capacity of a single machine as its purpose is to bring a higher geometric detail to data.

What is more, the delivery of 3D final products depends on a series of workflows varying from pre-processing of the point cloud to the final delivery of a digital elevation model. Not only does such a workflow demand high computing efficiency in the offline environment, but it also challenges the real-time processing on the web. All these processes require special storage and computing capacities and hence, a more complex approach when retrieved from a database and processed in the online environment. Li, Hodgson, & Li (2018) and van Oosterom, et al. (2015) propose different solutions for the LiDAR data integration process in a geodatabase.

When using a data model, each record of the geodatabase is being managed individually. Working with large volumes of data influences the performance of each query and hence, can result in long-lasting retrievals of data. As a solution, Shekhar, Xiong, & Zhou (2018) discuss using a spatial indexing technique in order to avoid the examination of every row and record. However, 3D data imposes a special data structure and relationships between entities, which, in turn, challenges the spatial indexing system whose solution is still under research.

In their research, van Oosterom, et al. (2015) discuss the capabilities and limitations of diverse infrastructure solutions available for the manipulation of massive 3D point clouds within a Database Management System (DBMS). Their research reveals that the best implementation strategy depends on the file size, hardware and software solutions available and the required functionality.

On the other hand, solutions for converting complex 3D data formats into easily manageable structures are being researched. The concept to compress the entire content of a dataset allows working with great volumes of data while being able to access each individual resource. Indexed 3D Scene layers (I3S) and, respectively, Scene Layer Packages (.SLPK) have been adopted as an OGC community standard for storing and managing 3D geographic data such as 3D objects, integrated meshes and point features (OGC, 2017). This solution focuses on converting the original dataset into a node-based hierarchical spatial index structure to allow the packaging for local storage, in the case of .SLPK package and consumption as a web service, in the case of the I3S layers (ESRI, 2017b). Hence, no DBMS approach is required, nor currently available in this case.

2.3 GIS SERVERS

2.3.1 Defining concepts

GIS data is handled on the web through different applications or programs depending on web browsers, web servers, and map servers to perform certain tasks over the internet. The web browser is the client as it is the one to make a request translated into an URL, while the web server gives the response to that request through the HTTP protocol. The geospatial component is handled by the map or GIS server which provides the core GIS functionality of the application and supports the derived web maps (Agrawal & Gupta, 2017). The link between the web server and map server is done by the application server (Shekhar, Xiong, & Zhou, 2018).

2.3.2 Classification

GIS servers are handled with the help of different software options available. In terms of acquisition costs, they can be either open or closed. Idrizi (2014) offers an analysis of the comparison between the two types of software for GIS practices.

A. Open source software servers

Open source movement in GIScience gathers a valuable community of dedicated peers that contribute with solutions to so-called “fee of costs” platforms. The efforts have gained value among the research area as Gaghegan (2018) argues that GIS platforms can develop in a healthy way if people contribute freely. However, open source software comes with a series of drawbacks and are free only to a certain extent, even though the price cannot compare with the commercial options on the market (Idrizi, 2014).

Agrawal & Gupta (2017) offer a review of the open source software options and their impact. Among the open source software options, the ones that are gaining popularity nowadays are GeoServer (2019) and MapServer (MapServer, 2018). An example of an entirely open source geoportal is istSOS (Cannata, Antonovic, Molinari, & Pozzoni, 2015), which combines free software solutions into a web map mashup to serve for flood protection.

B. Closed source software servers

Commercial software is intended to be user-friendly, requiring little development knowledge and training, while offering good infrastructure support for the client. Usually, closed source software options can be adapted to the users' specific needs and require fewer maintenance efforts (Idrizi, 2014). What is more, Gaghegan (2018) argues that commercial software is bringing the GIS community one step closer to contributing to a common platform for research in the realm, as producers are nowadays giving the users the opportunity to develop or improve missing functions of the available systems. However, all these benefits come in the exchange of a considerable price and such compromises as adapting to the producer's specifications and constraints (Idrizi, 2014).

A recent review of the options of software available on the market is given by Idrizi (2014). They also offer a comparison between the open source and commercial software options for GIS servers, providing a list of examples of implemented GIS platforms for each case. Among the most popular options of commercial GIS software stands ArcGIS, produced by ESRI. ArcGIS is a GIS dedicated software platform composed of four elements: a geographic information model, storage and management component, disseminating geoinformation, GIS applications, and related web services. The platform allows personalization and development of the built-in features or the creation of new applications or components (Shekhar, Xiong, & Zhou, 2018). ArcGIS Server is a web mapping and geoprocessing software of this platform, which enables the availability of spatial information through the communication between a server computer and other devices established by different web services. This communication is standardized by two protocols: HTTP and HTTPS. The server consists of two servers, a map and a web one, which is connected via APIs (ESRI, 2018b).

An example of an ArcGIS driven webGIS platform is given by Walsh, Page, McKnight, Yao, & Morrissey (2015) which have implemented a solution to offer the availability of the LiDAR driven digital terrain model of North Carolina. Chen, He, Zhang, & Nover (2016) have also used the option of ArcGIS Server to combine the 2D and 3D data on the same webGIS platform to ease the management of landslide hazards. More popular examples consist of the National Atlas of the United States (USGS, 2018), the Canadian GeoData Infrastructure (Canada, 2017) and the National Geographic Website (Society, 2017).

2.4 WEB MAPPING APIS

Application Program Interfaces or APIs are software interfaces that specify how pieces of software interact with each other. They can be either consumed or provided as services and they come in two main categories: server-side APIs and client-side APIs. For the communication with the HTTP web server, the web APIs usually use JSON or XML standard formats. For communication with the web browser, the APIs use standard JavaScript formats (Liu, Li, Huang, & Gong, 2015).

Web mapping APIs are dedicated to mapping as they are used to establish the communication and integration of web map services through classes of maps and layers. Currently, there are over 20405 web APIs, which include 1112 web mapping APIs, according to ProgrammableWeb (2018). Among the most popular, stands Google Maps, which holds the 8th position among all types of APIs. In their study, Liu, Li, Huang, & Gong (2015) give a review of the popular GIS mapping API choices. Slight changes have been made since which are reflected in the updated version of the selected GIS web mapping APIs in Table 1:

Provider	**URL**	**Authentication**
Google Maps	https://cloud.google.com/maps-platform/	No
ESRI ArcGIS	https://developers.arcgis.com/	No
Microsoft Bing Maps	https://www.microsoft.com/en-us/maps/choose-your-bing-maps-api	Yes
Here Maps	https://developer.here.com/	Yes
MapQuest	https://business.mapquest.com/products/	No
OpenLayers	http://openlayers.org/	No
Yandex	https://tech.yandex.com/maps/	Yes
OS OpenSpace	https://www.ordnancesurvey.co.uk/business-and-government/products/os-openspace/api/	Yes
GeoServer	https://docs.geoserver.org/latest/en/user/rest/api/index.html	No
GeoTools	http://docs.geotools.org/stable/userguide/library/api/	No

Table 1 Updated table of selected GIS web mapping APIs (Liu, Li, Huang, & Gong, 2015) (sites last accessed on November 5, 2018)

All these web APIs are dedicated to allowing developers to create or customize built-in location-based applications for modern platforms. ESRI's ArcGIS web APIs are offered for a wide variety of programming languages, including JavaScript, Flex, Silverlight/WPF, .NET and Java (Liu, Li, Huang, & Gong, 2015). The ArcGIS API for JavaScript is now enabling users to integrate 2D and 3D functionality in their webGIS based applications and deploy them on the web browser (ESRI, 2018j). The 3D functionality on the web was given with the release of the 4.0 version of the API through the Indexed 3D scene layers (I3S) capable to support large volumes of 3D geospatial data (ESRI, 2016b).

For non-developers, the ArcGIS API for JavaScript is integrated with the Web AppBuilder (WAB) software development kit (SDK), which requires minimal coding and allows easy creation of GIS web applications. This SDK comes with two versions, one for 2D applications and one for 3D, which are based on the two versions of the API, 3.x and 4.x (ESRI, 2018j).

The representational state transfer or REST API that uses HTTP requests in a common architecture for web services development (Rouse, 2016). ArcGIS Online and Server use this type of API for the management of web services, system properties and user roles (ESRI, 2017d).

2.5 GEOSPATIAL WEB SERVICES

While APIs represent the interface between two applications, the web services grant the communication between two machines. Web services are software or pieces of software that facilitate the availability of data the Internet through a standardized Extensible Markup Language (XML) which encodes the messages between the users and the services. Web services can be compatible with the characteristics of geospatial data and can hence, allow the access and server-side processing of such data via the Internet. In this way, geospatial technologies can take advantage of the capabilities of web services to offer accessibility of large volumes of multi-dimensional geodata to clients varying from human to application end-users focused on geospatial services (Veenendaal, Brovelli, Li, & Ivánová, 2017).

Web geospatial services enable the distribution and real-time processing of big geospatial data to reduce time, costs, duplicated data and required computing capacity. In this context, geospatial data analysts can now take a step forward from the traditional GIS workflows to efficiently explore geospatial information directly on the web without such dependencies as storage space and computing capabilities (Wagemann, Clements, Figuera, Rossi, & Mantovani, 2018).

A. OGC-specific web services

New directions in the realm are now focused on finding the best techniques to combine data access and analysis throughout web-based services. In this context, the integration of multi-source web services is a great challenge which comes with a series of disadvantages (Chen, He, Zhang, & Nover, 2016) (ESRI, 2018i). Agrawal & Gupta (2017) refer to the need to effectively implement these services as the need for a “revolution”. The Open Geospatial Consortium (OGC) responds to this urgency by being dedicated to initiating the standardization of the geospatial data sharing and interoperability (OGC, 2016b). According to GeoSeer (2018), at 2018-07-18 there were 1224379 OGC layers available. Their standard classifies the web services in web map services (WMS), web map tiling services (WMTS), web feature services (WFS) and web coverage service (WCS).

OGC describes the web map service (WMS) as a standard to share maps as georeferenced digital images in different formats (Agrawal & Gupta, 2017). OCS’s definition of WMSs (OGC, 2016a) covers the standards of requesting and retrieving online maps from existing geodatabases to allow the dynamic consuming of multiple maps or layers coming from multiple sources and allowing different styling schemes. The service uses the GetCapabilities and GetMap API calls at a basic level. ESRI (2014c) specifies that WMSs don’t expose actual data while allowing attribute requests throughout other operations.

According to the OGC standards, a web map tiling service (WMTS) is a complement for the WMS as it again represents an image covering a map extent for different scales. The difference is that the image is composed of multiple predefined tiles that ease the load of computation needed for large images (OGC, 2010b). An example of WMTS is the basemaps provided by ESRI are tiled map services (ESRI, 2018a).

Web feature services (WFS) allows the access of data by its feature and not via an image. Hence, this offers more capabilities together with a rich experience as a client can retrieve or modify features and their properties on the web directly. However, this comes with a considerable cost in terms of response time as the rendering is done at the client-side (OGC, 2010a).

A. ESRI-specific web services

ArcGIS Server is compatible with many web services, including the OGC compliant ones mentioned earlier. There are 7 services managed by the GIS Server in particular: geocode, geodata, geoprocessing, image, map, scene, and vector tile services. These services can be consumed either by using a web browser or a web mapping application or using a GIS desktop application (ESRI, 2018d).

Raster data or mosaics can be published via image services. In an Enterprise setting, these will generate either image or elevation layers depending on the settings of the source. Map services allow the publishing of maps over the Internet and it creates the map image layers. These layers are normally rendered on the server-side generating a low response size. Map services also allow enabling WMS, WMTS or WFs and hence allow the publishing of OGC specific layers (ESRI, 2018e).

Feature data is normally published as a feature service which is a feature-enabled map service. Once published, these services will generate feature layers that offer enhanced capabilities and an interactive experience compared to the map image but at a higher response size (ESRI, 2018e).

Scene services allow the publishing of complex 3D data structures or scenes. For example, scene layer packages can be consumed via these services (ESRI, Indexed 3D Scene Layers, 2015). These services can only be published as hosted layers as their content is stored in the NoSQL database of ArcGIS Data Store (ESRI, 2018e).

2.6 WEBGIS APPLICATIONS

Altogether with the growth of webGIS, the diversity of web mapping APIs and standardization of geospatial web services approaches to integrate emerging technologies into web mapping applications are setting the base for a new mashup paradigm. Data coming from different sources are being waved into modern, light-weighted web applications to offer their users a more interactive mapping experience (Liu, Li, Huang, & Gong, 2015).

As users tend to integrate web programming technologies into their maps, web developers are offering more intuitive ways to build web mapping applications. Configuring applications now becomes easier not only for developers but for non-programming peers as well. Among the plethora of tools, APIs and libraries, Buczkowski (2016) bring forward a classification of the most popular choices for web mapping.

A good example of an easy-to-use web application building software is given by ESRI's WAB for ArcGIS. WAB allows both developers and non-developers to create interactive mobile or desktop web mapping applications. The application can either be deployed using ArcGIS Online or Enterprise platforms or using a Developer Edition dedicated for customization (ESRI, 2014b). What is more, WAB can also integrate 3D data via the newest version of the ArcGIS API for JavaScript (ESRI, 2014a).

Stepping forward into the developments of web maps and applications realm also brings important issues to the surface. As tendencies are moving around 3D data, a current concern among web mapping developers is how 3D features can reach the same level of integration as 2D web maps in order to be used together for an enhanced webGIS environment (Chen, He, Zhang, & Nover, 2016).

2.7 WEBGIS SERVER ARCHITECTURE

GIS client-server architectures are network architectures dedicated to spatial data in which a web server works altogether with a map server to exchange geographic and non-geographic information with remote clients. Agrawal & Gupta (2017) discuss the multiple possible options for a webGIS architecture, which can vary between multi-layered, plug-and-play, service-oriented or cloud-based.

In general, an internet GIS architecture tends for a three-tiered system consisting of a presentation, an application and a database tier (Shekhar, Xiong, & Zhou, 2018). The presentation layer is the web browser that grants the exchange of information between the client and the web server. The application tier holds the logic of the entire system, ensuring the exchange of information between the client and the database. In the case of webGIS, this is done by the web and the GIS servers via the Internet. The database tier handles the storage and management of the geospatial data in order to return the requested data to the web server (Agrawal & Gupta, 2017).

In a three-tiered architecture, each component can physically reside on a different machine. This brings, therefore, both complexity and valuable gains over the traditional approaches, such as increased efficiency, security, scalability and flexibility as the workload is distributed between the different components and hence, between different computers. Such systems can access the database directly, without the need to locally store the data, providing the client with fast responses of complex features and even geospatial analysis tools residing on other systems (Shekhar, Xiong, & Zhou, 2018).

Some examples of applied three-tiered architectures are given by Chen, He, Zhang, & Nover (2016), Liu, Li, Huang, & Gong (2015) and Shekhar, Xiong, & Zhou (2018).

ESRI's ArcGIS Server can also be deployed as a multi-layered system, where the web browsers that offer access to the clients and administrators form the presentation tier, the web adaptor, and web and

GIS servers represent the application or middleware tier and the database layer is represented by the data server (Figure 1). In this case, the web adaptor is the application which links the GIS server or servers with the web server, by forwarding the requests to the machines where the GIS servers reside (ESRI, 2018b).

The data structure for GIS data management that powers web services and allows web editing on the ArcGIS Server is represented by the enterprise geodatabase. It is a relational database management system (RDBMS) with special characteristics destined for a large-scale GIS system: increased efficiency, data integrity, scalability, concurrent access, security and flexibility (ESRI, 2016a). Once registered with the GIS server, this structure allows referencing the source path of the data that is being published and turned into web services (ESRI, 2018c).

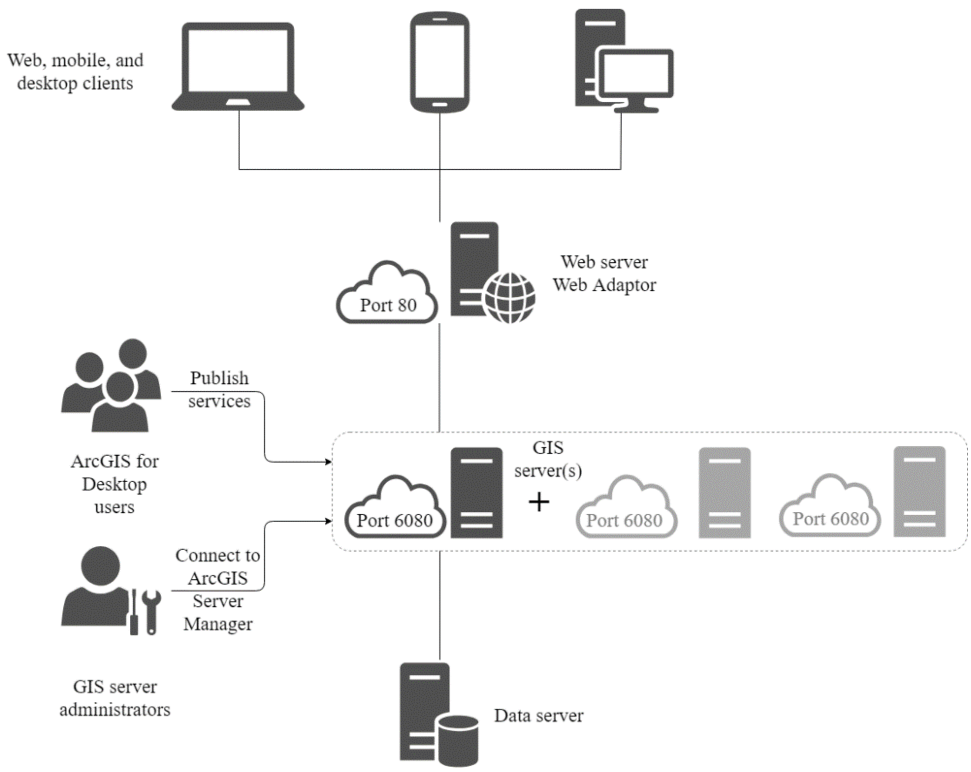


Figure 1 ArcGIS Server site architecture adapted from (ESRI, 2018b)

An advanced deployment is represented by the ArcGIS Enterprise multi-machine system (ESRI, 2018f) which offers a configuration of three main components that can reside on different machines: the ArcGIS Server, the Portal for ArcGIS and the ArcGIS Data Store (Figure 2) to grant the feature service data management. The system requires that all three components work together. The ArcGIS Server Site is federated and integrated with the portal. This system is configured with two data stores which deploy the hosting server: the relational and the non-relational or tile cache data store. While the relational database handles the hosted feature services managed in the portal, the non-relational manages hosted scene services. This configuration offers the highest level of integration of the system components and, hence, the most capabilities availability, at the moment being the only means of publishing complex 3D features via the I3S standard layer (ESRI, 2018g).

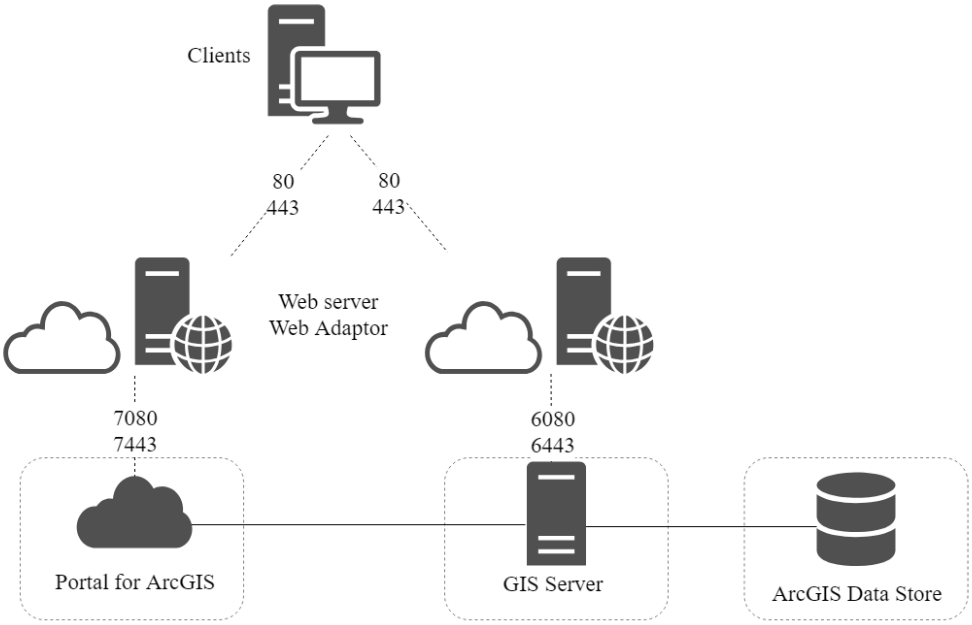


Figure 2 ArcGIS Enterprise multi-machine model adapted from (ESRI, 2018f)

In this architecture model (Figure 2) the communication between the portal and the GIS server is done via the HTTP and HTTPS protocols or can be restricted to HTTPS only. As Figure 2 displays, the portal communicates with the 7080 port for the HTTP protocol and with the 7443 port for the HTTPS (ESRI, 2018l). The GIS server, on the other hand, uses the HTTP port 6080 and the HTTPS port 6443 to communicate with the other machines via the Internet (ESRI, 2016c). The Web Adaptor manages the requests via the 80 and the 443 ports.

3. METHODOLOGY

The goal of the research is to integrate complex geospatial data and web-based services on an interoperable web platform by proposing and evaluating a GIS client-server architecture. In other words, the proposed approach refers to the creation of an artefact aiming to solve a problem. In this context, a design science research framework (Kanellis & Papadopoulos, 2009) is chosen from the existing research methodologies as the proposed approach intends to build knowledge through the creation of reality. This chapter focuses on describing the concept of design science research and its application to the current research.

3.1 DESIGN-SCIENCE RESEARCH

The paradigm of Design-Science is a research instrument commonly used in Information Sciences to solve problems by creating an artefact. Design-Science Research proposes a framework adapted by the researcher's aims to shape the artefact according to the results of a series of iterations of five processes as seen in Figure 3: the problem's awareness, the suggestion, the development, the evaluation and the conclusion (Kanellis & Papadopoulos, 2009).

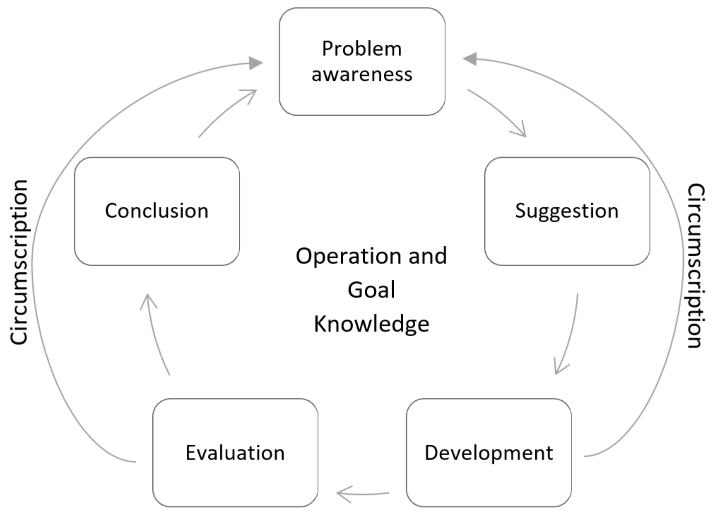


Figure 3 Design research process adapted from (Kanellis & Papadopoulos, 2009)

First, the problem (Figure 3) is shaped and addressed by the researcher. Based on empirical knowledge and accumulated experience, solutions to the problem are proposed in the suggestion phase. The suggestions are being pushed forward to the development process when an artefact is created according to the theory. The developed artefact is evaluated according to the suggestions proposed and all findings are cycled back to the problem's awareness and suggestion, to re-develop and re-evaluate the artefact. The process terminates with the conclusion and the knowledge is built through the two flows: Circumscription and Operation and Goal Knowledge (Kanellis & Papadopoulos, 2009).

3.2 STRATEGY IMPLEMENTATION

According to the design science research paradigm theorized previously, the methodology of the current research adopts the five phases of the framework proposed by Kanellis & Papadopoulos (2009) and adapts them to the main objectives: proposing, implementing and evaluating of a new client-server architecture for complex GIS data integration on a common, student-specific web platform (Figure 4).

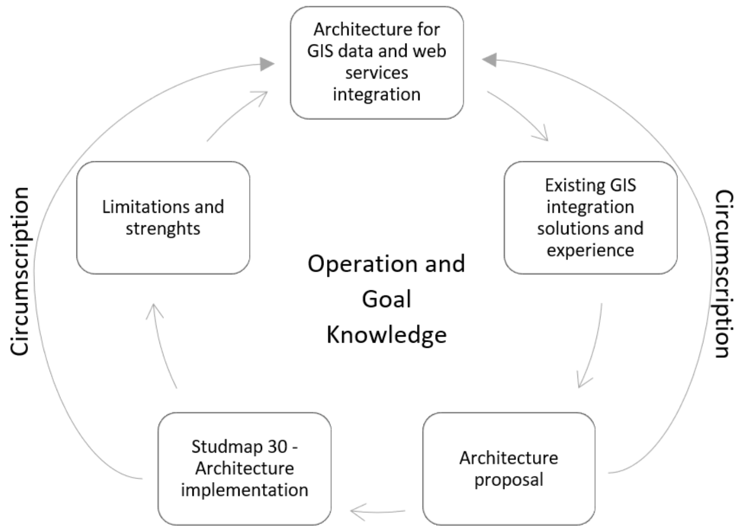


Figure 4. Design-science research framework implementation

As Figure 4 implies, each phase of the design-science research framework reflects one implementation step:

1. The awareness of the problem phase is presented at the beginning of the paper, by stating the two main objectives of the research: the proposal and implementation of a client-server architecture for complex GIS data and web services integration.

2. The suggestion phase reflects in the solutions proposed by the existing GIS integration solutions and the empirical experience gained through the operation and goal knowledge discovery.

3. The development phase is the construction of the artefact based on the theories condensed by the suggestion phase. In the current research, the artefact is represented by the proposal and design of a client-server architecture to serve for the integration of the motivated data and services in a common webGIS platform.

4. The evaluation consists of the practical implementation of the proposed architecture and validation of its functionality throughout the student dedicated platform. Studmap 3.0. A study case emerges at this point to test the theoretical concepts attained and the feasibility of the conceptual architecture proposed previously. The outcome of this phase is feed back to the

previous one and hence, the conceptual architecture is reshaped accordingly. The process flows back to the first phase and iterates through phases 2, 3 and 4 as experience is accumulated and new theories emerge.

5. The conclusion is drawn from the evaluation of the created artefact. Once the implemented architecture is adjusted to a final form according to the knowledge gained through the partial and complete cycles. The process iterates itself according to the feedback once again and it only terminates when it reaches the approval of the end-user. As a measure for the ultimate approval, a customized usability evaluation is designed.

4. PROPOSAL

This chapter describes the development of an artefact, namely a client-server architecture, according to the solutions reviewed in the recent literature findings. The proposed architecture is also validated at this stage by a real case application, hence by the implementation of Studmap 3.0 web platform.

4.1 ASSUMPTIONS

4.1.1 Software decision

Among the open and closed source software options available, ArcGIS Server was chosen as it comes with powerful geoprocessing functions appropriate for the needs and challenges of this project. Enhanced functionality is given to the system once the ArcGIS Server Site is federated with the Portal for ArcGIS and is configured as a hosted server. In this way, the system allows the publication of cached maps, feature and scene layers as hosted services on the portal (ESRI, 2018k). This configuration was chosen as it provides extra functionality to the system, namely: adding of zipped shapefiles, .csv or .gpx files to the map, feature and raster analysis and adding of geocoded data from .csv files or tables. Therefore, the software choice for the portal interface component is the Portal for ArcGIS, which is connected to the GIS Server and the ArcGIS registered Data Stores through a federation configuration (ESRI, 2018g).

The PostgreSQL open source database management system (DMBS) was chosen to function together with the ArcGIS registered data stores. This software was chosen for the storage and query of the locally stored geographical data because it has extended spatial functionality compared to standard SQL DBMS and because of its ease of administration. The support of spatial objects is supported by the PostGIS extensions which enable the GIS functionality according to the needs of the proposed platform.

For the web applications configuration, WAB SDK (ESRI, 2014b) was chosen as it offers an intuitive way of creating interactive mapping applications on top of the ArcGIS server without requiring enhanced programming skills. Another reason for this choice is that the JavaScript API standing at the base of this application can integrate 2D and 3D functionality.

4.1.2 Third party services

Among the variety of existent types of web-based services, the aimed services to fit the purpose of the research and the compatibility with the software choice, are OGC compliant web map services (WMS), web feature services (WFS) and web map tiling services (WMTS). All these web-based services are provided by third party servers or clouds, reducing the need to store the data locally and taking the workload off the GIS server to finally give fast responses to the users' requests.

The communication between compliant WMS, WFS and WMTS servers and the Portal for ArcGIS is done via the HTTP or HTTPS protocols, depending on each provider.

The administration of the web services' requests is done via the REST API and is handled by two web applications, the ArcGIS Server Administrator Directory or the ArcGIS Server Manager (ESRI, 2018b).

4.1.3 Architecture decision

The most fitted client-server architecture for the purpose of this research is multilayered, respectively the three-tier architecture consisting of the presentation, middleware and database tiers, each working as an individual component and residing on a different machine. In this way, the workload is divided, and better overall functionality of the platform is given.

To go along with the software choice, the most feasible approach for the publishing of the complex 3D layers is via the 3D indexed scene layers (I3S). A smart approach of publishing complex 2D layers is via the feature layers. These types of layers are stored on the web portal as hosted services and they are managed by the relational and tile cache data stores configured with the federated GIS Server. This structure allows the server to host thousands of scene services and all services published directly on the portal are hosted services. However, all hosted layers are only copied layers to the portal and cannot be managed by the user in real time. To allow this functionality, a registered user-managed database can work in parallel with the ArcGIS managed. However, this only allows the management of limited types of 3D layers, while offering a good functionality of complex 2D layers or registered features.

For secure communication between the components of this architecture, all communications are restricted to HTTPS-only. Hence, the port used for the communication for the portal is 7443 and for the server 6443, each communication being handled by a Web Adaptor managing requests via the 443 port.

4.2 ARCHITECTURE

The artefact created within the proposed methodology of the research is represented by a client-server architecture (Figure 5). The architecture is designed to respond to the need of finding the optimal system to integrate and handle different datasets and web-services coming from diverse sources to satisfy the needs of the targeted user groups, namely the needs of local students.

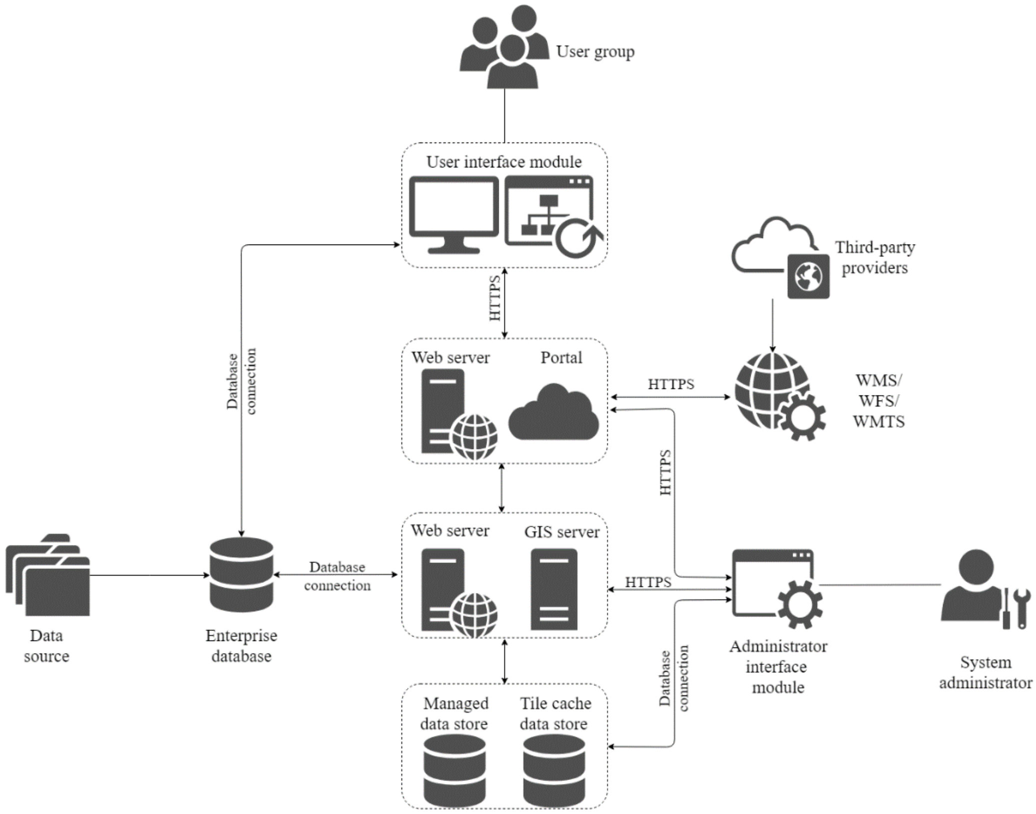


Figure 5 Conceptual architecture for the integration of geodata on a web-GIS platform – general diagram

At a basic level, the schema in Figure 5 is conceived according to the three-tiered conceptual Internet GIS architecture, consisting of the following levels:

- The presentation tier represented by the web browsers which allow the user groups and administrators to interact with the GIS server and the portal;
- The application or middleware tier represented by the web servers and the GIS server that is holding the logic of the system;
- The database tier represented by the Relational Data Store, where the data is stored and managed according to three different storage systems: the enterprise database, the ArcGIS managed data store and the ArcGIS tile cache data store.

The presentation layer is the one to receive the input from the client and display the output according to the request. The client is represented by the web browsers accessed by either administrators or targeted user groups. The GIS server administrator has access to the entire system, either by accessing the GIS Server or Portal, all accesses being done via the corresponding HTTPS uniform resource locators (URLs), or by a direct connection to the database tier. Depending on his role, each user group is given different privileges by the administrator. Every member of the user group can also have different roles: publisher, user or viewer, depending on the privileges granted by the administrator of the system. A publisher can directly publish services on the portal or edit the production database and synchronize the edits with the GIS server and hence, with the portal. Other users, with more limited privileges, are only allowed to access or view the items via the web applications published on the portal.

Each server presented in the architecture (Figure 5) is dedicated to a process. Each web server serves for hosting a web application. The GIS server is in charge of the GIS functionality of the system, handling the geospatial data from the Data Store and the web services. The portal is connected to the hosting server and hence, all items are automatically shared between the GIS server and the portal, except the web services which are only hosted by the portal.

The database layer consists of two relational database management systems (RDBMS) and one non-relational (NoSQL DBMS), synchronizing their activity. Each of these systems is dedicated to the management of a certain type of data. While the relational databases hold the GIS function of handling 2D and basic 3D features, the tile cache the manages hosted scene layers which allow storage and manipulation of the complex 3D data. Moreover, only the enterprise database allows real-time updates and is fully managed by the system administrator. In this context, the ArcGIS-specific data stores are making a copy of the layers on the database and hence, all edits done by the publisher in his desktop GIS environment require republishing or overwriting of the services. However, once published, all hosted layers are automatically handled by ArcGIS without the implication of user-management.

The architecture is conceived to integrate a broad series of data formats and functionalities to fit the needs of local students. The data varies from web-services such as WMS, WFS and WMTS services, to locally stored 2D and 3D data, user-specific temporary uploads or cloud-stored base maps. The web-based services are all OGC compliant and are granted by government-owned servers. Once connected to the portal interface, they are stored as hosted services. The locally stored 2D and 3D data comes in various formats, namely .shp, .tif and .las and is first stored in a development database, which, once ready for production, is cloned and connected to the GIS Server's relational data store. Throughout the user interface module, the user groups can have access to different web map applications which enable them to temporary upload diverse products such as .shp or .gpx files. Users also dispose of a collection of satellite imagery base maps hosted on the portal as map services.

4.3 CASE STUDY AND APPLICATIONS

Even though this conceptual architecture appears to easily integrate all components necessary to the portal, the real implementation is expected to be followed by diverse technical and non-technical difficulties. Taking into consideration that the integration of 2D and 3D data is still at the beginning of its era, a complex map mashup to satisfy both the proposed approach and the available tools on the market would inevitably impact the implemented schema. Validation of the conceptual model is required and followed by a final decision on the extents of its implementation.

This section is dedicated to the evaluation of the proposed client-server architecture through a case study implementation. First, an overview of the implemented portal is given. The following sections refer to the focus area of the study and the data of interest to the students of the WWU to be included on the portal. The implemented architecture is then discussed and followed by the description of the access to the portal, namely the user roles and privileges set for the platform.

4.3.1 Studmap 3.0

Studmap 3.0 represents the actual webGIS platform dedicated for students, that encompasses geographical data and web services of regional interest. This platform comes as a replacement for the old Studmap 1.4 portal, providing students with both the functionality that the older version had as well as enhanced features dedicated for both 2D and 3D data. The current version runs on a virtual machine belonging to WWU University and allows the download and temporary upload of spatial data for educational purposes. Its role is to guarantee the efficient use of the University's available software and personnel to avoid duplicated work and server maintenance difficulties.

4.3.2 Area of interest

The area of interest of the project is represented by the North Rhine-Westphalia state, located in the western hemisphere of Germany (Figure 6). Therefore, the selected data for the students of WWU university focuses on regional map services and project deliverables from this state. The purpose is to provide the main users of the proposed platform with datasets of educational interest.

Figure 6. Area of interest.

4.3.3 Data of interest

The data of interest (Table 2) for the implementation of Studmap 3.0 comes from three main sources: the Studmap 1.4 Portal, the newly generated data from the students' UAS2018 projects and the third-party services (OpenNRW, 2017) (IVVgeo, 2018). The data comes in four different coordinate systems: 25832 (ETRS 1989 UTM Zone 32N), 32632 (WGS 1984 UTM Zone 32N), 4326 (GCS WGS 1984) and 3857 (WGS 1984 Web Mercator Auxiliary Sphere). While all items were stored with their original reference system, all projections were handled on-the-fly, while using ArcGIS Pro for the publication of the web services. Moreover, there are six different format types: .shp, .tif, .slpk, WMTS, WFS and WMS.

No.	Source	Reference	Name	Format	EPSG
1	Studmap 14	studmap_prod.sde	Uncut areas NRW Studmap 14	.shp	25832
2	UAS2018	studmap_prod.sde	Centerline UAS2018	.shp	32632
3	UAS2018	studmap_prod.sde	Flight path UAS2018	.shp	32632
4	UAS2018	studmap_prod.sde	Flight path points UAS2018	.shp	32632
5	UAS2018	studmap_prod.sde	Land cover CORINE dissolve UAS2018	.tif	32632
6	UAS2018	studmap_prod.sde	Land cover dissolve UAS2018	.tif	32632
7	UAS2018	studmap_prod.sde	Land cover UAS2018	.tif	32632
8	UAS2018	studmap_prod.sde	DEM UAS 2018	.tif	32632
9	UAS2018	studmap_prod.sde	Elevation UAS2018	.tif	32632
10	UAS2018	studmap_prod.sde	LiDAR stations UAS2018	.shp	32632
11	UAS2018	studmap_prod.sde	Sensebox Stations UAS2018	.shp	32632
12	UAS2018	studmap_prod.sde	Air Quality UAS2018	.shp	4326
13	UAS2018	studmap_prod.sde	Study area UAS2018	.shp	32632
14	UAS2018	pc.slpk	Point cloud UAS2018	.slpk	32632
15	UAS2018	http://ivv6.maps.arcgis.com	NDVI UAS2018	WMTS	32632
16	third-party services	http://ivv6.maps.arcgis.com	Image composition UAS2018	WMTS	3857
17	third-party services	http://ivv6.maps.arcgis.com	Orthophoto Multispectral UAS2018	WMTS	3857
18	third-party services	http://ivv6.maps.arcgis.com	Orthophoto RGB UAS2018	WMTS	3857
19	third-party services	http://ivv6.maps.arcgis.com	Aspect UAS2018	WMTS	3857
20	third-party services	http://ivv6.maps.arcgis.com	Slope UAS2018	WMTS	3857
21	third-party services	http://ivv6.maps.arcgis.com	Hillshade UAS2018	WMTS	3857
22	third-party services	https://open.nrw	Official German basemap of NRW 1:5000	WMS	3857
23	third-party services	https://open.nrw	Digital Orthophotos NRW 10cm (Metadata, RGB, CIR, NIR)	WMS	3857
24	third-party services	https://open.nrw	Landscape Information Collection of NRW	WMS	3857
25	third-party services	https://open.nrw	Regional plan of NRW	WMS	3857
26	third-party services	https://open.nrw	Topographical basemap of NRW 1:5000	WMS	3857
27	third-party services	https://open.nrw	Topographical map of NRW 1:25000	WMS	3857
28	third-party services	https://open.nrw	DTM Relief of NRW	WMS	3857
29	third-party services	https://open.nrw	DTM Slope of NRW	WMS	3857
30	third-party services	https://open.nrw	DTM Isolines of NRW	WMS	3857
31	third-party services	https://open.nrw	Administrative boundaries of NRW - District municipalities &…	WFS	3857
32	third-party services	https://open.nrw	Administrative boundaries of NRW - Districts & country-level cities	WFS	3857

33	third-party services	https://open.nrw	Administrative boundaries of NRW - Administrative districts	WFS	3857
34	third-party services	https://open.nrw	Administrative boundaries of NRW - Border	WFS	3857

Table 2 Data of interest

4.3.3.1 Studmap 1.4 data

Studmap 1.4 Portal is the former and currently unfunctional GIS platform of the University of Münster. The portal used to encompass data of regional interest to the students, such as web-based map services and geographic data mostly in the common .tif and .shp formats. The structure of the geoportal is described by the Studmap 1.4's wiki page (IVVGeo-Team, 2018), which offers details related to the functionalities, external WMS services, post-installed packages, server configuration and web client communication.

Some of the main features of the Studmap 1.4 portal was to allow the upload of .gpx and .kml file formats and the download of the .tif, .shp and .kml file formats. Besides these, it included a tool to restore the application state and a search button. For the user interface, the map included a measuring tool, the context menu and a viewport layout, altogether with a built-in list of external web map services. Among the classic functions, it included the zoom slider, a graticule tool, a maximum extent button, the layer list, and the select feature tool. Prinz (2014) gives a visual insight into the Studmap 1.4 portal, through a series of screenshots and explanations on the workflow of the GPS (global positioning system) data transfer to a GIS.

The data and functionalities of the old Studmap 1.4 platform were investigated in order to offer a selection of relevant data and tools to be included on the newly implemented portal. As any backup files to restore the old database into a new one was lacking, no data migration from one system to another was possible. Hence, all selected data were first organized in a new geodatabase consisting of six feature datasets: biotope cadaster, fauna-flora-habitat, legally protected biotope, nature conservation area, composite surfaces, borders, and activity areas. Each dataset was analyzed for its corresponding online source, using the available list of web servers and their updated versions. One feature that had no online correspondent was found and stored in the initial development geodatabase: the uncut areas of North Rhine-Westphalia, representing the valuable ecological areas uncut by any form of infrastructure.

4.3.3.2 New 3D data of TLS and/or UAV

The new data is represented by the recent project deliverables of the students of the WWU university during the 2018 Unmanned Aerial Systems (UAS) class. The class objective is to process and analyze data captured via UAVs (Unmanned Aerial Vehicles) or TLS (Terrestrial Laser Scanning) techniques which always comes in 3D. In this time these data are produced in large amounts every year and lack an efficient way of storage, sharing, and presentation. The data consists of mostly raster and vector datasets, in three main formats .shp, .tif and the newly included file format for the LIDAR data captured via TLS, .las. Moreover, the new data that was already published online by the students of the university comes in the format of tiled map services.

The most challenging dataset included in the project consists of a small-size point cloud file in the standard .las format. The file properties and statistics of the file are presented in Figure 7. As observed in the figure, the file consists of approximately 33.5 million points, with a size of 667 MB. For easier processing, the point cloud was converted in a Scene Layer Package (.slpk) using the Create Scene Layer Package Geoprocessing Tool, resulting in a light file of only 61,4 MB. The pc_uas2018.slpk file was locally stored on the same machine that holds the databases as this type of file currently doesn't allow storage in a database.

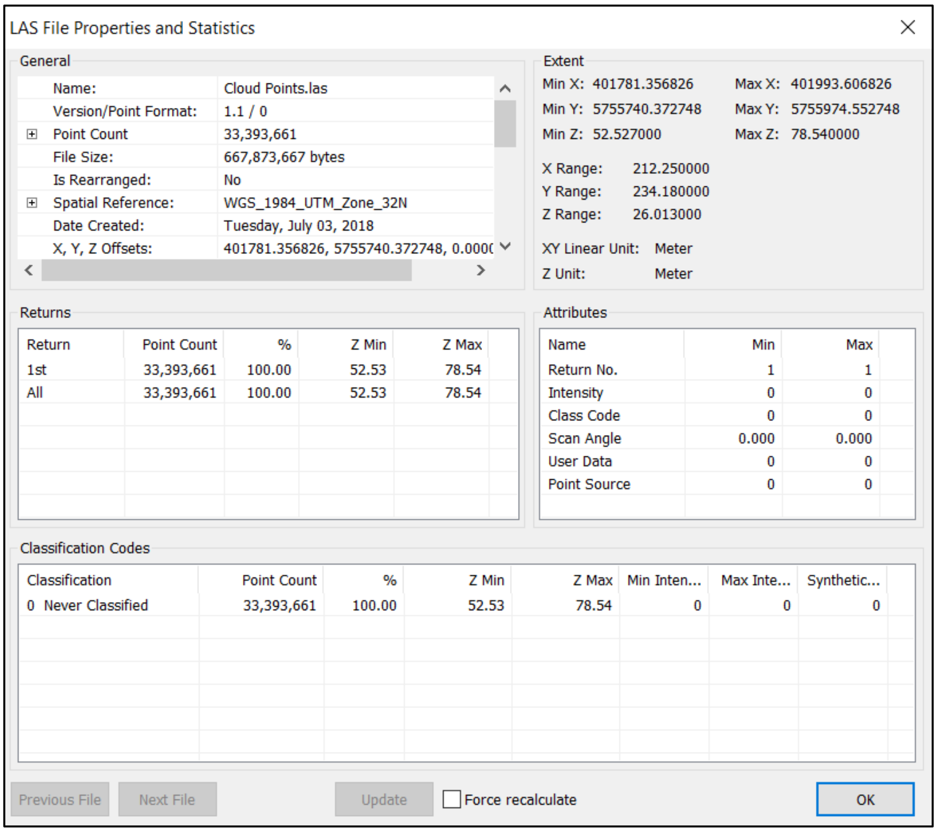


Figure 7 LAS File properties and statistics

4.3.3.3 Third party services

The data coming from the third-party servers is represented by the web services of regional interest to the students of the WWU University of Muenster, to which the portal is dedicated. Hence, the web services selected for this study come from two sources: the official GIS servers of the state of North Rhine-Westphalia (OpenNRW, 2017) and the cloud-based platform of the Institute for Geoinformatics of the University of Münster (IVVgeo, 2018). The services consist of three relevant types, WMS, WFS and WMTS and are selected to satisfy the needs of the students according to the availability offered by the local data providers of North Rhine-Westphalia, to the list of web services available in the wiki page of Studmap 1.4 (IVVGeo-Team, 2018) and to the recently stored projects on the cloud-based platform of the Institute of Geoinformatics.

4.3.4 Architecture Implementation

4.3.4.1 General aspects

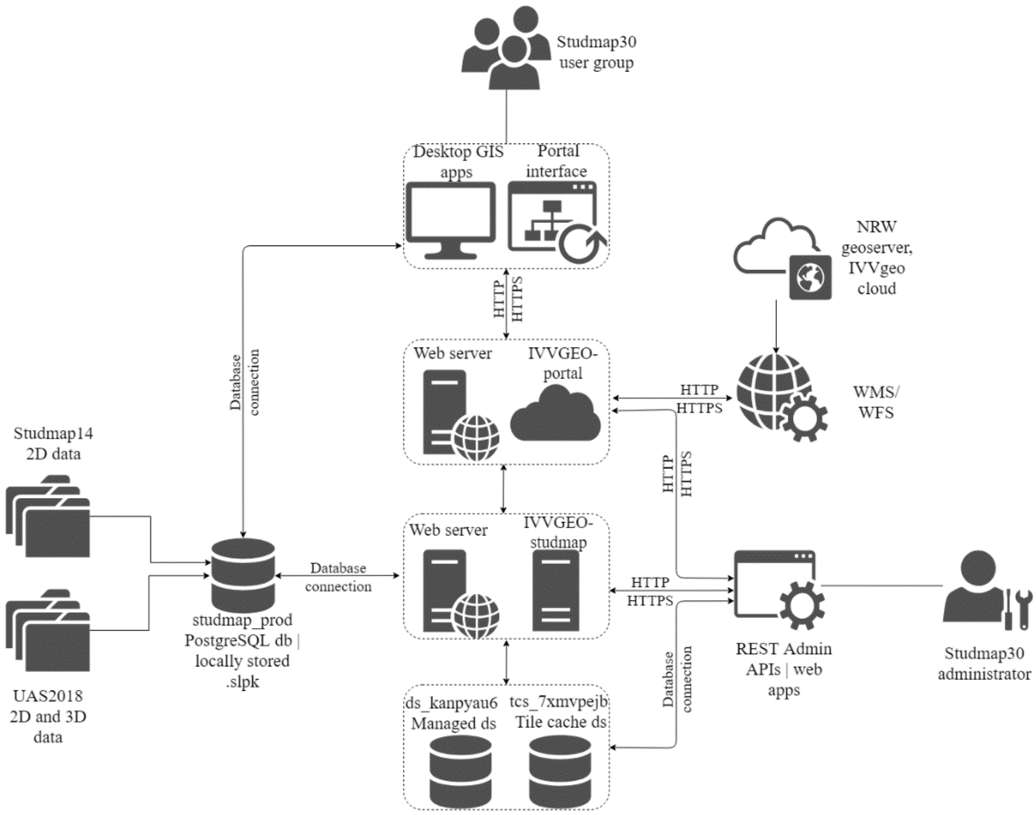


Figure 8 General diagram of the architecture implementation for Studmap 3.0

As the schema in Figure 8 reflects, the data is generated from three different sources: the old portal, Studmap 1.4, the recent projects that generated new 2D and 3D data and the third-party servers. The data coming from the old portal and the recent projects are stored in a common geospatial database which is further cloned for production. One type of data files is, however, stored locally in a converted format, SLPK as this type of data structure doesn't allow storage in a database. The data coming from the third-party servers is represented by the web map and feature services of the state of North Rhine-Westphalia and is hosted by the state's geodatabase servers.

The emphasis of this structure stands on the most challenging components to be integrated into the new platform: the different web-based services and the big data represented by the complex 3D point clouds. The creation of the web-based services that were set on the old platform, Studmap 1.4, includes primarily map services (WMS), feature services (WFS) and map tile services (WMTS) and APIs for the use of the third-party applications. What is more, an approach will be developed to migrate the old datasets into the new system and to re-develop the map services and APIs for the current and future third-party applications to integrate with the underlying infrastructure. On the other hand, handling big data in the geodatabase refers to finding the best approach to integrate heavy point cloud data that comes usually in the LAS format.

The components of the proposed architecture are distributed across different machines to increase computing power, as per Table 3:

System component	Machine reference
Web server with web adaptor	IVVGEO-STUDMAP.uni-muenster.de
GIS Sever (ArcGIS Server)	IVVGEO-STUDMAP.uni-muenster.de
Data Store (SQL and NoSQL)	IVVGEO-STUDMAP.uni-muenster.de
Web server with web adaptor	ivvgeo-portal.uni-muenster.de
Portal for ArcGIS	ivvgeo-portal.uni-muenster.de

Table 3 Components' distribution

The implemented web portal has a hybrid system architecture at all three component levels. The presentation tier consists of desktop GIS applications (ArcGIS Map and ArcGIS Pro) and web applications (Portal for ArcGIS, ArcGIS Server Manager) or REST Admin APIs (ArcGIS Portal Directory, Portal Administrator Directory, ArcGIS Server Administrator Directory) that allow the users and administrators to interact with the IVVGEO portal and server. As for the application layer, it consists of the two web servers holding the logic for both the portal and the server and the IVVGEO Server itself. The database tier consists of two relational data stores (a PostgreSQL enterprise geodatabase and the Managed ArcGIS Data Store) and one non-relational data store (the Tile Cache ArcGIS Data Store).

4.3.4.2 The presentation tier

The presentation layer represents all the interfaces that the users can access to interact with the IVVGEO portal and GIS server. The access to the different interfaces can be done according to the users' roles. Hence, regular roles, such as publishers, viewers or users normally operate with the desktop GIS applications and web applications, which tend to be more user-friendly. The administrators usually interact with the system using the REST Admin APIs. Since this study is intended for the development of a webGIS platform to serve the students for their necessities, the discussion is further focused around the main interface of the system, namely the Studmap 3.0 Portal.

The Studmap 3.0 Portal, also referred as IVVGEO, is currently accessible via the REST Admin APIs for administrators' access and the Portal for ArcGIS web application for all user roles. The web application can be accessed using the web-browser via the following URL: http://ivvgeo-portal.geo.uni-muenster.de/portal (site last accessed on February 7, 2019). Up to now, the portal components are organized in different ways: by folders, categories, item types, date modified, date created, shared and status. Items falling into the same category were given a common tag using the name of that category.

The content of the Studmap 3.0 Portal is divided between web layers organized in web maps, web scenes and web applications. At this time, there are 46 web layers hosted on the portal divided in seven types of layers and hosted on three main sources as shown in Table 4:

Type	Tile	Map image	Feature	Imagery	Scene	WMS	WFS
Nr.	7	12	12	1	1	9	4
Source	IVVGEO cloud	IVVGEO MapServer	IVVGEO FeatureServer	IVVGEO ImageServer	IVVGEO SceneServer	NRW geoserver	NRW geoserver

Table 4 Web layers types and distribution

The layers are grouped in two web maps, NRW 2Dmap and UAS 2Dmap and two web scenes, NRW 3Dmap and UAS 3Dmap according to their content and relevance. As seen in Figure 9 one layer was not added to any of the enumerated web maps and scenes, namely the “Uncut Areas of NRW Studmap 1.4” as it contains more features than the map extent is able to draw (ESRI, 2018n).

Figure 9 Feature service error when exceeding feature limit on a web map (left) or web scene (right)

A GIS web application was created for each map using WAB: NRW 2Dapp, NRW 3Dapp, UAS 2Dapp and UAS 3Dapp. All applications’ interfaces are displayed in Appendix A. Each application was configured with personalized widgets (Table 5) according to its purpose and the limitations of the API specific for each type of application, 2D or 3D. Due to the limitations of the application building SDK, capabilities like adding data, editing data, select, query are only available on the 2D applications. Moreover, according to an incompatibility of the developer’s edition of the application builder with the WFS services required, the applications were finally built using the built-in tool of the Portal for ArcGIS, which doesn’t allow customizations for the applications. For a better visualization of the functionality of the main widgets of the applications, they are presented in Appendix B.

	UAS 2Dapp	Studmap 3.0 2Dapp	UAS 3Dapp	Studmap 3.0 3Dapp
Attribute table	x	x		
Coordinate	x	x	x	x
Full screen	x	x	x	x
Scalebar	x	x		
Zoom slider	x	x	x	x
Search	x	x	x	x
Home	x	x	x	x
My location	x	x	x	x
Basemap gallery	x	x	x	x
Layer list	x	x	x	x
Legend	x	x	x	x
Add Data	x	x		
Edit	x			
Query	x			

Select	x			
Measurement	x	x	x	x
Share	x	x	x	x
Compass			x	x
Navigate			x	x

Table 5 Widgets configured for each web application of the Studmap 3.0 portal

The basemaps used for the web interface of each map and, hence, application consist of the standard tiled map services granted by ESRI. According to Kong, Zhang, & Stonebraker (2015), users tend to favor a familiar, neat and easy to interpret map as a base for their applications. Therefore, the basic Grey Scale basemap offered by ESRI was chosen for the applications created to avoid the user being distracted by an unnecessary load of details. For the users that have the right permissions, one can opt for any of the available basemaps offered by ESRI (2018a) or from the list of dedicated WMS services published to the portal.

To grant the ease of manipulation on the IVVGEO Portal for the local students, the Portal items were organized in a more comprehensive way using an ArcGIS Enterprise Site, Studmap 3.0 which can be accessed using: http://ivvgeo-portal.geo.uni-muenster.de/portal/apps/sites/#/studmap30 (site last accessed on February 7, 2019). The site is simple and consists of a short description of the portal, the contact information and three main sections: Find data, Applications and Data categories. The Find Data section offers an enhanced functionality to the portal as users can easily navigate through the data available on the portal either by text or by location. This section is the first one to appear on the Site, together with the description and name of the portal (Figure 10). The Applications section gives access to the 4 main applications of the portal (Figure 11). The Data Categories section is designed to allow students to find the available web layers by sorted categories and is followed by the contact information (Figure 12). This section selects the layers by tag query and hence, each tag that fits to a certain category will be selected for that query (Figure 13). The full extent of Studmap 3.0 Site is presented in Appendix C.

Figure 10 Studmap 3.0 Portal interface - Find data section

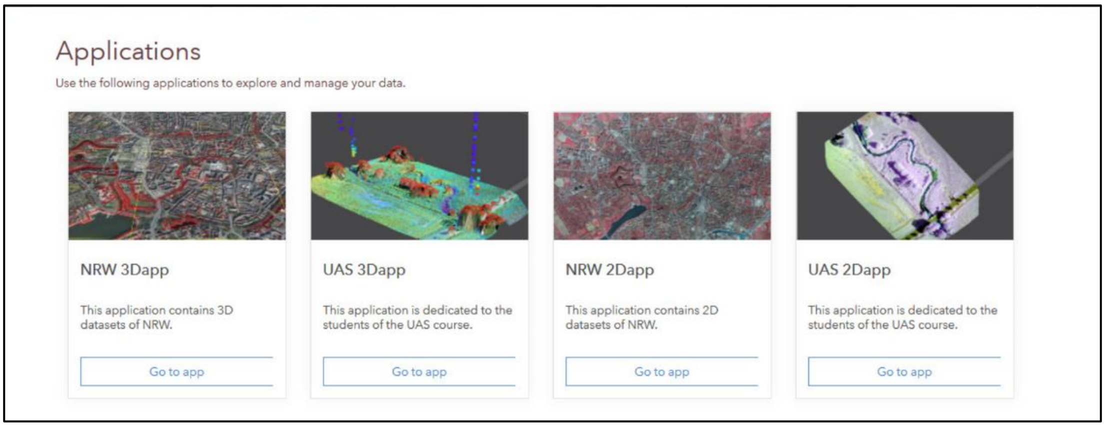


Figure 11 Studmap 3.0 Portal interface - Applications section

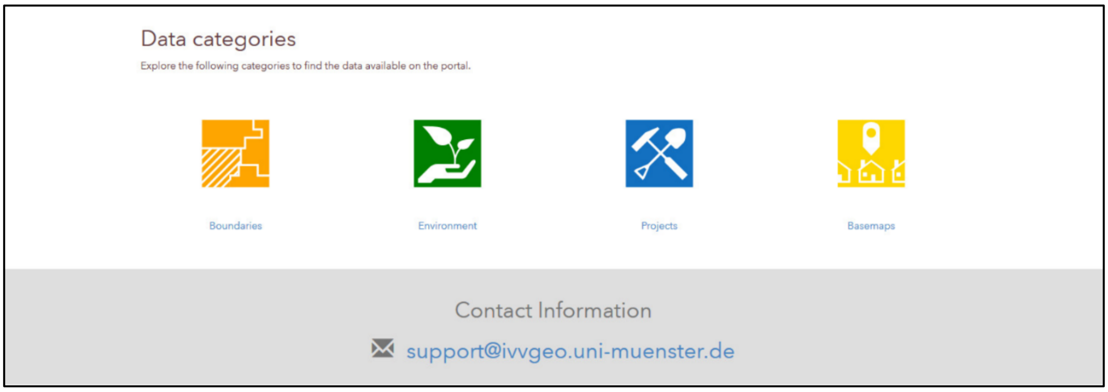


Figure 12 Studmap 3.0 Portal interface – Data categories section

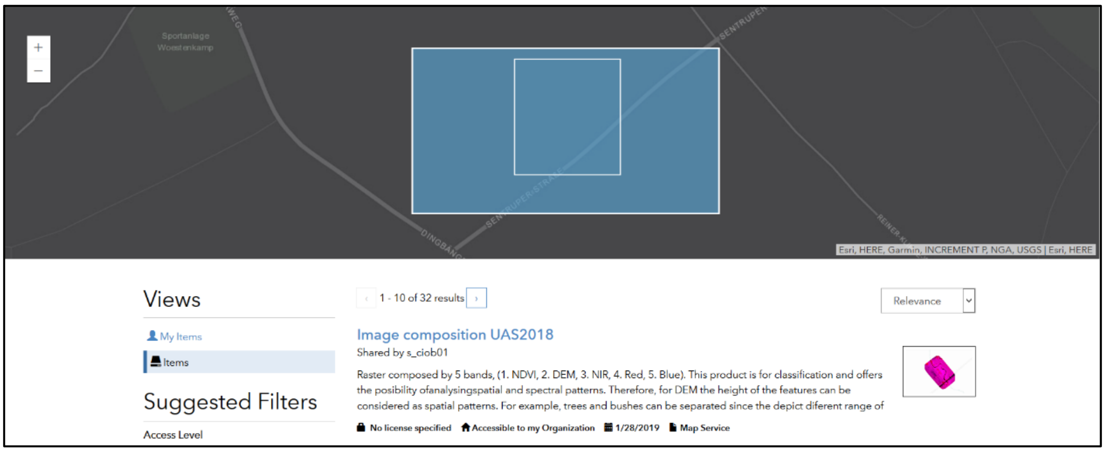


Figure 13 Studmap 3.0 Portal interface - Results by tag filter

Students can also benefit from accessing the items available in their portal account by using a desktop GIS application, ArcGIS Pro, by adding the portal connection via the Portal's URL: https://ivvgeo-portal.uni-muenster.de/portal (last accessed on February 7, 2019). Students with publishing rights are also allowed to publish items on the Studmap 3.0 Portal using the ArcGIS Pro application or the portal's original interface. Using either the ArcGIS Pro or ArcGIS Map applications, users are also allowed to access the services on the IVVGEO Server by creating an ArcGIS Server connection between their local machines and the remote one holding the GIS server application (Figure 14).

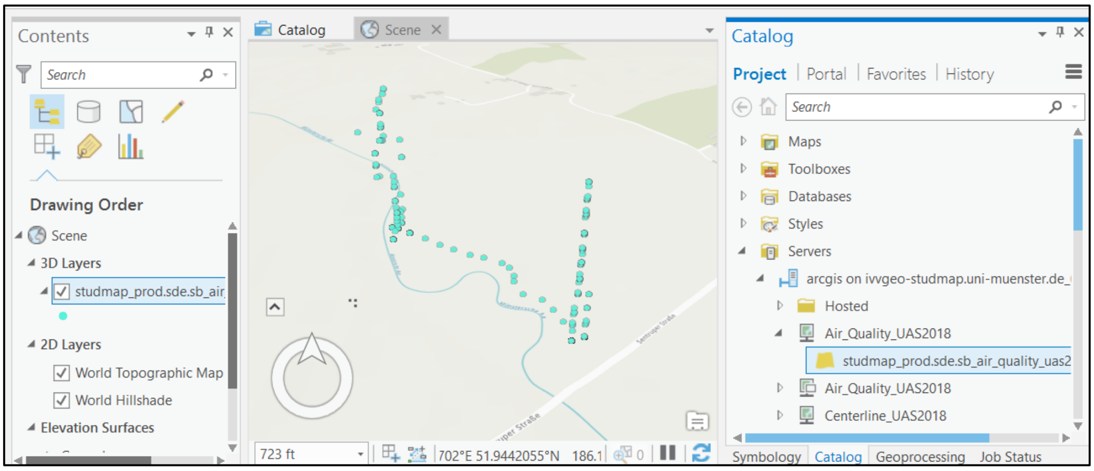


Figure 14 Accessing the geospatial services from IVVGEO Server using ArcGIS Pro

4.3.4.3 The application tier

The application layer is entitled with the GIS functionality of the system enabled by of two web servers installed on the two machines holding the portal and the GIS server and the IVVGEO Server itself. IVVGEO is the GIS server that holds and distributes the geospatial services of the implemented architecture. As specified in the previous section, the GIS server can be managed by either the ArcGIS Server Administrator Directory REST Admin API or by the ArcGIS Server Manager web application.

All web layers published on the Studmap 3.0 portal are hosted on the deployed instance of IVVGEO Server as geospatial web services. There are currently 42 web services lying on the GIS server. They are organized in three main folders: Root, Hosted, System and Utilities. Only the first two folders host GIS services, while the latter are dedicated for geoprocessing and come together with the ArcGIS Server. Depending on the service's type, each GIS service is managed by a different server type as seen in Table 6. The published services can be accessed via the ArcGIS Pro or Map desktop GIS applications, by establishing a connection to the server (Figure 14). However, the full control over the web services is only given by the ArcGIS Manager web application or by the REST endpoint of the GIS Server available at: https://ivvgeo-studmap.uni-muenster.de/server/admin/services (site last accessed on February 7, 2019). Both interfaces allow navigation through the published web services, resources and corresponding operations.

Nr.	Service name	Server type	Service type
1	Air Quality UAS2018	MapServer | FeatureServer	Map | Feature
2	Centerline UAS2018	MapServer | FeatureServer	Map | Feature
3	DEM UAS2018	MapServer	Map
4	Elevation UAS2018	ImageServer	Elevation
5	Flight path points UAS2018	MapServer | FeatureServer	Map | Feature
6	Flight path UAS2018	MapServer | FeatureServer	Map | Feature
7	Land cover CORINE dissolve UAS2018	MapServer | FeatureServer	Map | Feature
8	Land cover dissolve UAS2018	MapServer | FeatureServer	Map | Feature
9	Land cover UAS2018	MapServer | FeatureServer	Map | Feature
10	LiDAR stations UAS2018	MapServer | FeatureServer	Map | Feature
11	NDVI UAS2019	MapServer	Map

12	Sensebox stations UAS2018	MapServer | FeatureServer	Map | Feature
13	Study Area UAS2018	MapServer | FeatureServer	Map | Feature
14	Uncut Areas NRW	MapServer | FeatureServer	Map | Feature
15	Point cloud UAS2018	SceneServer	Scene (Hosted)

Table 6 Listed GIS web services on the IVVGEO Server

4.3.4.4 The database tier

At the database level, a hybrid model was chosen as the approach combines an open source database system, PostgreSQL with an ESRI proprietary software, the ArcGIS Data Store. The main components are the open-source enterprise database, the ArcGIS Managed database and the ArcGIS tile cache database. All three components are registered data sources for the published services of the Studmap 3.0 Portal, hence once the layers are published, the system points them to a source location according to their storage choice. The enterprise database and the ArcGIS managed one fall within the relational database management system, while the ArcGIS tile cache is a NoSQL type.

The main database function is to allow location search on the Studmap 3.0 Portal. Moreover, the relational data store types also allow information query on the feature web layers, which makes it possible for the configured 2D web applications to allow students to evaluate the available geospatial data using an attribute table or diverse widgets edit, select and query.

A. The enterprise database

The enterprise database is a relational database maintained by the open source PostgreSQL RDBMS. Its practical implementation is represented by the “studmap_prod” database, which is now hosted on the IVVGEO-STUDMAP.uni-muenster.de machine and is fully compatible with the ArcGIS specific spatial database, the geodatabase. As this is a user-managed data store type, the user has full control over it, while also being in charge with continuously managing it.

The spatial data lying on the “studmap_prod” database currently consists of 14 data files which point to registered services published on the Studmap 3.0 Portal. Hence, it is important to mention that the data that has been published from this geodatabase is referenced and not copied, as it is the case with the other two databases.

The current version, “studmap_prod” is the production database generated from the firstly implemented version, “studmap_dev” development geodatabase. Before deploying it into production, the geodatabase was populated and organized locally, using ArcGIS Pro. Once ready for production, “studmap_dev” was cloned and set as an enterprise geodatabase using the Create Enterprise Geodatabase geoprocessing tool available in ArcGIS Pro (Figure 15). In the end, the newly created geodatabase was registered with the IVVGEO GIS server using a database connection (Figure 16).

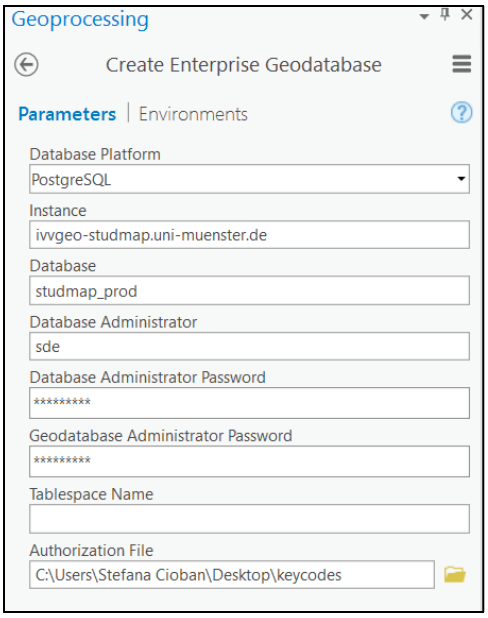


Figure 15 Creating the studmap_prod enterprise geodatabase

The "studmap_prod" enterprise database can be accessed either via the PostgreSQL application, using a connection between the local server and the remote one or via a desktop GIS Application using a database connection (Figure 16). The connection between the two machines is allowed according to the configurations of user roles explained in Section 4.3.5. The connection can be checked using the command: psql -h ivvgeo-studmap.uni-muenster.de -U studmap_viewer studmap_prod.

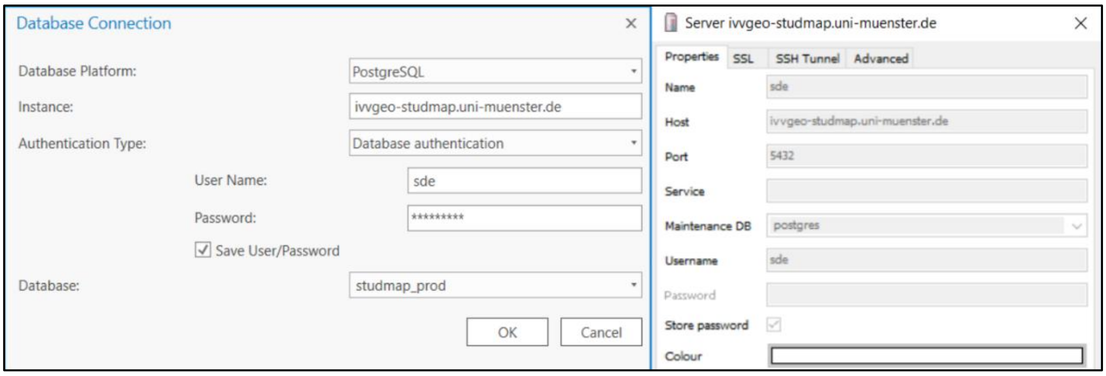


Figure 16 Create a connection to the production database using ArcGIS Pro (left) and PostgreSQL (right)

B. The ArcGIS Managed database

The ArcGIS managed data store, "ds_kanpyau6" is a relational database created using the ArcGIS Data Store configuration wizard (Figure 17). The software automatically created both the relational database, and the tile cache and their users.

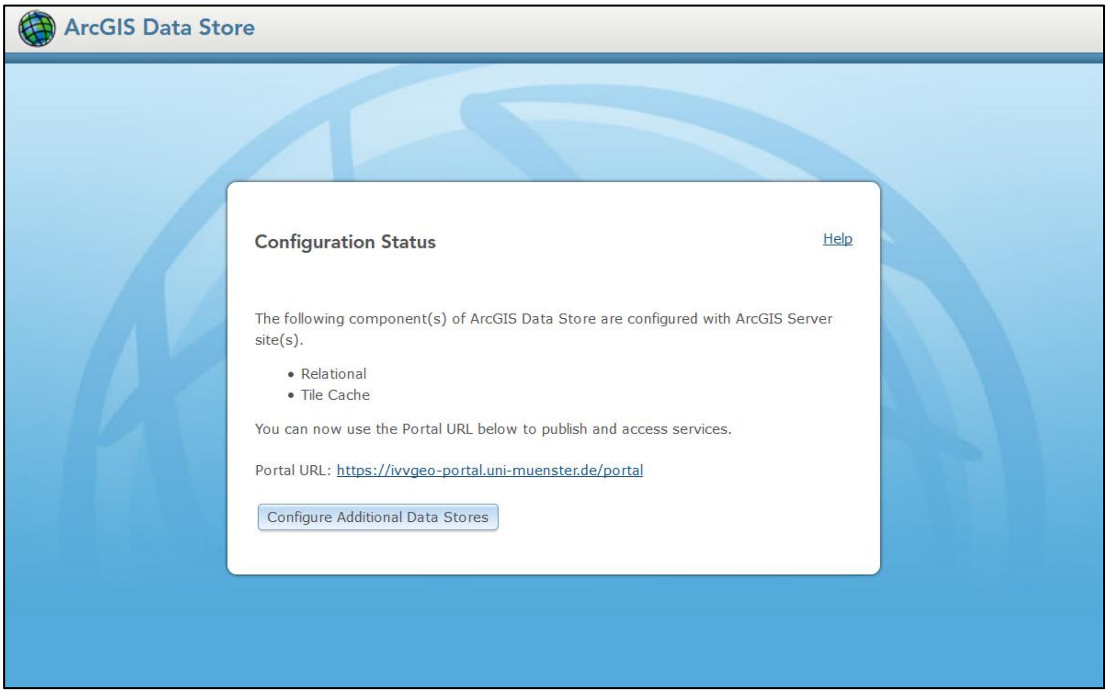


Figure 17 The ArcGIS Data Store configuration wizard - installed databases

This type of data store is intended for the storage and management of the hosted feature services managed by the IVVGEO portal and server. Hence, once the layers are published, the data is only copied or overwritten on the data base.

Compared to the other two data stores installed in this architecture, the ArcGIS managed data store offers a medium level of control for the user. Only the data store administrator is allowed to access and configure this database and the access is provided only by the utility commands (ESRI, 2017a).

C. The ArcGIS Tile Cache database

As specified in the previous section, the ArcGIS tile cache data store, "tcs_7xmvpejb" and its user were created using the Data Store configuration software. This is a non-relational database that handles the hosted scene layers, intended for the complex 3D spatial data management of the system. Once again, this type of data is only copied or rewritten on the database and not pointing to an existing geodatabase as it is the case with the enterprise data store.

Similar to the ArcGIS relational database, the tile cache can only be managed using the utility command. Compared to the other two databases, the administrator has a rather weak control over the tile cache data store, as this type is intended to be managed by ArcGIS. For example, 10 out of the 29 utility commands currently available to manage the ArcGIS Data Stores are used with the relational data store only (ESRI, 2017a).

This difficulty of management and lack of documented support for the communication of the tile cache database with the GIS server have had serious implications in the configuration of the system. One main configuration needed was to set all service users for ArcGIS Data Store, Portal and Server to a common domain account, a solution that was predicted only after a series of experiments supervised by qualified personnel from the behalf of ESRI. The combination of solutions that eventually allowed the ArcGIS-specific services to communicate properly has led to a less secure configuration of the proposed system based on both HTTP and HTTPS protocols, together with a secure socket level certificate (SSL) allowance.

4.3.5 User roles and privileges

The authentication of the implemented client-server architecture was configured separately for the access to the IVVGEO Portal and Server and the database.

On the portal and GIS server side, the IVVGEO Portal is set to allow a limited number of 10 members with the possibility of extending this specification according to the needs of the University of Muenster. The user roles created up to this date are the following: three administrators of the portal, a publisher, a user and a viewer. Each is configured to have separate access to different groups and to have different publishing and access capabilities to the items on the portal, according to the default roles given by the Portal for ArcGIS (ESRI, 2018h). As the system is adapted to ESRI's hosting server model (ESRI, 2018g), the administrators of the IVVGEO Portal coincide with the administrators of the ArcGIS Server and hence, have complete control over the entire system. There are two groups existing by this date on the portal: the Studmap 3.0 group, intended for general access and the Studmap 3.0 site administrator group, intended for the administration of the site only.

On the database side, the "studmap_prod" relational database is set to allow access for four types of user roles: "sde" as superuser, "studmap_creator" as creator, "studmap_editor" as editor and "studmap_viewer" as viewer, each having a separate configuration of access and separate privileges to the tables and schemas of the database as per the functionality described in Table 7:

Functionality	**Access right**			
	superuser	creator	editor	viewer
Log in/out	x	x	x	x
Usage	x	x	x	x
Select	x	x	x	x
Insert	x	x	x	
Update	x	x	x	
Delete	x	x		
Create schema	x	x		
Override access	x			

Table 7 Functionality table for the enterprise database access

The communications between machine hosting the GIS Server and student's machines was allowed by adjusting the pg_hba.conf file on server machine to allow the students in the Muenster's university network to access the production database "studmap_prod". An IP-address in the Muenster University's network matches one of two patterns: 128.176.0.0/16 or 10.0.0.0/8 . Hence, the access to the "studmap_prod" database was granted to the same patterns in order to allow all students connected to the university's network to access it for all different types of users:

```
host    studmap_prod    studmap_viewer  128.176.0.0/16  md5
host    studmap_prod    studmap_viewer  10.0.0.0/8  md5
host    studmap_prod    studmap_editor  128.176.0.0/16  md5
host    studmap_prod    studmap_editor  10.0.0.0/8  md5
host    studmap_prod    studmap_creator  128.176.0.0/16  md5
host    studmap_prod    studmap_creator  10.0.0.0/8  md5
```

This step was processed in parallel with the creation of the three users: studmap_viewer, studmap_editor and studmap_creator. The studmap_creator user role was created using the Create Database User geoprocessing tool from ArcGIS Pro (Figure 18).

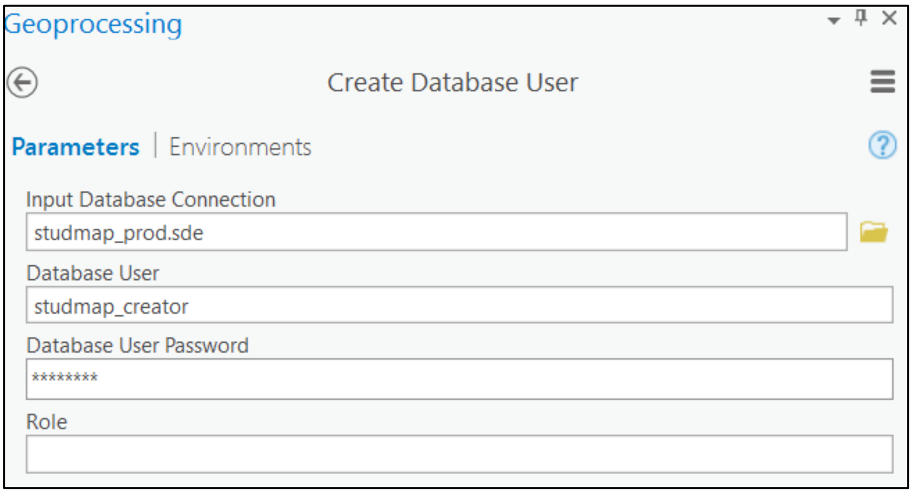


Figure 18 Creation of the studmap_creator user role using the Create Database User tool

For security measures, tha database access can only be granted via a user-password authentication. Hence, every time that a user tries to access the enterprise geodatabase, he has to create a database connection using one of the log-in credentials given according to his rights.

```
CREATE USER studmap_viewer WITH PASSWORD 'viewer1';
CREATE USER studmap_editor WITH PASSWORD 'editor1';
```

The other login roles for the enterprise geodatabase where created using PgAdmin. Both the viewer and the editor were given the USAGE and SELECT privileges on all created schemas. The editor was also given INSERT and UPDATE privileges on the tables from the schemas "sde" -the "sde" schema is owned by the "sde" superuser, which is the geodatabase administrator- and "studmap_creator" -the "studmap_creator" schema is owned any creator user role. For a deeper understanding of this process, refer to the commands listed below:

```
GRANT USAGE ON SCHEMA studmap_creator, public, sde  TO studmap_viewer;
GRANT USAGE ON SCHEMA studmap_creator, public, sde TO studmap_editor;
```

```
GRANT SELECT ON ALL TABLES IN SCHEMA studmap_creator, public, sde TO
studmap_viewer;
GRANT SELECT ON ALL TABLES IN SCHEMA studmap_creator, public, sde TO
studmap_editor;
GRANT UPDATE ON ALL TABLES IN SCHEMA studmap_creator, sde TO studmap_editor;
GRANT INSERT ON ALL TABLES IN SCHEMA studmap_creator, sde TO studmap_editor;
```

5. DISCUSSION

This chapter offers the final discussion on the benefits and limitations of the proposed and implemented client-server architecture. The comparison was done in terms of different criteria: data, system functionality, system usability and ease of implementation. The first three criteria were specified according to the trends identified by Veenendaal, Brovelli, & Li (2017) and focus on the technical objectives of this study: the implementation and evaluation of the proposed architecture in terms of complex data integration and functionality according to the students' needs. The latter focuses more on a personal approach to validate the overall implementation of the entire system.

As specified in Chapter 3, the measure for the termination of the design research process proposed for this study is the ultimate usability evaluation of the artefact, namely the implemented portal. This process consisted of two phases: a customized expert usability evaluation followed by a standardized user test. The first phase was an inspection of the interface of the portal followed by a customized questionnaire addressed to specialized people. The first 10 questions were designed according to the standardized SUS system (Sauro & Lewis, 2016) while the last four questions were open-ended and aiming at revealing the experts' opinion on the strengths, limitations and recommendations for the portal. The second phase consisted of a set of 11 tasks followed by the SUS questionnaire and it was addressed to twenty students.

The chapter finally addresses a section dedicated for future developments of the portal based on the conclusions and feedback drawn from this study.

5.1 DATA

The proposed webGIS architecture was evaluated for the data completeness using the implemented model of the Studmap 3.0 webGIS portal according to the three types of sources included in the implemented model: data coming from Studmap 1.4, new data and third-party services.

In terms of data migration from the Studmap 1.4 portal to the newly created portal, the lack of backup files from the old system made it impossible to migrate the schema from the old database to a new one. This has led to a new approach of organizing the data and finding the updated online corresponding sources, in the form of web-based services. One feature which had no online correspondent was locally stored as part of the created and registered enterprise geodatabase.

In terms of data coming from the new projects, the model has proven to be partly functional for the desired data types. While most formats are easily integrated with the system, the complex 3D point cloud data types were locally stored as the standard .slpk packages. This was due to the incompatibility between the data format allowed being stored in the database, namely the multipoint feature, and the required data format for publishing. Hence, such compromise may cause some difficulties in terms of storage and organization of data as the data of the implemented architecture is now stored in an enterprise geodatabase and a registered folder, both stored on the same machine.

In terms of data coming from the third-party services, out of the three web-based services proposed in the initial model, only two were able to satisfy the entire schema: WMS and WFS. The WMTS service type was proven to partially satisfy the system as only the ESRI specific layers were fully compatible with the required parameters for web services publishing as specified by the OGC standards.

The data were also evaluated according to its ease of access. At this time, the students can choose to access the portal items from both the Portal's interface or from the ArcGIS Desktop application. In this case, ArcGIS Pro was used for the publishing of the web services and for enabling the connections to the GIS Server and to the enterprise geodatabase. In this way, the end users benefit from two different options of accessing the data, depending on their familiarity with the products. The access to the tables of the enterprise database can only be done using a DBMS, such as PostgreSQL or using a desktop GIS software, such as ArcGIS Pro. Using a desktop GIS software to access the database tables comes as an asset to the system as the "studmap_prod" enterprise geodatabase is fully compatible with the ArcGIS specific geodatabase and hence, no advanced databases skills are required. For example, the student can interact with the database using basic operations such as drag and drop.

5.2 SYSTEM FUNCTIONALITY

The overall functionality of the implemented system is given by functions imposed by a set of non-functional requirements, such as performance, security and cost of equipment. The overall functionality of the implemented portal was ultimately measured using the usability evaluation described in the following section.

A. FUNCTIONAL REQUIREMENTS

The functional features were defined according to the eight criteria identified by Kong, Zhang, & Stonebraker (2015) and the desired capabilities of the Studmap 3.0 portal in the context of its implementation. The desired range of capabilities was specified at the beginning of this study: to allow students to explore, download, manage and upload data of regional interest in a 3D capable and smart webGIS environment. Therefore, the system was analyzed according to five main aspects, adapted from Kong, Zhang, & Stonebraker (2015) to the web applications created: basemap availability, application elements, map products, information query and location search. The first three refer to the mapping functionality, while the last refer to the database side.

Compared to the old portal version, not only does Studmap 3.0 support both 2D and 3D applications, but it also allows a wider range of tools as seen in Table 8:

Functional criteria	Tools	Studmap 1.4 2D	Studmap 3.0 2D	Studmap 3.0 3D
Basemap availability	Basemap gallery		x	x
Application elements	Scalebar	x	x	x

	Zoom slider	x	x	x
	Pan		x	x
	Home		x	x
	Full screen	x	x	x
	Layer list	x	x	x
	Legend		x	x
	Measurement	x	x	x
	Compass			x
	Navigate			x
	Add data	x[*]	x	
	Restore app state	x		
	Graticule	x		
Map products	Save	x	x	x
	Share	x	x	x
	Download	x	x	x
	Open in Desktop		x	x
Information query	Query		x	
	Select	x	x	x
	Edit		x	
Location search	Search by location	x	x	x
	My location		x	x

Table 8 Functionality of Studmap 1.4 and Studmap 3.0

The basemap chosen for the web applications available on the portal is ESRI's Grey Scale Basemap to meet with the general student's expectations in terms of level of detail and organization. A student can, however, switch the basemap from the list offered by ESRI using the basemap gallery widget in the web applications or customize it using a published WMS service to set the base interface for new web maps or scenes.

For the application elements, the widgets of the built-in edition of ArcGIS's WAB were added to each application according to both the students' needs, and the limitations given by the different types of applications. The current developer's edition of the WAB is incompatible with the WFS services provided by the third-party servers and hence the applications were constructed with a less flexible application builder. The result was the creation of an application for each type of data: 2D and 3D. While the 2D type allows the integration of a wide range of widgets, the 3D applications have less functions and flexibility. All applications were given the traditional functionalities: scalebar, an interactive zoom slider and pan, home, full screen, layer list and legend. What is more, the measurement tool was configured for both 2D and 3D applications, to allow the students to interpret distances and area sizes easier. A compass and a navigation tool were added to the 3D applications for a better location orientation and for a dynamic interaction with the 3D environment. Enhanced functionality was given

[*] WFS, WMTS and .shp not included

with the add data widget that was added on the 2D applications. Again, the widget is not available in the 3D type of applications. The widget brings value to the system as one of the main characteristics intended for the creation of the portal was to allow students to interact with the existing services on the portal while temporarily adding their own data. This functionality is also given by the basic publishing options that ArcGIS Portal has students with publishing permissions can publish services on the portal, can add them to web map or scenes, which they can incorporate in new web applications.

As the creation of different applications was limited by the widgets available for each type, the information query functionality was only possible for the 2D applications. For students to understand the information better, the 2D applications were designed with such widgets as: attribute table, edit, select and query.

Regarding the map products, one can easily save, share or download the web maps and applications available on the portal, with limitation based on the defined user roles hierarchy. Individual web layers can be locally accessed using the ArcGIS desktop application

Location search is essential for any webGIS application and hence, has been included in all applications on the portal as well as on the portal's interface. Using the search by location tool, the students can input the name of a place, its address or its coordinates to locate a point on the map.

B. NON-FUNCTIONAL REQUIREMENTS

The overall functionality of the system was limited by some the non-functional requirements: system performance and security and cost of equipment.

The overall performance of the system is dependent on the resources available to support the installed components as well as on the limitations of the chosen products. Such resources as firewall settings, operating system, hardware (disk space and memory) and web browsers should be considered for a good performance of the system, especially if the current database component is intended to be expanded. Among the product limitations, two major problems were identified. First is the inability of the ArcGIS Portal-specific web maps to draw a large number of features which lead to the decision of excluding the "Uncut Areas of NRW Studmap 1.4" feature service from the web maps and scenes. The second is represented by the products offered by the third-party service providers. As an example, a simple web feature service takes more than one minute to load on an empty map. This is because the services provided by the official institution are lacking a good performance. Geospatial web services coming from external servers should comply not only with the OGC standards, but also with the general interoperability request.

A closed source and hence, costly equipment (ESRI Enterprise) were preferred over the open source options on the market. This was done to allow the series of benefits the products are coming with, about the system maintenance and performance, security and available technical support.

To eventually ensure the proper communication between the scene cache data store and the GIS server a compromise was made resulting into a less secure configuration of the system. Compared to the conceptual model proposed at the beginning of this study, the components of the implemented system communicate using both HTTP and HTTPS protocols, together with a secure socket level certificate (SSL) allowance.

5.3 SYSTEM USABILITY

To ultimately reach the end of the cycle of the design methodology chosen for this research, the suitability of the platform for the specific academic use was tested using a mixed usability evaluation of the portal's interface. The usability was counted as the implemented architecture resulted in the creation of a tool – a web-based GIS platform for academic purposes. The evaluation took place in two stages: a customized expert inspection followed by a standard user testing.

5.3.1 Expert evaluation

The usability evaluation addressed to the experts was done in the following order: the development of the questions, the selection of the experts and the evaluation of the results.

First, the experts were given important details about the product: what is it destined for, which are the end users and what type of items are hosted on the portal. Second, they were asked to inspect the portal's interface in order to answer the developed questionnaire. The experts were then given the questionnaire to assess their opinion about the usability of the portal.

The series of questions was developed according to the key-aspects of the implemented portal's interface and to the SUS standardized usability questionnaire (Sauro & Lewis, 2016). The questionnaire consists of the ten standard SUS multiple-choice questions with the answer choice from "Strongly Disagree", "Disagree", Neutral, "Agree" and "Strongly Agree" and four customized open-ended questions relevant to the interface of the portal. Google Forms was used to collect and organize the questionnaire and its results. All questions are presented in Appendix D.

The experts were selected according to their experience with the ESRI Enterprise-specific products, their geographic location, the working status and availability. Table 9 contains a short description of each expert regarding their working status and expertise criteria:

Full Name	Working status	Organization	Background
Mitzi Araujo Vidal	Master student in Geospatial Technologies	NOVA IMS, Lisbon Portugal	Geographer with Environmental Management Background; GIS Analyst responsible for Spatial Analysis in Public Security; GIS manager with experience with ESRI suite of applications and open source tools; ArcGIS Server and Portal Manager; Currently, finalizing the

			Masters in Geospatial Technologies with focus on locational privacy protection
Tiago H. Moreira de Oliveira	PhD student in Information Management & GIS	NOVA IMS, Lisbon Portugal	Executive Coordinator for R&D national and international Projects at NOVA IMS; Coordinator of the GIS & Science master course; Member of the UNIGIS International Network; Assistant in teaching the courses of Geographic Information Systems and Science; Active participant on scientific events, Author of 45 research papers

Table 9 Description of each expert chosen for the usability evaluation

Finally, the results of the expert questionnaire were analyzed. The first 10 SUS standard questions were analyzed according to the standard scaling method of the system and resulted in a final score of 83.75%. Considering acceptability measures proposed by Bangor, Kortum, & Miller (2008), the experts have found the portal's interface as acceptable, in between good and excellent.

The last 4 open-ended questions reflected four main aspects of interest for the intended functionality of the portal and are summarized in Table 10. The complete set of results is presented in Appendix E.

Criteria of interest	Answer summary
Benefits	The interface is easy to use and offers good access to data and tools of interest to the students. Publishers can create their own apps, using the published layers on the portal.
Drawbacks	Issues with the 3D rendering were detected. Once authenticated, certain operations require a confirmation/reauthentication. The icon for the share data widget might be misinterpreted as an angle measurement tool.
Improvements	Improve the 3D data rendering quality, the navigation and visual capacities. Add a tool to help students understand the functionalities and tools on the portal and applications.
Overall usability	Students shouldn't face usability problems according to the intended functionality of the portal. The data is easily accessible. The portal can also be considered for the public access. However, the third-party 3D data rendering issues should not be neglected.

Table 10 Responses to the open-ended questions of the expert questionnaire

5.3.2 User testing

The standardized user testing preceded the expert usability evaluation and took place in four stages: the development of the tasks, the development of the question, the selection of the users and the evaluation of the results.

Ten straightforward tasks were designed according to the key functionalities of the portal: ability to access public data and previous projects, ability to compare own data with published services and both 2D and 3D functionality. The intention was to give the participants a heuristic approach to get acquainted with the interface before answering the questionnaire. The estimated time interval of completion for all tasks was 10 to 15 minutes, with a desired 100% completion rate. All tasks were described at the beginning of the form that was sent to the participants.

Similar to the expert evaluation, a standard SUS questionnaire (Sauro & Lewis, 2016) was preferred for this phase: 10 multiple choice questions and one open-ended question to ask participants about the overall opinion on the interface. The survey used Google Forms to collect the answers from the participants. All questions together with the description of the tasks are presented in Appendix F.

Twenty students were selected, with ages between 23 and 31 years, all being informed about the consequences of the evaluation as volunteers. The users were selected according to the aimed audience of the portal: students that are acquainted with 2D and 3D geospatial data in a webGIS environment. Not all students that have participated in the survey have already studied in WWU. To these participants a brief explanation of the data of interest for the WWU students was given to avoid any ambiguities related to the data referred to during the completion of the tasks.

Finally, the results of the expert questionnaire were analysed. The first 10 SUS standard questions were weighted according to the standard analysis. The responses to the open-ended question at the end of the questionnaire were also considered. Although the students were only asked to state general comments about the interface of the portal, the tendency was to divide their answers in different criteria, like the ones used for the expert evaluation. Therefore, the most significant answers have been grouped in four criteria as summarized in Table 11:

Criteria of interest	**Answer summary**
Benefits	The portal is easy to use and learn, intuitive and neat. It is easy to access existing data. The portal is helpful for the students of WWU and the applicability is clear. Both 2D and 3D functionality are covered, together with the direct data import, search data and measurement features. The data is classified in a clear way. Fast responses are given for both 2D and 3D data. Pleasant choice of background.
Drawbacks	The speed of response is depending on the servers' capacities. There is a need to meet GPU criteria to run 3D applications. There is no possibility to switch from one application to another. The legend of one layer is missing. The preview of some of the layers is only displayed in a square. There are not many widgets on the applications. Students form other domains might find it difficult to use.
Improvements	Add the missing legends to the layers for a better interpretation of the maps. Implement a solution to switch from one application to another. Improve the preview of layers.
Overall opinion	The portal is appreciated by students and applicable for research, well designed and useful for students. It offers a good user experience, but also open for improvements.

Table 11 Responses to the open-ended question of the student usability test

The tasks were generally well received by the students, all stating that they got used to the interface easily during the evaluation. All results of the test are presented in Appendix G. To measure the efficiency of the test, the time of completion for all tasks was accounted. The time fitted in the estimated interval as the average didn't surpass 9 minutes (Figure 19). Two students took more than the estimated maximum of 15 minutes to complete the tasks. To measure the effectiveness, the accuracy of completing the tasks was measured. Two out of twenty students couldn't complete the last three tasks (Figure 20) as they were facing the problem of incompatibility of the graphics requirements of the 3D applications based in the Scene Viewer (ESRI, 2017c).

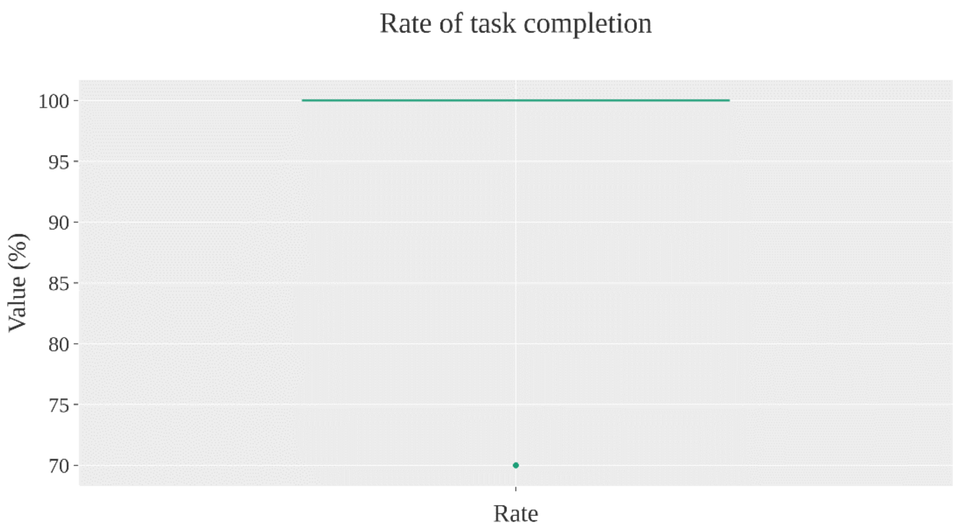


Figure 19 Boxplot to measure the effectiveness of the user study

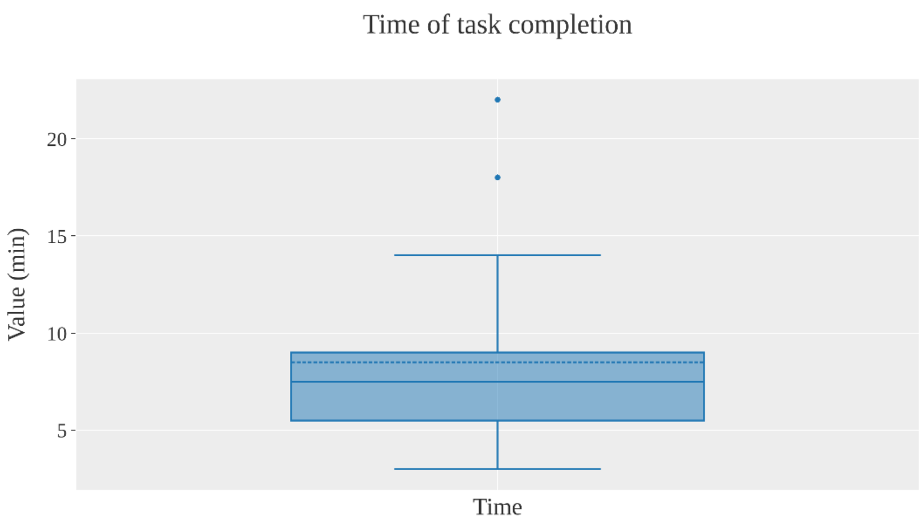


Figure 20 Boxplot to measure the efficiency of the user study

The final SUS score for the student evaluation is 83.87%, which, according to the acceptability rate proposed by Bangor, Kortum, & Miller (2008) situate the final product among the third quartile range, which fits in the acceptable range. According to the adjective ratings, students found the final interface of the portal in between good and excellent.

As an ultimate step of the evaluation, the SUS scores' statistics computed for the students were displayed in a boxplot and compared to the ones computed for the experts. As seen in Figure 21, both means are above the score of 80 on the scale from 1 to 100, students tending to appreciate the platform as closer to the excellent rating than the participating experts with a SUS score difference of 0.125.

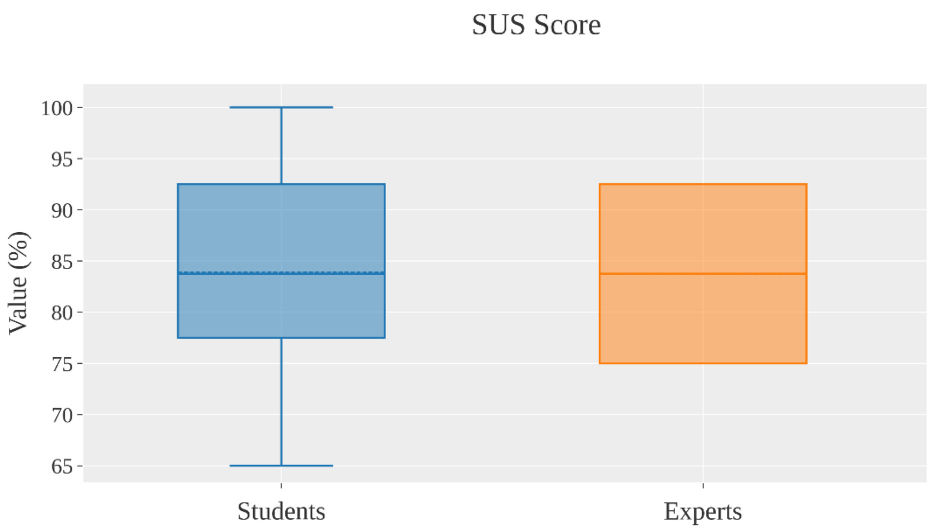


Figure 21 Boxplots of the SUS scores computed for the expert and student evaluations

5.4 Ease of implementation

Regarding the overall ease of implementation of the system, the proposed client-server architecture required a well-documented basis with an overall complex setup of the back-end and an overall straightforward configuration of the front-end.

The documentation support for the installation and configuration of the systems' components has proven to be efficient and effective at all main levels: requirements, architecture, technical and end user. However, there were situations where the software documentation regarding the architecture design and technical specifications did not include support for some specific issue. Changes that require un-federation or re-indexing of the services of the portal lead to serious technical issues, that have no feasible solution documented by this date.

Another important issue is raised around the ArcGIS Data Stores. Changes that require uninstallation, reinstallation, reconfiguration and back-up of the Data Store can cause failure or incomplete restoring of the databases. Inconsistencies in documentation can also occur. For example, the need to unregister the data store before uninstallation is not mentioned in the main documentation, while it appears as a technical support solution (ESRI, 2018n). The tile store database configuration had proven to be the most challenging due to the lack of specific documentation for the service communication (ESRI, 2018m).

Up to this date, there is little and vague documentation about these important issues and no online forums solutions. Hence, a good implementation can only be attained via different tests and empirical experience altogether with supervised support from qualified people.

In our opinion, the connection between its components was successful once both the available documentation and the practical experience have led to an in-depth knowledge of how the overall system should work. Once the components were setup and validated, the implemented system became easily operable and intuitive, offering a plethora of benefits: no need for programming skills, no need to handle projections, ease of publishing and storage of complex 3D features, clear delimitation between user roles and easy access to the webGIS services, web layers and database tables.

The selected software products are dedicated to offer an easy manipulation of the front-end components, once the back end is successfully set. Due to this client-dedicated approach and the throughout end user documentation, the portal interface was rapidly designed, and the webGIS infrastructure was easily organized to be shared according to the needs of the local students. Once the hosted items were given category tags and added to thematic maps, scenes and applications, a site was created to offer a user-friendly interface of the Portal and to take advantage of the multitude of published item types.

5.5 FUTURE DEVELOPMENTS

To fit the time destined for the evaluation of the implemented webGIS portal, the usability was assessed using an expert questionnaire and a standardized lab-based user test with twenty students. For the future improvement of the Studmap 3.0 portal, we encourage both the consideration of the improvements suggested by the experts and the integration of the obtained results of the SUS questionnaires in the following software development process. The summaries for the benefits, drawbacks and recommendations resulted from the two stages of the evaluation should be feed back to the process and followed by a second stage of student evaluation and comparison of evolution between the two in terms of efficiency, effectiveness and satisfaction.

Once the portal starts being used by its intended end-users, a continuous assessment method should be chosen to grant a satisfying performance. Number of users, groups and consumed services will increase once the Studmap 3.0 Portal becomes available for public use and hence, they should be carefully assessed in order for the system administrator to decide upon enhancing capabilities of the main machines holding the system to balance the computation load accordingly.

As the validation of the proposed architecture and hence, the creation of the new web platform was restricted to the resources given by the University of Muenster, the components of the system are currently hosted over two machines as specified in Section 4.3.4.1. All three data stores configured at the moment are hosted on the same machine. For an improved future performance, we encourage that ESRI's recommendations (ESRI, 2018k) should be followed: each data store should be installed on a separate machine. The complex 3D features stored locally as .slpk files should be considered for a better organization on this extra machine, using a referenced folder storage system. More available data store types can be further added to the system according to other needs that might be identified as the students start using the proposed web platform.

For an easy collection of data, the system is recommended to also take advantage of applications designed for collecting data from the field. A good example consists on Survey123 (ESRI, 2016d) as the current deployment of the Studmap 3.0 Portal allows it.

6. CONCLUSION

The purpose of the current thesis was to create an integrated web-based GIS platform to grant relevant services and geospatial data to the students and staff of the university. To attain this, a design science approach was adopted to offer solutions based on literature review and experience to propose a conceptual client-server architecture, and further implement and evaluate it through a case-study platform, Studmap 3.0. Conclusions from this evaluation were drawn and feed back to the previous stages until the implemented artefact reached the approval of the end-user.

The last phase consisted of a mixed usability evaluation addressed two different types of audience. First, the study was done by two experts that were asked to inspect the interface of the resulting portal and answer a set of questions formulated according to the intended functionalities and audience of the portal. After this stage was completed, the interface was evaluated by twenty students that were given a set of tasks designed corresponding to the general needs of the students defined at the beginning of the study. The tasks were well received by all participants, with a completion rate of 100% for all students whose graphics were compatible with the products' requirements. Both the experts and the students had to ultimately respond to a standardized SUS questionnaire which delivered a score of 83.75% for the experts and 83.87% for the students. A summary for the benefits, drawbacks, future improvements and overall opinion was also produced for both categories of participants.

Therefore, this paper offered a practical approach to complement the purely theoretical one. The proposed framework has eventually resulted in a portal dedicated to support students in their real life which also leaves place for further feedback and adaptation to future needs. Studmap 3.0 webGIS portal is an example of a flexible client-server, user-oriented architecture composed of three layers: presentation, application, and database.

In such circumstances, two main strengths were identified in the proposed system:

- Provides students with an effective tool to interact with available official data and previous projects via an interactive web mapping portal interface;
- Integrates both 2D and 3D features in a smart GIS environment capable of handling big data on the web.

One essential compromise was necessary to fit with the chosen schema and products:

- The storage of the complex 3D datasets is needed to be done separately from the databases, in a local folder.

The architecture proposed and evaluated in this thesis is limited by a series of non-functional requirements depending on the context of the implementation of the Studmap 3.0 portal. The first dependency is given by the resources available in terms of both hardware and software and influences the overall performance of the system. System security comes as the second dependency as the communications of the implemented systems are done via both HTTP and HTTPS protocols which gives a less secure alternative compared to the conceptual model that was proposed. Last, the cost of equipment also comes as a restriction for the designed architecture as the chosen software to offer the main GIS function, namely ESRI Enterprise, is a closed source.

An additional study addressed to the students of WWU is recommended to further improve of the platform and to provide comparative results for the improvements proposed during this stage of evaluation. Moreover, an extension of the machines hosting the main components of the proposed architecture should be considered in order to increase the performance of the 3D features hosted on the portal. For an improved quality of the storage system, a solution to organize the complex 3D data files needed to be saved locally is required. Finally, to allow real-time collection of data in the same system during students' surveys, we suggest the configuration and use of a data collection application.

Nonetheless, this work can be perceived as a reference for any peers interested in the implementation and evaluation of an interoperable and 3D-friendly webGIS platform for academical use.

BIBLIOGRAPHIC REFERENCES

Agrawal, S., & Gupta, R. D. (2017). Web GIS and its architecture: a review. *Arabian Journal of Geosciences, 10*(23), 518. doi:https://doi.org/10.1007/s12517-017-3296-2

Bangor, A., Kortum, P. T., & Miller, J. T. (2008, July 30). An Empirical Evaluation of the System Usability Scale. *International Journal of Human-Computer Interaction, 24*(6), 574-594. doi:https://doi.org/10.1080/10447310802205776

Buczkowski, A. (2016, November 5). *Top 19 geovisualization tools, APIs and libraries that will let you create beautiful web maps*. Retrieved January 20, 2019, from Geo Awesomeness: http://geoawesomeness.com/top-19-online-geovisualization-tools-apis-libraries-beautiful-maps/

Canada, G. o. (2017, May 17). *The Atlas of Canada*. Retrieved November 5, 2018, from Natural Resources Canada: https://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada

Cannata, M., Antonovic, M., Molinari, M., & Pozzoni, M. (2015). istSOS, a new sensor observation management system: software architecture and a real-case application for flood protection. *Geomatics, Natural Hazards and Risk, 6*(8), 635-650. doi:http://dx.doi.org/10.1080/19475705.2013.862572

Chen, W., He, B., Zhang, L., & Nover, D. (2016, October 16). Developing an integrated 2D and 3D WebGIS-based platform for effective landslide hazard management. *International Journal of Disaster Risk Reduction, 20*, 26-38. doi:http://dx.doi.org/10.1016/j.ijdrr.2016.10.003

ESRI. (2014a, January 24). *ArcGIS API for JavaScript*. Retrieved December 3, 2018, from ArcGIS for Developers: https://developers.arcgis.com/javascript/

ESRI. (2014b, December 18). *Web AppBuilder for ArcGIS (Developer Edition)*. Retrieved January 5, 2019, from ArcGIS for developers: https://developers.arcgis.com/web-appbuilder/guide/xt-welcome.htm

ESRI. (2014c, December 13). *WMS services—Documentation*. Retrieved September 22, 2018, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/server/latest/publish-services/linux/wms-services.htm

ESRI. (2015, May 6). *Indexed 3D Scene Layers*. Retrieved September 27, 2018, from ArcGIS for Developers: http://enterprise.arcgis.com/en/server/latest/publish-services/linux/scene-services.htm

ESRI. (2016a, February 3). *ArcMap - Types of geodatabases*. Retrieved November 23, 2018, from ArcGIS for Desktop: http://desktop.arcgis.com/en/arcmap/latest/manage-data/geodatabases/types-of-geodatabases.htm

ESRI. (2016b, September 25). *Indexed 3D scene layers - ArcGIS for Developers*. Retrieved September 28, 2018, from ArcGIS Online: https://developers.arcgis.com/3d/indexed-3d-scene-layers/

ESRI. (2016c, December 9). *Ports used by ArcGIS Server*. Retrieved January 5, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/server/latest/install/windows/ports-used-by-arcgis-server.htm

ESRI. (2016d, June 18). *Survey123 for ArcGIS*. Retrieved January 23, 2019, from Survey123 for ArcGIS: https://survey123.arcgis.com/

ESRI. (2017a, July 17). *ArcGIS Data Store command utility reference*. Retrieved January 7, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/data-store/latest/install/windows/data-store-utility-reference.htm

ESRI. (2017b, March 30). *Indexed 3D Scene (I3S) Layers Specification*. Retrieved October 17, 2018, from Esri video: https://www.esri.com/videos/watch?videoid=flTeHaeN4rA&title=indexed-3d-scene-i3s-layers-specification

ESRI. (2017c, September 23). *Scene Viewer requirements—ArcGIS Online Help*. Retrieved February 5, 20191, from ArcGIS Online: https://doc.arcgis.com/en/arcgis-online/reference/scene-viewer-requirements.htm

ESRI. (2017d, June 4). *The ArcGIS REST API*. Retrieved September 24, 2018, from ArcGIS for Developers: https://developers.arcgis.com/documentation/core-concepts/rest-api/

ESRI. (2018a, April 12). *ArcGIS Online Basemaps*. Retrieved January 5, 2019, from ArcGIS: https://www.arcgis.com/home/group.html?id=702026e41f6641fb85da88efe79dc166#overview

ESRI. (2018b, June). *ArcGIS Server*. Retrieved June 6, 2018, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/server/latest/get-started/windows/what-is-arcgis-for-server-.htm

ESRI. (2018c, July 10). *ArcGIS Server - Register your data with ArcGIS Server using Manager*. Retrieved November 22, 2018, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/server/latest/publish-services/windows/registering-your-data-with-arcgis-server-using-manager.htm

ESRI. (2018d, January 11). *ArcGIS Server - What types of services can you publish?* Retrieved January 20, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/server/latest/publish-services/windows/what-types-of-services-can-you-publish.htm

ESRI. (2018e, January 12). *ArcGIS Server web services—Portal for ArcGIS*. Retrieved January 2, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/portal/latest/use/arcgis-server-services.htm

ESRI. (2018f, January 9). *Base ArcGIS Enterprise deployment.* Retrieved January 9, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/get-started/latest/windows/base-arcgis-enterprise-deployment.htm

ESRI. (2018g, January 10). *Configure a hosting server for portal*. Retrieved January 7, 2019, from ArcGIS Enterprise| Portal for ArcGIS: http://enterprise.arcgis.com/en/portal/latest/administer/windows/configure-hosting-server-for-portal.htm

ESRI. (2018h, January 10). *Levels, roles, and privileges - Portal for ArcGIS*. Retrieved January 9, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/portal/latest/administer/windows/roles.htm

ESRI. (2018i, January 12). *OGC - Portal for ArcGIS*. Retrieved November 11, 2018, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/portal/latest/use/ogc.htm

ESRI. (2018j, April 20). *Overview | ArcGIS API for JavaScript*. Retrieved November 6, 2018, from ArcGIS for Developers: https://developers.arcgis.com/javascript/

ESRI. (2018k, January 12). *Portal for ArcGIS - Apps and functionality that require ArcGIS Data Store*. Retrieved January 11, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/portal/latest/administer/windows/what-requires-arcgis-data-store.htm

ESRI. (2018l, January 11). *Ports used by Portal for ArcGIS*. Retrieved January 5, 2019, from ArcGIS Enterprise: http://enterprise.arcgis.com/en/portal/latest/install/windows/ports-used-by-portal-for-arcgis.htm

ESRI. (2018m, December 21). *Scene layer package (.slpk) and Portal for ArcGIS*. Retrieved January 24, 2019, from Geonet - The Esri Community: https://community.esri.com/message/821063-scene-layer-package-slpk-and-portal-for-arcgis

ESRI. (2018n, December 31). *Technical support -Error: Layer did not draw completely because there are too many features to display*. Retrieved January 6, 2019, from ESRI: https://support.esri.com/en/technical-article/000014750

Gaghegan, M. (2018). Our GIS is too small. *The Canadian Geographer*(62), 15-26. doi:10.1111/cag.12434

GeoSeer. (2018, July 18). *So, how many OGC layers are there?* Retrieved from GeoSeer: https://www.geoseer.net/blog/?p=2018-07-18_how_many_layers_are_there

GeoServer. (2019, January 19). Retrieved September 16, 2018, from http://geoserver.org/release/stable/

Idrizi, B. Z. (2014, September 1). Defining methodology for selecting most appropriate GIS software. *Survey Review, 46*(338), 383-389. doi: https://doi.org/10.1179/1752270614Y.0000000116

International Organization for Standardization. (2018, March). Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts (ISO 9241-11). *2*. Retrieved January 3, 2019, from https://www.sis.se/api/document/preview/80003410/

IVVgeo. (2018, July 3). *Gallery for Geo Münster*. Retrieved January 8, 2019, from IVVgeo Geo Münster: http://ivv6.maps.arcgis.com/home/index.html

IVVGeo-Team, U. o. (2018, 09 18). *StudMap14 Dokumentationen*. Retrieved 10 16, 2018, from IVVgeo Wiki: https://ivv6-wiki.uni-muenster.de/neu/dokuwiki/doku.php?id=dev_studmap14:old:inhalt:dokumentation

Kanellis, P., & Papadopoulos, T. (2009). Conducting Research in Information Systems: An Epistemological Journey. In A. Cater-Steel, & L. Al-Hakim (Eds.), *Information Systems Research Methods, Epistemology, and Applications* (pp. 1-34). Hershey, PA: IGI Global. doi:10.4018/978-1-60566-040-0.ch001

Kong, N., Zhang, T., & Stonebraker, I. (2015). Evaluation of web GIS functionality in academic libraries. *Applied Geography, 60,* 288-293. Retrieved May 8, 2018, from https://sciencedirect.com/science/article/pii/s0143622814002720

Li, Z., Hodgson, M. E., & Li, W. (2018, January 2). A general-purpose framework for parallel processing of large-scale LiDAR data. *International Journal of Digital Earth, 11*(1), 26-47. doi:https://doi.org/10.1080/17538947.2016.1269842

Liu, X., Li, S., Huang, W., & Gong, J. (2015, September). Designing sea ice web APIs for ice information services. *Earth Sci Informatics, 8*(3), 483-497. doi:https://doi.org/10.1007/s12145-015-0207-5

MapServer. (2018, September 23). *Welcome to MapServer*. Retrieved 9 16, 2018, from http://www.mapserver.org/

OGC. (2010a, November 11). OpenGIS Web Feature Service 2.0 Interface Standard (ISO/DIS 19142). (P. Panagiotis, & A. Vertanos, Eds.) Open Geospatial Consortium Inc. Retrieved December 15, 2018, from https://www.opengeospatial.org/standards/wfs

OGC. (2010b, April 06). OpenGIS® Web Map Tile Service Implementation Standard (ISO 9241-11). (J. Masó, K. Pomakis, & N. Julià, Eds.) Open Geospatial Consortium Inc. Retrieved January 15, 2019, from https://www.opengeospatial.org/standards/wmts

OGC. (2016a, June 24). *Introduction to WMS*. Retrieved September 24, 2018, from OGC: http://www.opengeospatial.org/standards/wmshttp://www.opengeospatial.org/standards/wms

OGC. (2016b, June 24). *Welcome to The Open Geospatial Consortium*. Retrieved October 24, 2018, from OGC: http://www.opengeospatial.org/

OGC. (2017, September 5). OGC Indexed 3d Scene Layer (I3S) and Scene Layer Package Format Specification. (C. Reed, & T. Belayneh, Eds.) Retrieved January 9, 2019, from OGC: http://docs.opengeospatial.org/cs/17-014r5/17-014r5.html

OpenNRW. (2017, January 5). *Open Data*. Retrieved January 8, 2019, from Open NRW: https://open.nrw/suche

Prinz, T. (2014, 05 14). *Fünfte Sitzung*. Retrieved 10 16, 2018, from GPS in den Geowissenschaften: http://ivvgeo.uni-muenster.de/vorlesung/GPS_Script/praktikum5.html

ProgrammableWeb. (2018, September 25). *API Directory*. (D. Berlind, W. Santos, & K. Sundstrom, Editors) Retrieved November 23, 2018, from ProgrammableWeb: https://www.programmableweb.com/category/all/apis

Rouse, M. (2016, December 8). *RESTful API*. Retrieved January 6, 2019, from SearchMicroservices: https://searchmicroservices.techtarget.com/definition/RESTful-API

Sauro, J., & Lewis, J. (2016). Standardized Usability Questionnaires. In *Quantifying the user experience: Practical statistics for user research* (pp. 185-186). Cambridge, MA: Elsevier Inc.

Shekhar, S., Xiong, H., & Zhou, X. (2018). *Encyclopedia of GIS* (2nd ed.). Springer International Publishing. doi:10.1007/978-3-319-17885-1

Society, N. G. (2017, May 16). *Maps - National Geographic*. Retrieved November 5, 2018, from National Geographic: https://www.nationalgeographic.com/maps

USGS. (2018, September 5). *The National Map: Small Scale*. Retrieved November 5, 2018, from USGS: https://nationalmap.gov/small_scale/

van Oosterom, P., Martinez-Rubi, O., Ivanova, M., Horhammer, M., Geringer, D., Ravada, S., . . . Gonçalves, R. (2015). Massive point cloud data management: Design, implementation and execution of a point cloud benchmark. *Computers & Graphics, 49*, 92-125. doi:http://dx.doi.org/10.1016/j.cag.2015.01.007

Veenendaal, B., Brovelli, M. A., & Li, S. (2017, October 21). Review of Web Mapping: Eras, Trends and Directions. *International Journal of Geo-Information, 6*(10), 317. doi:https://doi.org/10.3390/ijgi6100317

Veenendaal, B., Brovelli, M. A., Li, S., & Ivánová, I. (2017, September 12). What is web mapping anyway? *ISPRS - International Archives of the Photogrammetry, Remote*

Sensing and Spatial Information Sciences, XLII-2/W7, 155-160. doi:https://doi.org/10.5194/isprs-archives-XLII-2-W7-155-2017

Wagemann, J., Clements, O., Figuera, R. M., Rossi, A. P., & Mantovani, S. (2018). Geospatial web services pave new ways for server-based on-demand access and processing of Big Earth Data. *International Journal of Digital Earth*, *11*(1), 7-25. doi:https://doi.org/10.1080/17538947.2017.1351583

Walsh, S. J., Page, P. H., McKnight, S., Yao, X., & Morrissey, T. P. (2015). A reservoir siting tool for North Carolina: System design & operations for screening and evaluation. *Applied Geography, 60*, 139-149. doi:https://doi.org/10.1016/j.apgeog.2015.03.015

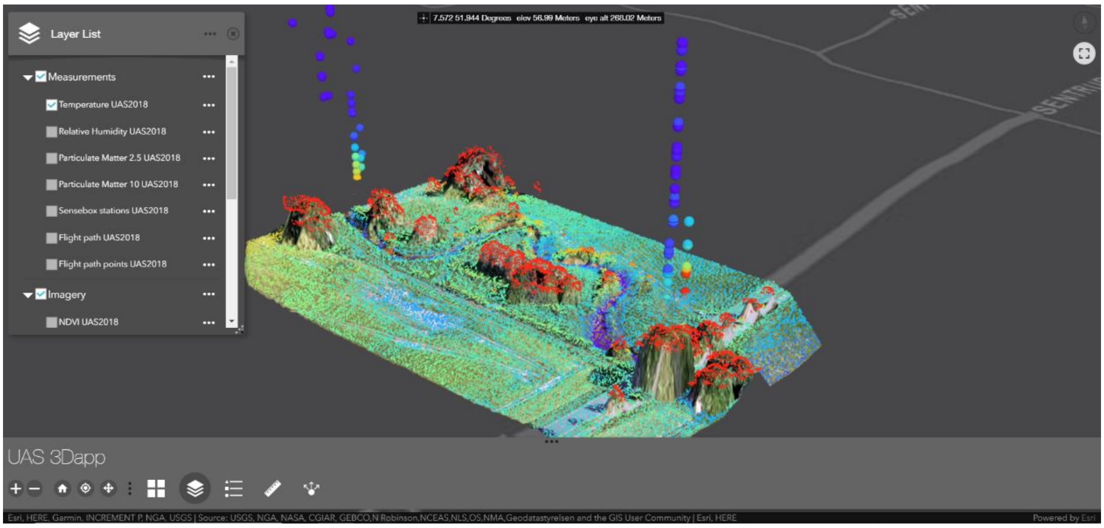
Yang, C., Huang, Q., Li, Z., Liu, K., & Hu, F. (2017, January 2). Big Data and cloud computing: innovation opportunities and challenges. *International Journal of Digital Earth, 10*(1), 13-53. doi:https://doi.org/10.1080/17538947.2016.1239771

APPENDIX

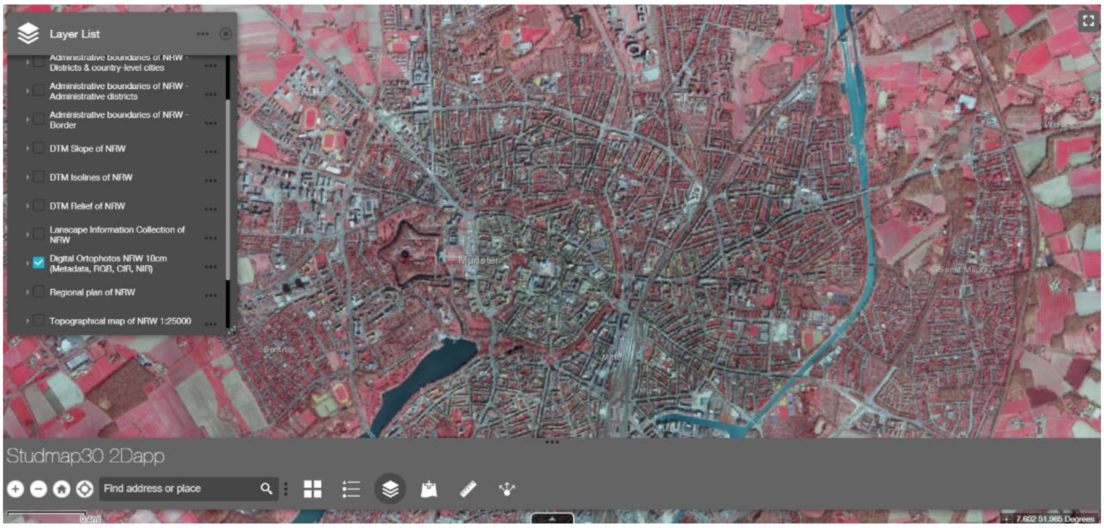
A. Applications interfaces

1. NRW 3Dapp

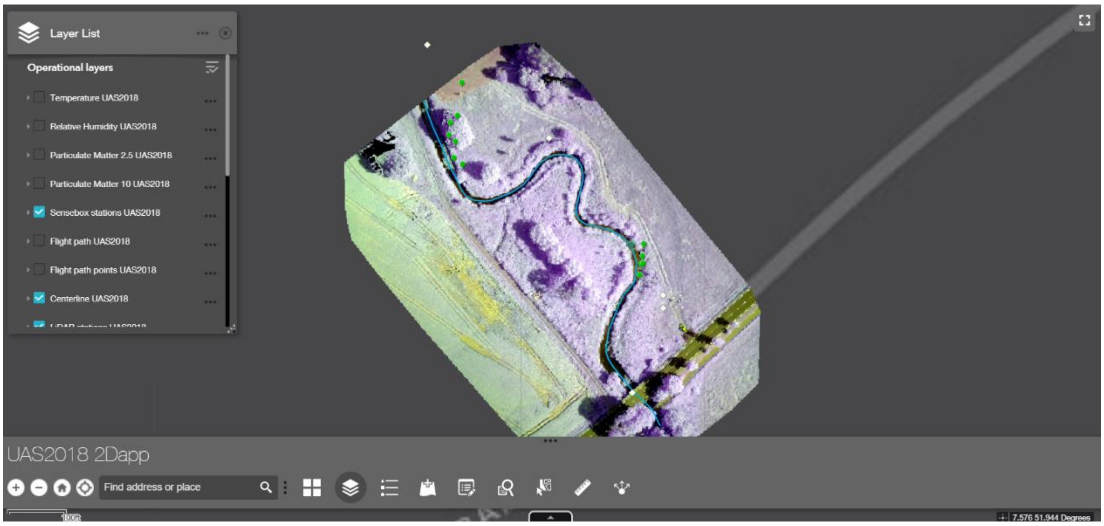
2. UAS 3Dapp



3. NRW 2Dapp

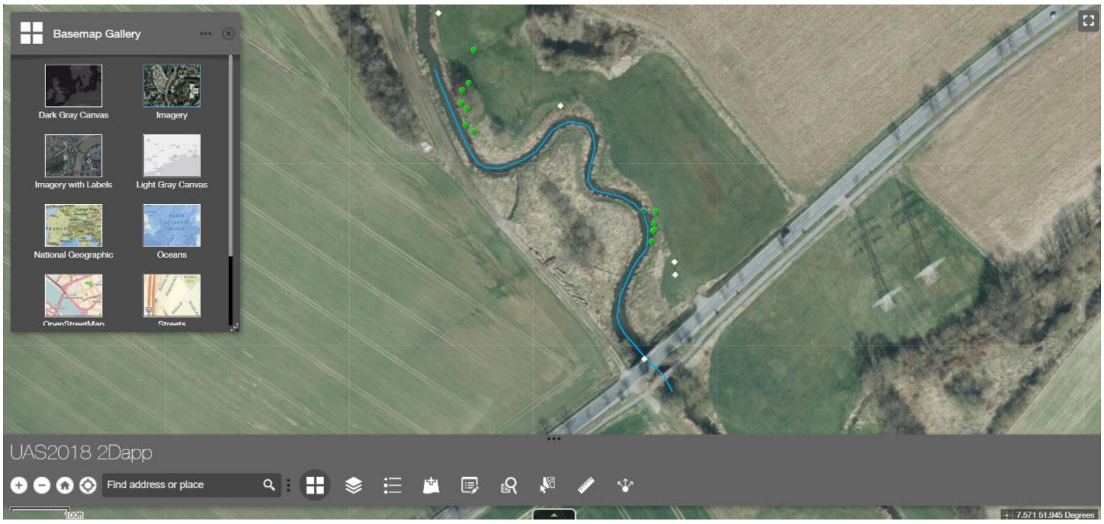


4. UAS 2Dapp



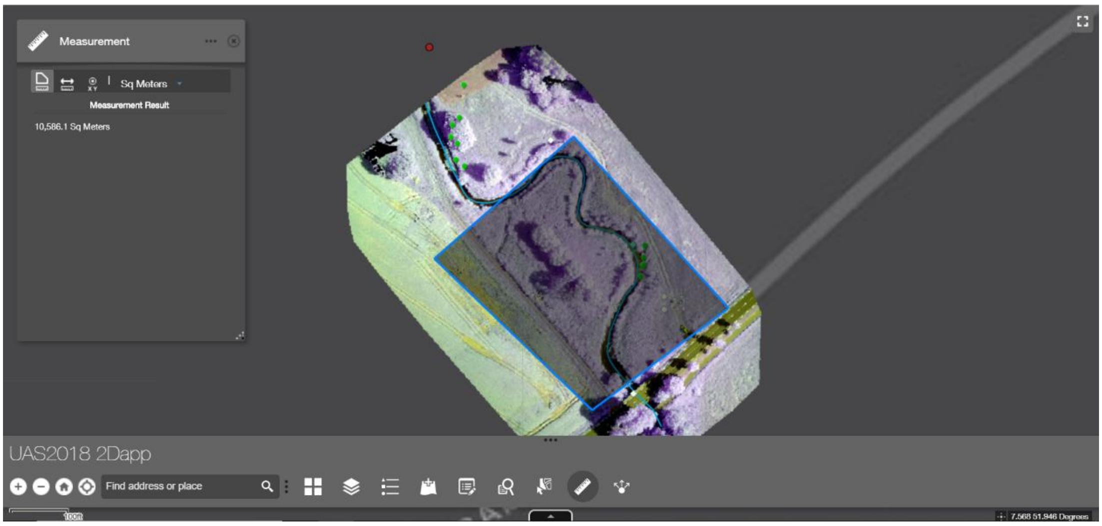
B. Functionality of the main widgets of the Studmap 3.0 applications

1. Basemap gallery

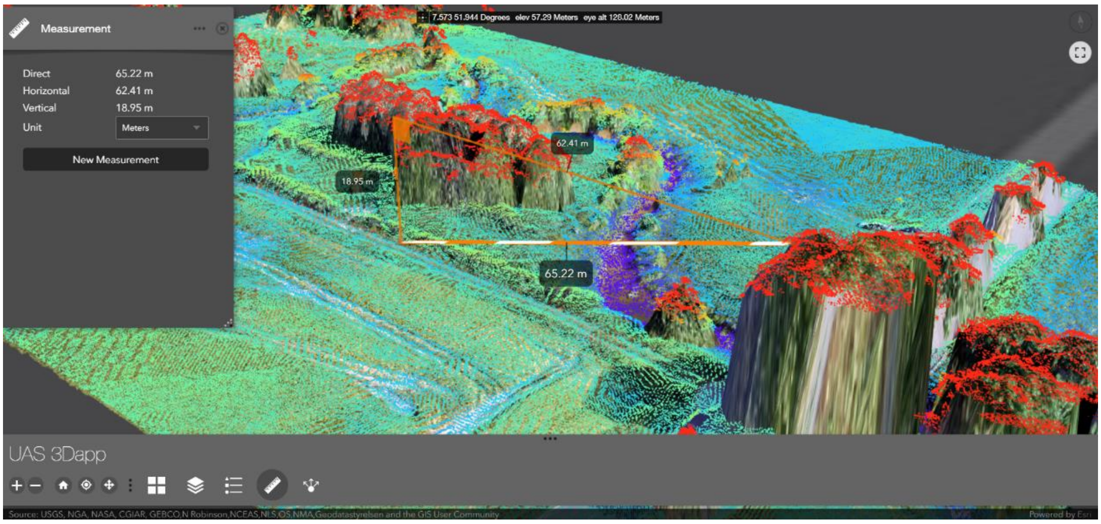


2. Add data

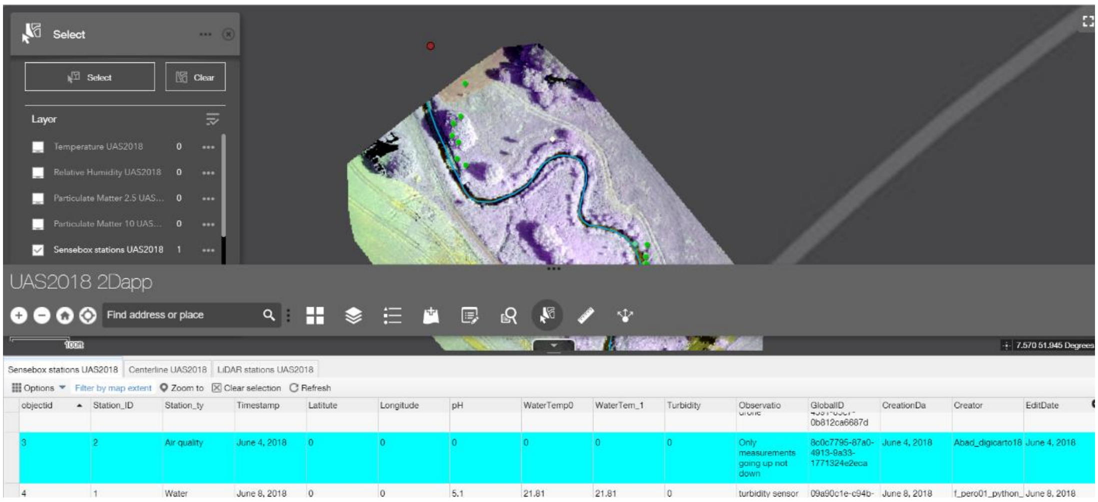
3. Measure 2D



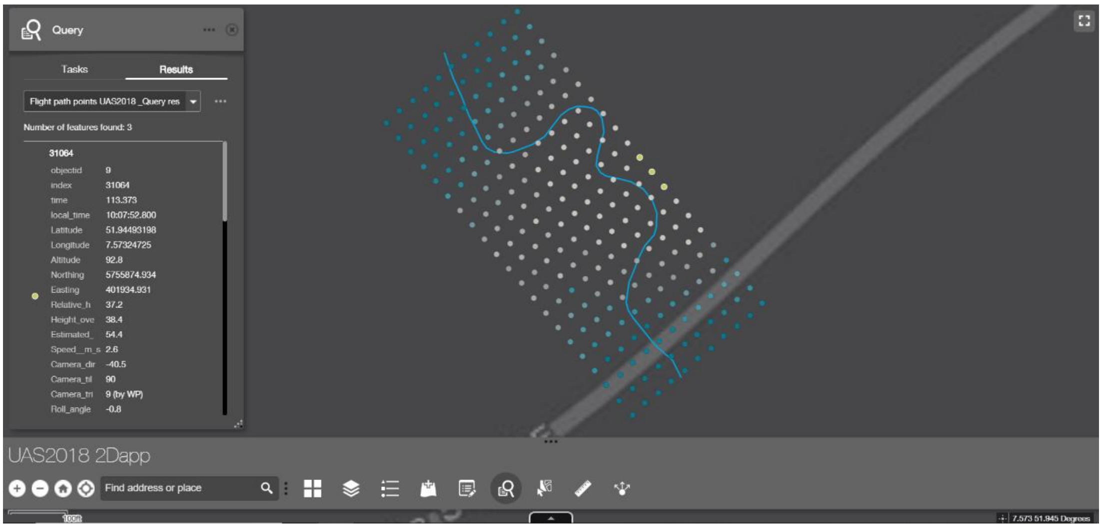
4. Measure 3D



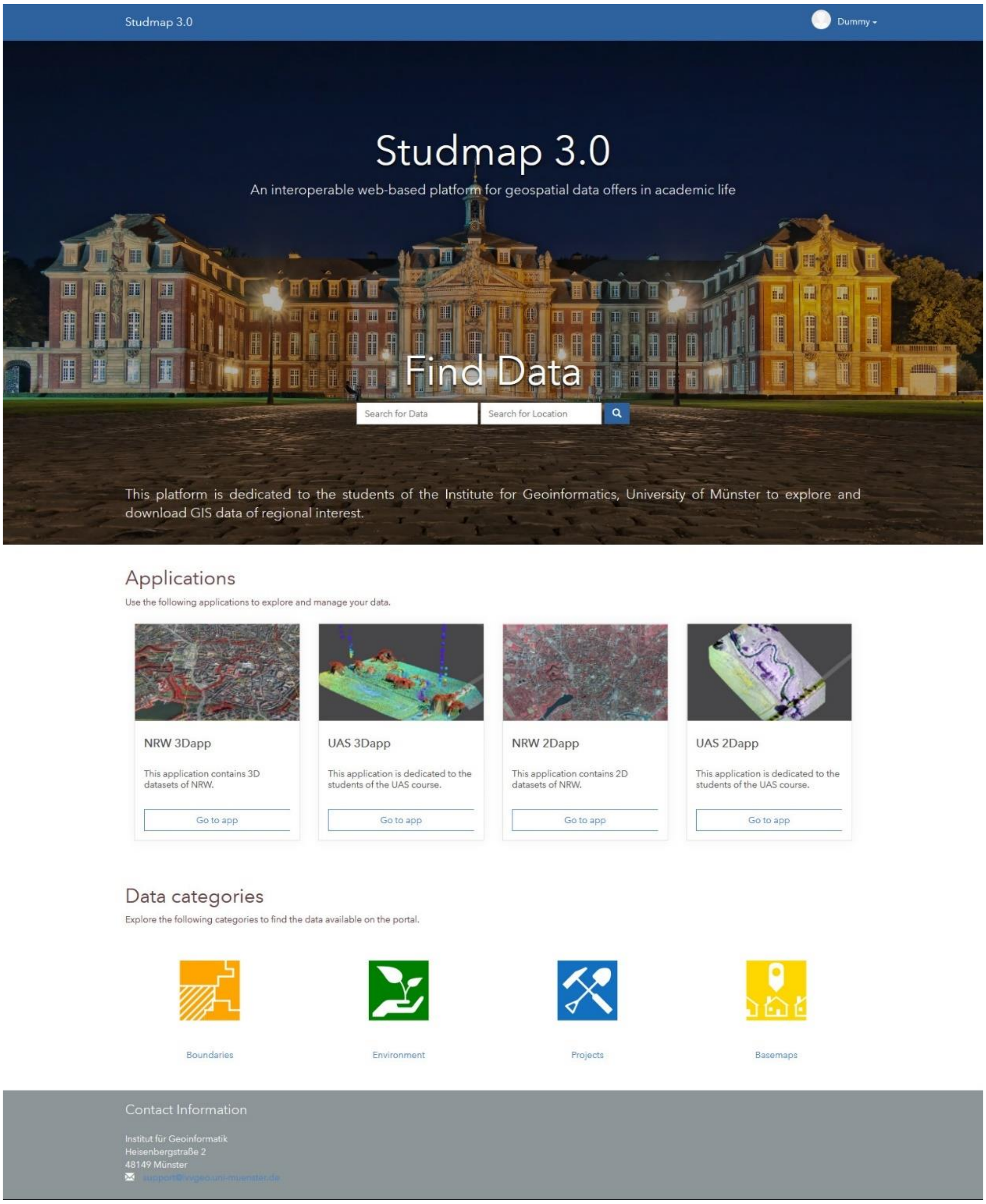
5. Select



6. Query



C. Full extent of the Studmap 3.0 Site web interface



D. Usability evaluation – expert evaluation questionnaire extracted from Google Forms

2/9/2019 Studmap 3.0 – expert usability evaluation

Studmap 3.0 – expert usability evaluation

This form is destined for the evaluation of usability of the Studmap 30 portal interface. Questions should be answered with regard to the following aspects:
- Studmap 30 is a student-dedicated portal
- Studmap 30 should allow the students to access official data and previously published projects, to publish or temporary upload their own filed data in order to compare it with the existing services
- Studmap 30 is intended for both 2D and 3D functionality

* Required

1. **If I were a student of WWU, I think that I would like to use this website frequently.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

2. **I found this portal unnecessarily complex.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

3. **I thought this portal was easy to use.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

https://docs.google.com/forms/d/1slrEkEsQT8EnjqrNRL3Y7ogi5SAvhUVtHUBICkw4Ssw/edit 1/4

4. **I think that I would need assistance to be able to use this portal.** *

Mark only one oval.

- ⬭ Strongly Disagree
- ⬭ Disagree
- ⬭ Neutral
- ⬭ Agree
- ⬭ Strongly Agree

5. **I found the various functions in this portal were well integrated.** *

Mark only one oval.

- ⬭ Strongly Disagree
- ⬭ Disagree
- ⬭ Neutral
- ⬭ Agree
- ⬭ Strongly Agree

6. **I thought there was too much inconsistency in this portal.** *

Mark only one oval.

- ⬭ Strongly Disagree
- ⬭ Disagree
- ⬭ Neutral
- ⬭ Agree
- ⬭ Strongly Agree

7. **I would imagine that most people would learn to use this portal very quickly.** *

Mark only one oval.

- ⬭ Strongly Disagree
- ⬭ Disagree
- ⬭ Neutral
- ⬭ Agree
- ⬭ Strongly Agree

8. **I found this portal very cumbersome/awkward to use.** *

Mark only one oval.

- ⬭ Strongly Disagree
- ⬭ Disagree
- ⬭ Neutral
- ⬭ Agree
- ⬭ Strongly Agree

9. **I felt very confident using this portal.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

10. **I needed to learn a lot of things before I could get going with this portal.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

11. **Which are the benefits of the interface of the portal addressed to the students' needs?** *

12. **Which are the drawbacks of the interface of the portal addressed to the students' needs?** *

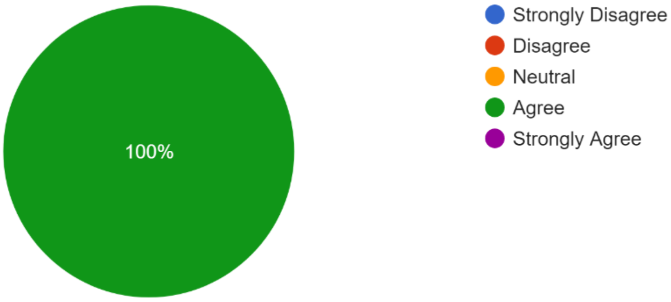
13. **Which are the improvements that you would suggest being done to this portal?** *

14. As an overall experience, what comments do you have about the usability of the portal? *

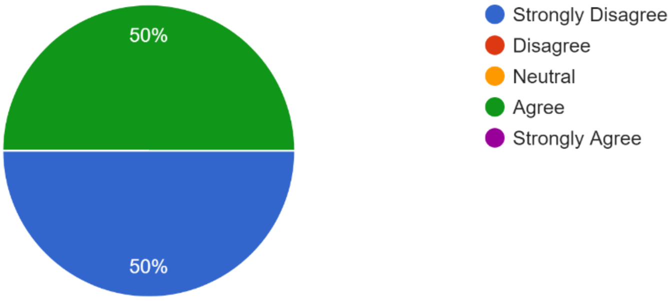
Powered by
Google Forms

E. Usability evaluation – expert evaluation results extracted from Google Forms

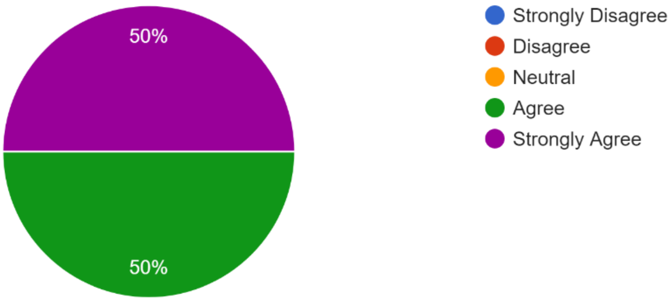
1. Diagram of answers to the statement “If I were a student of WWU, I think I would like to use this website frequently.”



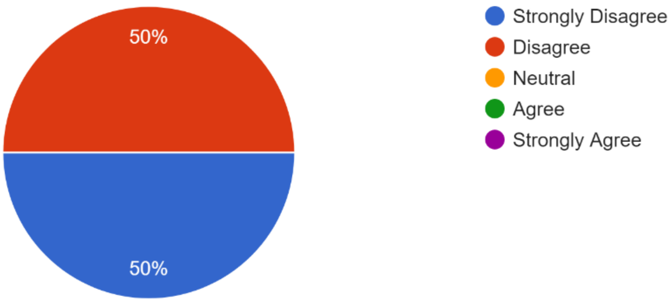
2. Diagram of answers to the statement “I found this portal unnecessarily complex.”



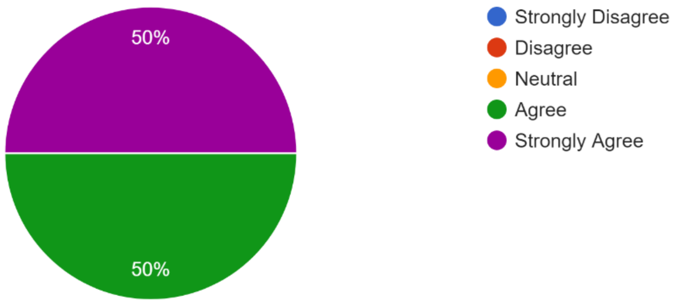
3. Diagram of answers to the statement “I thought this portal was easy to use.”



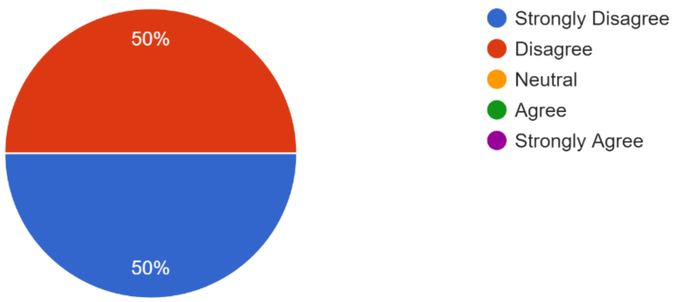
4. Diagram of answers to the statement “I think that I would need assistance to be able to use this portal.



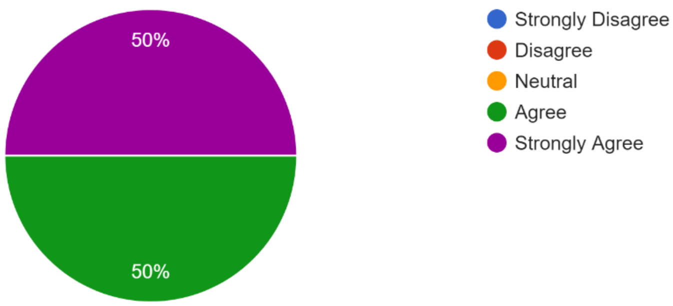
5. Diagram of answers to the statement “I found the various functions in this portal were well integrated.”



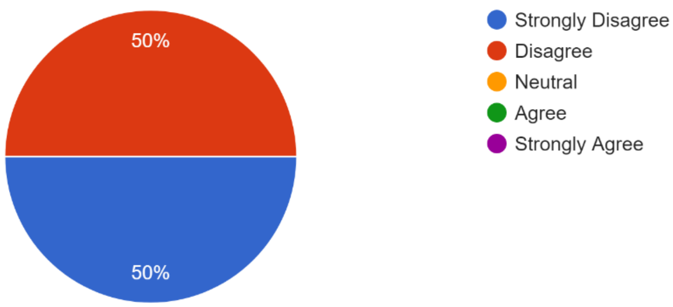
6. Diagram of answers to the statement "I thought there was too much inconsistency in this portal."



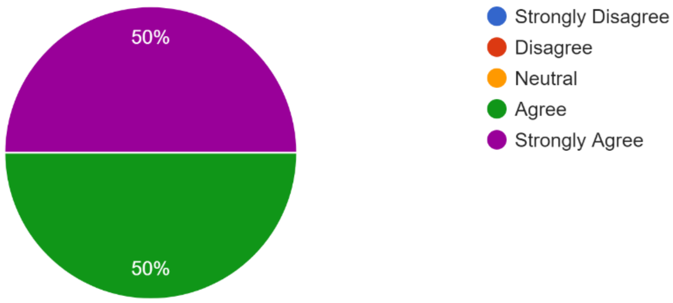
7. Diagram of answers to the statement "I would imagine that most people would learn to use this portal very quickly."



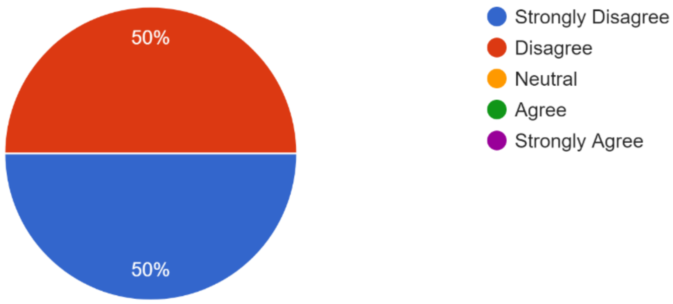
8. Diagram of answers to the statement "I found this portal very cumbersome/awkward to use."



9. Diagram of answers to the statement "I felt very confident using this portal."



10. Diagram of answers to the statement "I needed to learn a lot of things before I could get going with this portal."



11. List of answers to the question "Which are the benefits of the interface of the portal addressed to the students' needs?"

"The ease of use, since students just need to access one unique application that contains all the required data. Another + is the fact that users can create their own apps, based on the published information."
"Easy access to data and tools."

12. List of answers to the question "Which are the drawbacks of the interface of the portal addressed to the students' needs?"

"The 3D application has some rendering issues."
"The need to confirm an authentication already given, the sharing icon can be understood as a measurement of angles or azimuths."

13. List of answers to the question "Which are the improvements that you would suggest being done to this portal?"

"Some minor navigation or visual improvements. I would suggest the implementation of several tool tips or hints integrated within the application, shortly explaining how to use some features/widgets/functionalities."
"Rendering of the 3D data from other sources."

14. List of answers to the question "As an overall experience, what comments do you have about the usability of the portal?"

"Since this is an application intended for the use of students (experts), I think that they should not face any usability difficulties.

I would also consider this application and data for the use of public in general.”
“The portal is easy to use, the applications accessible, but there was an issue with rendering the third-party 3D Data.”

F. Usability evaluation – user testing questionnaire extracted from Google Forms

2/9/2019 Studmap 3.0 – student usability evaluation

Studmap 3.0 – student usability evaluation

This form is destined for the evaluation of usability of the Studmap 3.0 portal interface.
Before answering the questionnaire, please complete the following tasks to get acquainted with the interface:

1. Access Studmap 3.0 Portal at: http://ivvgeo-portal.geo.uni-muenster.de/portal/apps/sites/#/studmap30 (make sure you access the portal using the internal network of the WWU or through VPN) and log in using the following credentials:
   username: dummy_viewer
   password: PasswordViewer1
2. Find and access one official layer of NRW (eg. Administrative boundaries of NRW) - go back to the main interface
3. Find and access one layer published during the class of UAS2018 (eg. Image composition UAS2018) - go back to the main interface
4. Open a 2D application
5. Switch the basemap
6. Add data to the application and compare it with the existing data on the application
7. Measure a short distance on the map - go back to the main interface
8. Open a 3D application
9. Switch the basemap
10. Measure a short distance on the map

* Required

1. I think that I would like to use this website frequently. *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

2. I found this portal unnecessarily complex. *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

https://docs.google.com/forms/d/1IcnbNRvHdAPbjPFIQG-KkbLKXigiUUJefB8V6evU7QE/edit 1/3

3. **I thought this portal was easy to use.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

4. **I think that I would need assistance to be able to use this portal.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

5. **I found the various functions in this portal were well integrated.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

6. **I thought there was too much inconsistency in this portal.** *

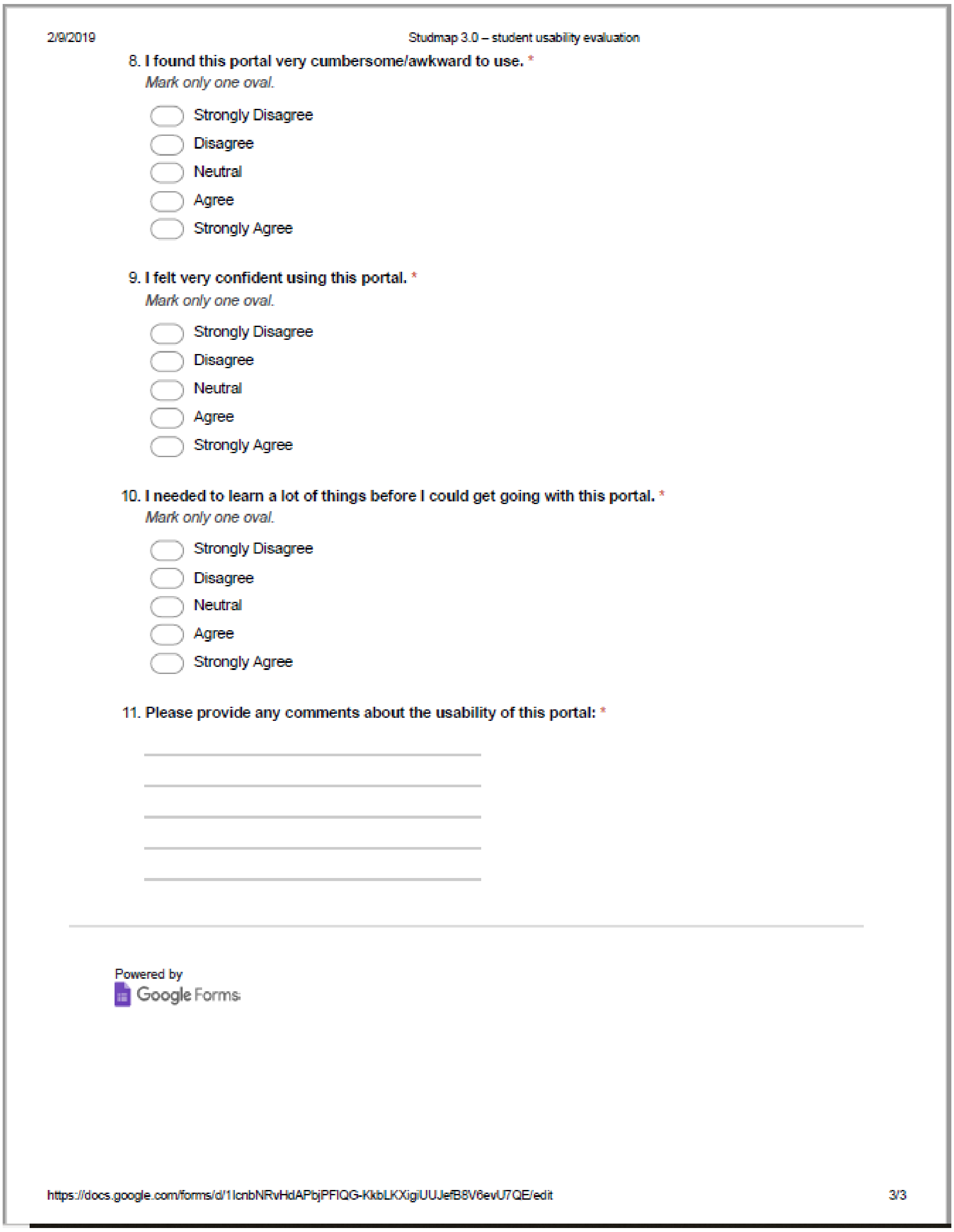
Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

7. **I would imagine that most people would learn to use this portal very quickly.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree


2/9/2019 Studmap 3.0 – student usability evaluation

8. **I found this portal very cumbersome/awkward to use.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

9. **I felt very confident using this portal.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

10. **I needed to learn a lot of things before I could get going with this portal.** *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

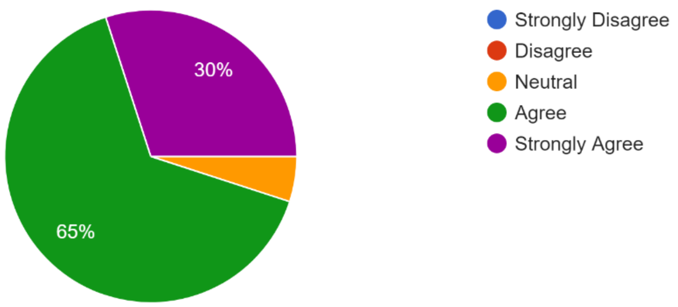
11. **Please provide any comments about the usability of this portal:** *

Powered by Google Forms

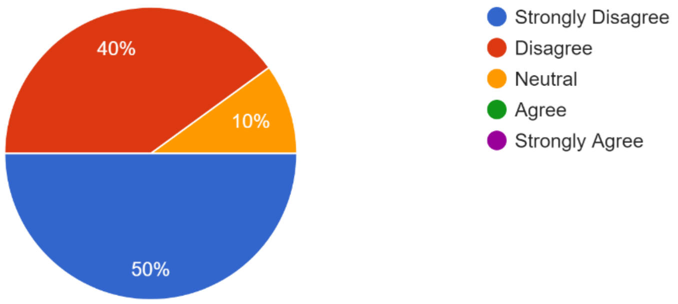
https://docs.google.com/forms/d/1IcnbNRvHdAPbjPFIQG-KkbLKXigiUUJefB8V6evU7QE/edit 3/3

G. Usability evaluation – user testing results extracted from Google Forms

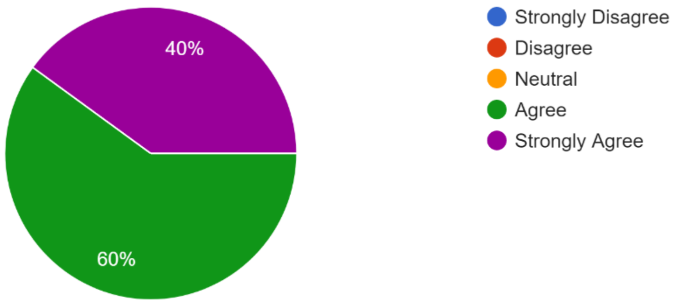
1. Diagram of answers to the statement “I think I would like to use this website frequently.”



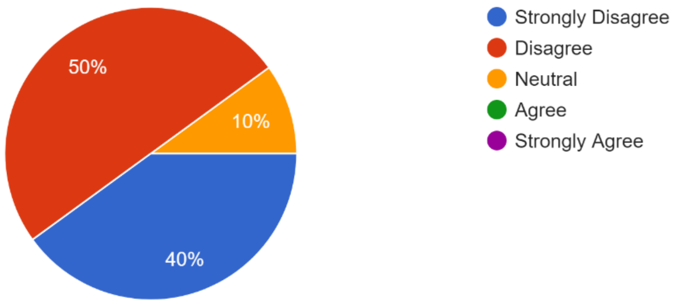
2. Diagram of answers to the statement “I found this portal unnecessarily complex.”



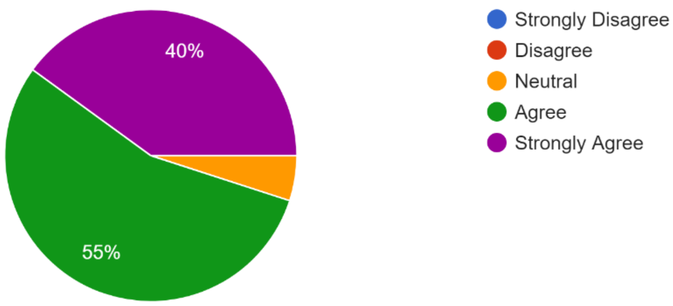
3. Diagram of answers to the statement “I thought this portal was easy to use.”



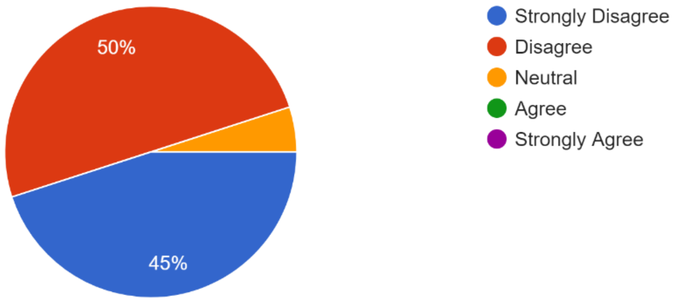
4. Diagram of answers to the statement “I think that I would need assistance to be able to use this portal.



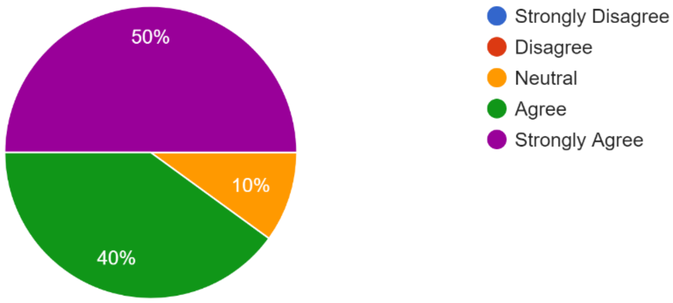
5. Diagram of answers to the statement “I found the various functions in this portal were well integrated.”



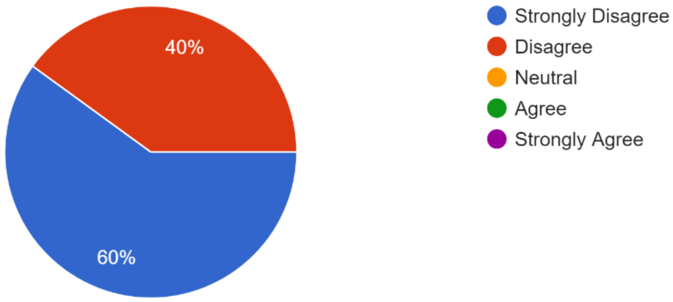
6. Diagram of answers to the statement “I thought there was too much inconsistency in this portal.”



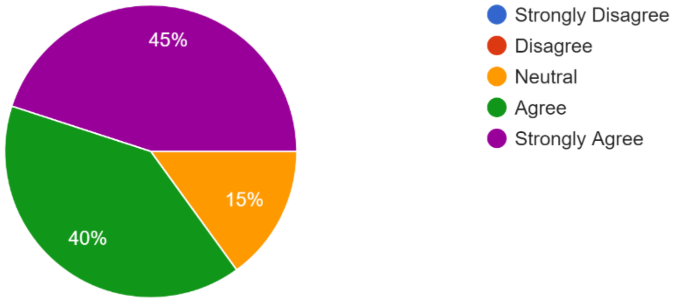
7. Diagram of answers to the statement “I would imagine that most people would learn to use this portal very quickly.”



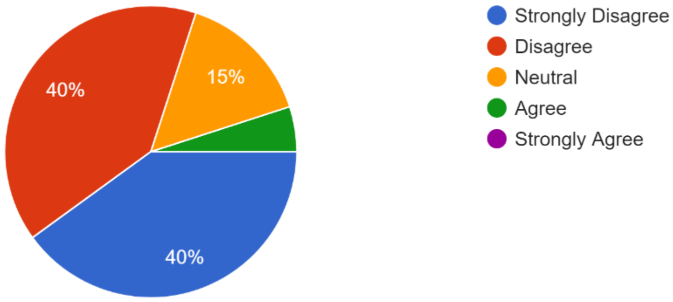
8. Diagram of answers to the statement “I found this portal very cumbersome/awkward to use.”



9. Diagram of answers to the statement “I felt very confident using this portal.”



10. Diagram of answers to the statement “I needed to learn a lot of things before I could get going with this portal.”



11. List of answers to the statement “Please provide any comments about the usability of this portal:”

• “Very fast and simple to use, maybe change the application to data or to database”
• “This portal looks interesting to access the data to the users, specially it would help the students of WWU. If these kinds of portal existed before, I could have benefited while I (sic!) was working on some projects while I was studying in WWU. This project is very appreciative and can be applied for research purpose for students and researchers. Since the portal works on ArcGIS server, the speed depends on the server capacity. Therefore, (sic!) the capacity of the server would determine the speed. The interface of the portal looks interesting and easy to use even for the new explorer. Good Luck. You did a great job!”
• “It looks and works great! Really cool.”
• “I think it is very useful geoportal with the access to both maps and meta data information. The different interfaces with 2d and 3d functionalities, import features even from csv (useful for direct field data import), measurement features are really appreciable.”
• “Well designed, convenient to use.”
• “This portal could be really helpful for the students to explore the existing geospatial data in the common platform.”
• “The user interface is very friendly and the portal tools easy to learn. The layers are displayed very quickly, regardless of whether it is 2D or 3D. I only have one suggestion: during the navigation through the layers was missing a legend of the layers. This will allow us to give a better interpretation of the maps. For example, the red and green colors in the aspect and slope rasters should have a meaning.”
• “It was well designed, (sic!) and everything was nicely integrated.”
• “It's a great one.”
• “Helpful tool for the specific are it's located.”
• “The portal is simple, fast and looks neat. I could not use the 3D viewer because apparently I have issues with GPU performance.”
• “Nice and intuitive interfaces!”

• “The portal is very straightforward and user friendly with very clear classification of the data available. I just found little problems switching from one app to other one (from 2D to home page to enter again 3D).”
• “The portal looks really nice, it was easy to do all the task and the web performance was good. I also tried "find data" option and was good.”
• “It would be nice if the user could start its own app, to explore its own data in combination with the available one. As far as I could see only the predefined apps are available. I found it a bit weird that some layers I try to preview just show as a square, but I think that is more related to the ESRI platform.“
• “Nice and fluent.”
• “The user experience was very good. All the tasks were very easy to implement.”
• “Portal was quite easy to use from the first time. No need to look for a long time to find a proper bottom or layer, though there were not many of them. Also, (sic!) the dark interface background was really pleasant. “
• “Very user friendly and clean.”
• “The applicability of the portal was pretty straightforward. The learning curve is not steep and will only provide minor inconvenience to people who are not even remotely associated with geospatial background.”