DEVELOPMENT OF CARTOGRAPHIC STYLING TOOL TO SUPPORT GEOSPATIAL DATA INTEROPERABILITY

MUHAMMAD HANIS BIN RASHIDAN

UNIVERSITI TEKNOLOGI MALAYSIA

DEVELOPMENT OF CARTOGRAPHIC STYLING TOOL TO SUPPORT GEOSPATIAL DATA INTEROPERABILITY

MUHAMMAD HANIS BIN RASHIDAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Geoinformatics)

Faculty of Build Environment and Surveying
Universiti Teknologi Malaysia

AUGUST 2018

The sake of Allah Almighty
Dearest parents, Abah & Emak,
And to beloved people of my life

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my supervisor, Dr. Ivin Amri Musliman for the continuous support of my studies, patience, and kindness in completing this research. This research would not be completed without the generous guidance, motivation and persistent help from him from the beginning till its final stage. May Allah reward you with goodness. A thousands of thanks to my co-supervisor Assoc. Prof. Dr. Zulkepli Majid, examiners Assoc. Prof. Sr. Mohamad Nor Said and Assoc. Prof. Sr. Dr. Jasmee Jaafar, and postgraduate office members Faculty of Build Environment and Surveying for your supports, encouragement, and motivation throughout this postgraduate journey. Abundance of thanks to all fellow friends Akmal, Jahidi, Farid, Azizol, Amirul, Ain, and Radhi for all the fun we had together within these few years, otherwise would be a somewhat stressful. Last but not least, my deepest gratitude to my beloved parents, sister and brothers for their endless love, prayers and encouragement. To those who indirectly contributed in the research, your kindness means a lot to me. May Allah bless ALL of you.

ABSTRACT

Cartographic styling is a technique used to present geographic data layers in various ways, and controls the appearance of geospatial data. Current practices used to maintain and store cartographic styling are through stylesheet formats, such as Styled Layer Descriptor, Esri layer file, and QGIS Style. However, the use of these formats in current geospatial applications is limited, especially in cross-platform applications. Therefore, a geospatial data format called GeoPackage has been used in this study to provide a new technique of maintaining cartographic styling, apart from the current practices. GeoPackage is an emerging geospatial data format introduced by Open Geospatial Consortium (OGC), with features including open-standard, independent, portable, robust, and cross-platform applications. In this study, a styling extension for GeoPackage was designed and developed to support the storage of styling data. The development of styling extension involves creation of data tables that is styling data model into the existing GeoPackage data model. The main function of the styling data model is to store styling records for geographic data layers within the GeoPackage. The capabilities of the new data model were tested in cross-platform applications including Windows, Linux, and Mac operating system. The testing was limited to vector data types such as point, line, and polygon, which represent geographic data layers. Results show that GeoPackage with the built-in styling extension is capable to store styling data, which can be loaded to cross-platform applications without the need for format conversion. In addition, the extension stores styling records together with the geographical data layers in a single file format (i.e. *.gpkg), in contrast to the use of other stylesheets, which store styling records in separate file format. This is possible because GeoPackage is a cross-platform geospatial data format that supports interoperability and thus, only requires single file format. Finally, this study successfully explores the capability of GeoPackage data format in maintaining and storing cartographic styling.

ABSTRAK

Penggayaan kartografi adalah teknik yang digunakan untuk memaparkan lapisan data geografi dalam pelbagai cara dan mengawal persembahan data geospatial. Amalan semasa yang digunakan untuk mengekal dan menyimpan penggayaan kartografi adalah melalui penggunaan format lembaran gaya seperti lapisan deskriptor bergaya, lapisan fail Esri, dan gaya QGIS. Namun, penggunaan format lembaran gaya ini dalam aplikasi geospatial semasa adalah terhad, terutamanya dalam aplikasi merentas platform. Oleh itu, satu format data geospatial yang dipanggil GeoPackage telah digunakan dalam kajian ini untuk menyediakan satu teknik baru dalam mengekalkan gaya kartografi, selain daripada amalan semasa. GeoPackage adalah format data geospatial yang diperkenalkan oleh konsortium geospatial terbuka (OGC), dengan ciri-ciri yang bersifat terbuka, bebas, mudah alih, teguh dan aplikasi merentas platform. Dalam kajian ini, satu penggayaan lanjutan untuk GeoPackage telah direka dan dibangunkan untuk menyokong penyimpanan data penggayaan. Pembangunan pelanjutan penggayaan ini melibatkan penambahan jadual data yang baru iaitu penggayaan model data ke dalam model data sedia ada GeoPackage. Fungsi utama penggayaan model data ini adalah untuk menyimpan rekod pengayaan bagi lapisan data geografi yang terdapat di dalam GeoPackage. Keupayaan model data yang baru ini telah diuji dalam aplikasi merentas platform termasuk dalam sistem operasi Windows, Linux, dan Mac. Ujian ini terhad kepada jenis data vektor seperti titik, garis, dan poligon yang mewakili lapisan-lapisan data geografi. Keputusan menunjukkan GeoPackage dengan penggayaan lanjutan yang dibangunkan mampu untuk menyimpan data penggayaan yang kemudiannya boleh digunakan semula pada aplikasi yang merentas platform tanpa perlu kepada penukaran format data. Selain itu, melalui penggayaan lanjutan ini maklumat penggayaan dapat disimpan bersama-sama dengan lapisan data geografi di dalam satu fail format (iaitu *.gpkg), berbeza dengan penggunaan lembaran gaya lain yang menyimpan maklumat penggayaan dalam format fail-fail yang berasingan. Ini kerana GeoPackage adalah satu format data geospatial yang bersifat merentas platform dan menyokong kebolehoperasian, justeru hanya memerlukan satu fail format. Akhirnya, kajian ini berjaya meneroka keupayaan format data GeoPackage dalam mengekalkan dan menyimpan penggayaan kartografi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

API	-	Application Programming Interface
FGDC	-	Federal Geographic Data Committee
FOSS4G	-	Free Open Source Software for GIS
FME	-	Feature Manipulation Engine
GDAL	-	Geospatial Data Abstraction Library
GeoSWG	-	Geospatial Science Working Group
GIS	-	Geographic Information System
IT	-	Information Technology
NSDI	-	National Spatial Data Infrastruture
MyGDI	-	Malaysia Geospatial Data Infrastructure
OGC	-	Open Geospatial Consortium
QML	-	Qt Modeling Language
SLD	-	Styled Layer Descriptor
SE	-	Symbology Encoding
SDK	-	Software Development Kit
XML	-	eXtensible Markup Language

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In Geographic Information Science (GIS) map is defined as a representation of earth features, and carries information about specific things. Nowadays maps can be found in several types such as topographic, physical, climate, and thematic map. A good map will make the user to understand the map faster and accurate, this can be done by organizing the elements of the map to convey its message to its users. Hence, there are several elements that play an important role in the process of map making (cartography); such as projection, scale, title, data frame, symbology and styling, generalization, legend and others. For example, styling is used for highlighting geographic features by manipulating different colours and elements.

Map styling is one of the most important aspects in geographic data representation to the end user. It is a process done by cartographer to utilize colour, shape, width, transparency and pattern on the map features. The styling used might have relationships to the features represented. For instance, a blue colour is chosen to represent fresh water or ocean, while green colour is almost chosen to represent green areas in the real world (e.g. forest and vegetation).

There are numerous map styling encoding standards available, defined by the authorised and non-profit agencies. The purpose of the styling encoding standards is to aid cartographers in the production of map, as well as to ensure a more consistent appearance and data content. For instance, in the Malaysian Geospatial Data Infrastructure (MyGDI), the Standard Technical Committee is dedicated to develop standards for geographic information for the purpose of data sharing. There are three types of geospatial-related standards covered by the MyGDI, i.e. contents standards, access standards and exchange standards. Contents standards include land parcel identifier (UPI), features and attributes code (MS1759) and geographic place names (MyGeoName). Access standards take into account standards in the data communication such as ISO 19100 series for geographic information. Exchange standards include XML and GML.

Meanwhile, at the international level there are several agencies such as Federal Geographic Data Committee (FGDC) – a digital cartographic standard for geologic maps symbolization; Geography and Geospatial Science Working Group (GeoSWG) – cartographic guidelines for public health; United States Geological Survey (USGS) – selection of colours and patterns for geologic maps; and many more. Because of maps are the end user products, therefore they must be produced strictly under the defined guidelines and standards, in order to avoid misleading maps interpretation.

Nowadays, *digital maps* have become more popular and common due to the advancement in the Information Technology (IT). Map production is seen to move from traditional method to a digital production. This is due to the countless geographic data being stored and shared in digital format. There are varieties of geospatial data formats such as geodatabase, MySQL, Oracle, PostgreSQL, etc. or file format such as Shapefile, MapInfo TAB, GeoJSON, and GeoPackage. A variety of GIS software and applications (proprietary and open source) is available on the market, offering supports (read and write access) for these data formats. These software allow users to manipulate and visualize geographic data easily using the spatial tools available.

Moreover, there are variety of web GIS software (ArcGIS Server, GeoServer, MapServer, and MapGuide) and web service APIs (Google Maps, OpenLayers, ArcGIS Online, and OpenStreetMap) available for users to publish their data online. The abundance of these software packages in the market has encouraged more users to exchange their data, thus leading to the term of *geospatial data sharing*. Sharing geospatial data has become widespread among GIS users due to the government departments, agencies and professional are actively involved in the distribution of these data.

The geospatial data sharing activities are progressively increasing with the establishment of *National Geospatial Data Infrastructure* (NSDI). Developed countries have implemented and established their national geospatial data centre. The *Malaysia Geospatial Data Infrastructure* or known as MyGDI is an initiative by the government to develop a geospatial data infrastructure to enhance the awareness on the availability of dataset and improve access to geospatial information (MaCGDI, 2016). MyGDI comprises of policies, standard, technology, research and development that benefits government, agencies, non-profit sectors and academic community in terms of cost effective and timely delivery of geospatial data to facilitate the sharing and dissemination of geospatial information.

The Open Geospatial Consortium (OGC) is an international non-profit organization responsible in making quality open standards for the global geospatial community (Daisey, 2016). These standards are made through a consensus process and are freely available for users to use to improve sharing of the world's geospatial data. They are used in a wide variety of areas including environment, military, agriculture, education, and sustainable development. Due to the overwhelming geospatial data sharing among users over the globe and the need for interoperability, OGC has introduced a new GIS data format called GeoPackage (.gpkg) which was carefully designed to facilitate a widespread adoption by both commercial and open-source software applications - on enterprise production platforms as well as mobile handheld devices (OGC Network, 2016).

The geopackage format was designed with a database capability, lightweight, interoperable across all computing platforms, and can be used without intermediate format translation. As this format is still under development by the OGC, exploring its benefits and uses towards interoperability would be interesting.

1.2 Problem Statement

The current practices used by geospatial communities for storing and maintaining cartographic styling are through the use of SLD (Styled Layer Descriptor), GeoJSON, ESRI Layer, or Qt Modelling Language (Ordnance Survey, 2015). These stylesheets are used to store symbology and styling, and then can be applied to the data. Styled Layer Descriptor is an XML based, specified by the OGC to allow user-defined symbolization and colouring of geographic features (OGC, 2007). It is capable of defining the rendering of vector and raster dataset and typically used to instruct Web Map Service (WMS) on how to render specific layers. In August 2007, the SLD specification was split up into two new OGC implementation specifications – Symbology Encoding (SE) and Styled Layer Descriptor (SLD) (Bacharach, 2007). Users now may use SDL or SE as a medium to carry and share their styling on the Internet. For example in GeoServer users may import SDL into styles directory to apply the defined styles on specific layers.

Besides that, there are reports on the users who used GeoJSON for storing and maintaining styling on geometry features (Agafonkin, 2017). GeoJSON is a format known as the de facto data standard for web mapping applications, which open-standard for representing geographic data along with attributes, based on JavaScript Object Notation. Even though there is no standard in the GeoJSON for storing styling; few parties (fulcrum, mapbox and leaflet) have seen to implement styling specification in GeoJSON (McBride, 2015) (Mapbox, 2016) (Agafonkin, 2017). They applied *simplestyle* (an open source specification for styling GeoJSON

data) as a practical approach for defining features on a map while it preserves data cleanly and allowing a light layer of visual style.

Furthermore, ESRI introduced a Layer file (.lyr) that stores the path to a source dataset and other layer properties, including styling. In comparison to a Shapefile, a Layer file is a just a reference to actual data, such as the Shapefile, feature class, etc (ESRI, 2016a). A Layer file does not store the data's attributes or geometry since it is not an actual data. The purpose is to store the symbology and styling of the feature layers. For instance, if a Layer file (.lyr) shares to other users together with the actual data file (.shp), the new users can display the data with the applied style from the previous user.

Another method used to store styling is through the Qt Modelling Language (QML) – a user interface markup language. It is a JSON-like declarative language for designing user interface–centric applications. The use for QML for styling has commonly been used in QGIS applications (previously known as Quantum GIS). QML supports for both GML (Geography Markup Language) and Shapefile data (Ordnance Survey, 2015). To apply QML style in QGIS, users need to load the data and navigate to the style tab within the layer properties windows, and from there navigate to the directory containing the QML and apply.

As discussed, the current practices used for storing and maintaining cartographic styling have some limitations in several aspects. The use of SLD and GeoJSON are only applicable for web GIS applications, thus limits its uses within the desktop environment. Meanwhile, ESRI Layer file is an extension to the Shapefile and it holds the symbology and styling information of data feature, but with disadvantages due to the format which is in binary and not published, thus the conversion from that format would be more difficult and hence limits its usage. After all, the SLD, ESRI Layer and QML are simply stylesheet file formats that work on a specific platform, thus require extra time and work to re-apply styling when changing a platform. It depends on the product and the software that one wishes to use. For

example, QML is best to use in the QGIS, while ESRI Layer is for ArcGIS, and SLD is mainly used in GeoServer (and other web application) (Ordnance Survey, 2015).

The needs for an interoperable styling mechanism for a better geospatial data sharing is highlighted by Ardung (2017) on how to increase interoperability of ESRI Layer style between proprietary and open source GIS software. Therefore, for a greater interoperability, this study focuses on the enhancement of the GeoPackage capability to store and carry styling for cross-platform geospatial applications. If this happens, users can use GeoPackage as a medium to maintain styling which can then be opened in any working platforms such as desktop (Windows, Linux or Mac), website or mobile (Android). For this reason, a styling extension is needed for GeoPackage for greater data interoperability across multiple platforms and applications.

GeoPackage was introduced by the OGC on 13 February 2014 and became a robust geospatial data format that supports current trends and meets the geospatial data requirements in multiple domains, including defence and intelligence, emergency management, and mobile services (Daisey, 2016). GeoPackage is an open, standards-based, platform independent, portable and interoperable data format for sharing and displaying geospatial data in cross-platform desktop, website and mobile mapping applications (OGC, 2017). It has been recognized as a data format that enables the next generation of geospatial technologies (Brachman, 2017).

GeoPackage has been tested in a mobile embedded system to increase support for field operations in agriculture application (Zhang et al., 2016) and increased situational awareness for emergency support application (Adams & Suykens, 2013). Many software vendors have already implemented OGC GeoPackage encoding standard in their software packages, such as GDAL (Geospatial Data Abstraction Library), Quantum GIS, GeoServer (Web GIS), ESRI (Pioneering ArcGIS), NGA (National Geospatial-Intelligence Agency), Safe Software (FME Desktop), GeoTools, TerraGo, OpenJUMP, and Luciad (Mobile GIS).

GeoPackage is seen to provide a greater support for cross-platform geospatial applications either on desktop, website or mobile devices. It also provides interoperability capability for the users by reducing the needs for data conversion and translation, thus facilitates the process of data sharing and exchange. However, the current version of GeoPackage is 1.0.1 does not support styling (Daisey, 2016). It has to be noted that styling is undeniably an important element in cartography because it controls how the data are manipulated and visualize in delivering information to the end users.

1.3 Research Aim

The aim of this study is to design and develop a styling extension for GeoPackage data format to enable the storage of styling data.

1.4 Research Objectives

To achieve the stated research aim, the following objectives are formulated:

a. To study the potential and suitability of GeoPackage to store styling information.
b. To design and develop a styling extension within the GeoPackage data model.
c. To implement and test the GeoPackage styling extension in cross-platform geospatial applications.

1.5 Research Questions

There are several research questions developed in this study, as listed in the Table 1.1 below.

Table 1.1: Research questions based on the objectives

Objectives	Research Questions	Outcome
1. To study the potential and suitability of GeoPackage to store styling information.	i. What is the potential and suitability of GeoPackage to store styling? ii. How GeoPackage becomes a data format that carries styling?	i. Creation of new data tables into the existing GeoPackage data model.
2. To design and develop a styling extension within the GeoPackage data model.	iii. What are the criteria needed in designing a styling extension? iv. How to integrate the developed styling extension in GeoPackage data model?	ii. Styling data models for point, line and polygon. iii. GeoPackage plugin for a selected GIS package (QGIS).
3. To implement and test the GeoPackage styling extension in cross-platform geospatial application.	v. What methods should be used to implement and test the GeoPackage styling extension in cross-platform geospatial application?	iv. The GeoPackage extension capability and evaluation. v. Application in cross-platform.

1.6 Research Scope

The scope of the research comprises of design and development of the styling extension for GeoPackage data format which is then to be implemented and tested in cross-platform geospatial applications. Thus, there are several important aspects that need to be addressed, as described in the following sections.

1.6.1 GeoPackage Styling Extension

The styling extension is designed and developed specifically for OGC GeoPackage data format. It only covers vector data types for point, line and polygon geometries. To implement a styling extension, a styling data model (for point, line and polygon) is designed. This data model will define how styling data are connected to each other and how they are processed and stored inside the existing GeoPackage data model. The designed styling data model is referenced and based on the existing international standard (Styled Layer Descriptor) and QGIS Qt Modelling Language. This study only applies basic styling elements in designing the styling data model as styling is a huge topic thus required time and expertise to develop a complete package. Moreover, the design and development does not include symbology aspects but limited to the basic styling. It is because the study focuses on the capability of OGC GeoPackage to carry the styling information across multiple platforms.

1.6.2 Development and Implementation

The development and implementation of the styling extension are done in selected software, i.e. QGIS. QGIS is one of the best Free and Open Source Software for Geospatial (FOSS4G) which offers users to create, edit, visualise, analyse and publish geospatial information on Windows, Mac, Linux, and Android. Its versatility, allows GIS users to develop their own geospatial scripts which can then be deployed in the QGIS Plugin repositories. In this study, a GeoPackage plugin is developed to support the implementation process. The plugin works by creating styling data model in the GeoPackage data model, and control read and write access for storing and accessing data styling. The implementation and testing are done in multiple platform application to test the interoperability of the new extension. A sample dataset with a custom styling standard is used to test the styling extension in Windows, Linux, Mac, and Android platforms.

1.6.3 Dataset

Klang Valley dataset which is centred in Kuala Lumpur and includes the adjoining cities and towns in the state of Selangor is used in this study. It consists of vector points, lines, and polygons that describe the study area, the street, as well as several public transports such as buses and trains. The dataset is obtained from the OpenStreetMaps - free and open license geographic data. The dataset is downloaded in Shapefile format and then converted into PostgreSQL database format through PostGIS extension for data cleaning and post processing. Data cleaning is the process of detecting and correcting (or removing) corrupt or inaccurate records from a record set, table, or database and refers to identifying incomplete, incorrect, inaccurate or irrelevant parts of the data and then replacing, modifying, or deleting the dirty or coarse data. After cleaning, the dataset is translated into the GeoPackage format and ready to be tested with the developed extension. Figure 1.1 shows the Klang Valley area as captured from the OpenStreetMap.

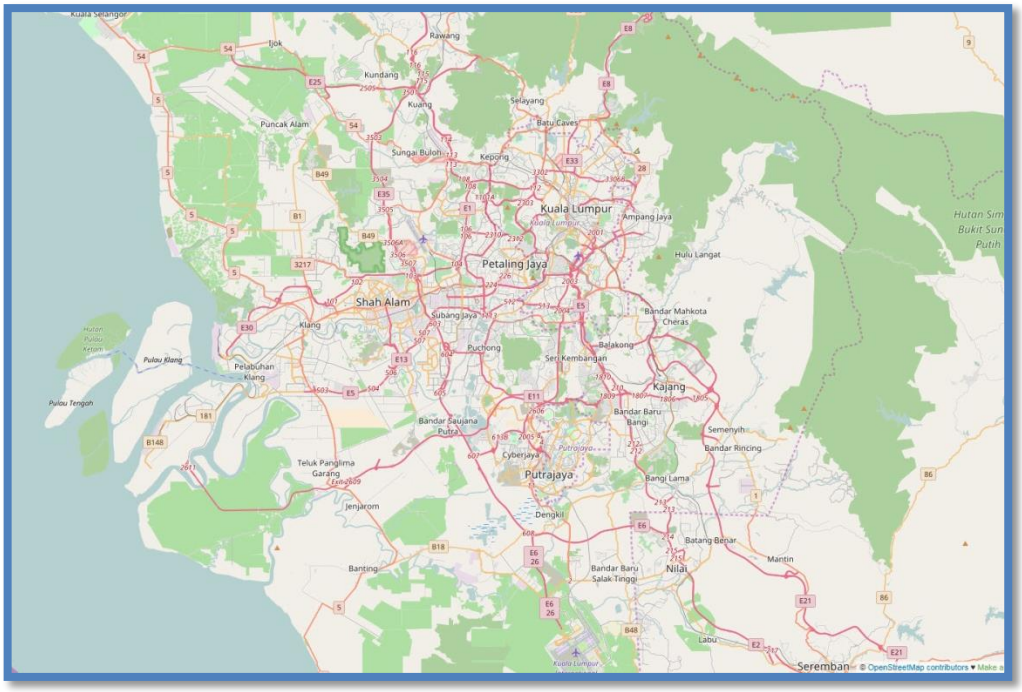

Figure 1.1: Klang Valley area viewed on OpenStreetMap

Source: Image captured based on OpenStreetMap

1.6.4 Software

There are several important software used for this study as shown in Table 1.2.

Table 1.2: Software used for this study

Software	Function	Description
QGIS	Desktop GIS	Used to implements GeoPackage styling extension
GDAL	Geospatial Data Abstraction Library	Used for data conversion between Shapefile, PostgreSQL and GeoPackage
PostgreSQL	Advanced open source database	Used as a database management system

PostGIS	Extension to PostgreSQL	Used to provide spatial data objects
ArcGIS	Desktop GIS	Used to test GeoPackage styling extension
Qt Designer	Tool for designing and building graphical user interface	Used for designing the extension's graphical user interface
Spatialite GUI	Open source tool for supporting SpatiaLite	Used to check GeoPackage data table and structure.

1.7 Research Significance

This study is significant in order to response to the problem statement which has been stated earlier. Due to the need for an interoperable styling mechanism for styling data sharing, the research has proposed a styling extension for GeoPackage data format. This extension is expected to preserve cartographic styling during geographic data transfer across different operating platforms. Through a GeoPackage, styling data can be kept together with the geometries and attributes in a portable and single-file based, thus provides a different way in maintaining styling information without the need for stylesheet files. To conclude, this research is significant in studying GeoPackage as a data format that is capable for storing cartographic styling information.

1.8 Thesis Structure

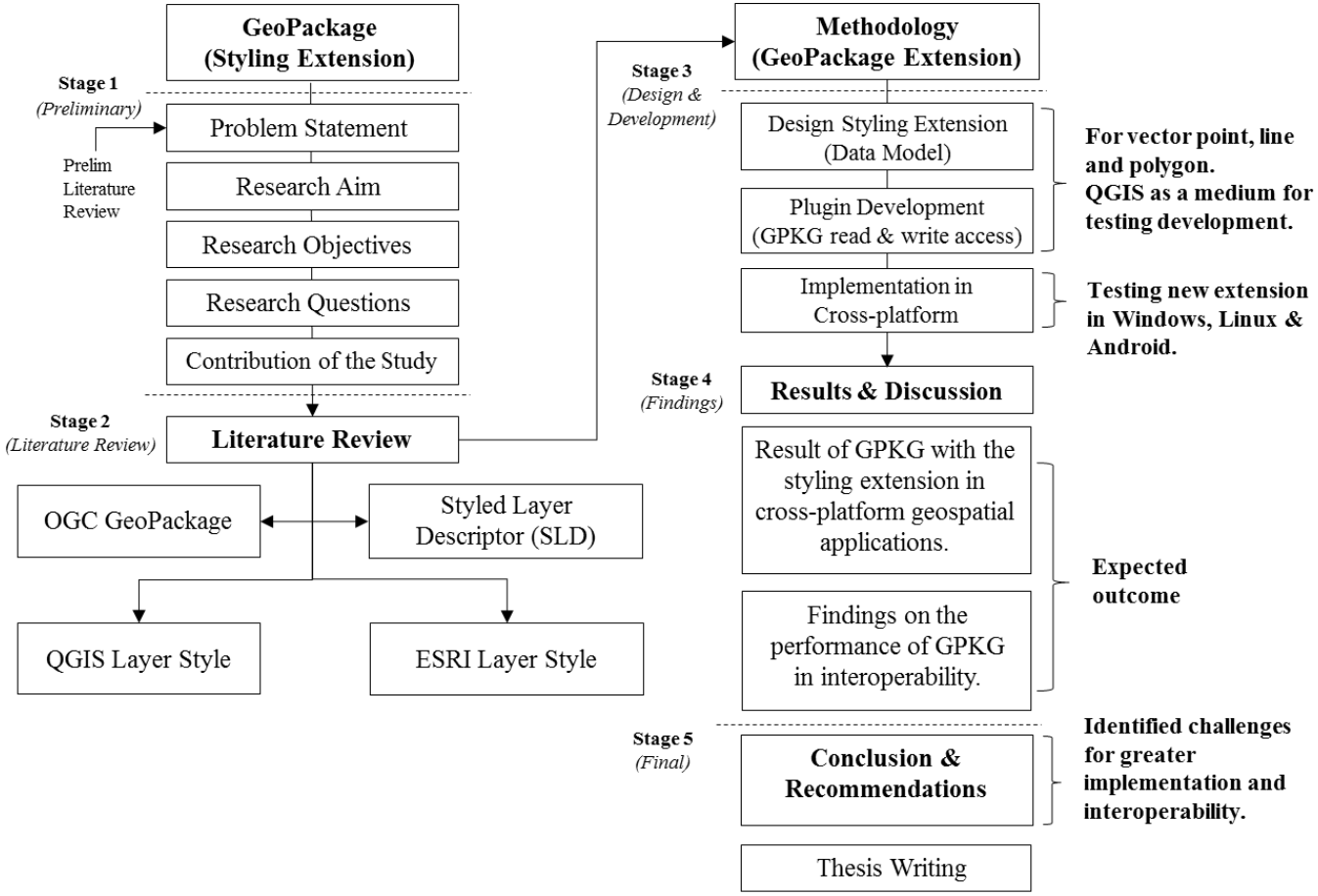

Figure 1.2: The thesis structure consists of five stages and each stage is accordingly written in the following Chapter 1, 2, 3, 4 and 5

REFERENCES

Adams, B., & Suykens, F. (2013). Astute: Increased Situational Awareness through proactive decision support and adaptive map-centric user interfaces. *European Intelligence and Security Informatics Conference*, pp. 289-293. doi:10.1109/EISIC.2013.74

Agafonkin, V. (2017). *Using GeoJSON with Leaflet.* Retrieved from Leaflet - an open-source JavaScript library for mobile-friendly interactive maps: http://leafletjs.com/examples/geojson/

Ardung, O. (2017). *Closed To Open Source GIS: First Steps In Reverse Engineering ESRI's Layer Definition File Format.* Dissertation.

Bacharach, S. (2007). *The OGC Announces Styled Layer Descriptor & Symbol Encoding Specifications.* Retrieved from Open Geospatial Consortium Inc.: http://www.opengeospatial.org/pressroom/pressreleases/761

Bishr, Y. (1998). Overcoming the semantic and other barriers to GIS interoperability. *International Journal of Geographical Information Science*, 299-314.

Borcher, E., & Ertz, O. (2015). Towards Cartographic Portrayal Interoperability – the Revision of OGC Symbology Encoding Standard. *1st ICA European Symposium on Cartography*, *1*, pp. 116-119.

Brachman, M. (2017). *OGC GeoPackage: Enabling the Next Generation of Geospatial Technologies.* Retrieved from Open Geospatial: http://www.opengeospatial.org/

Brodie, M. (1992). The promise of distributed computing and the challenge of legacy Information systems. *In Proceedings of the IFIP WG2-6 Database Semantics Conference on Interoperable Database Systems (DS-5), Lorne,*, (pp. 1-31). Victoria, Australia (Amsterdam).

Bruy, A., & Svidzinska, D. (2015). *QGIS by Example - Leverage the power of QGIS in real-world applications to become a powerful user in cartography and GIS analysis.* Packt Publishing Ltd.

Buehler, K., & McKee, L. (1996). *The OpenGIS Guide: Introduction to Interoperable Geoprocessing: Part I of the Open Geodata Interoperability Specification (OGIS).* Open GIS Consortium, Incorporated.

Christophe, S., Dumenieu, B., Turbet, J., Hoarau, C., Mellado, N., Ory, J., . . . Vergne, R. (2016). Map style formalization: rendering techniques extension for cartography. *Expressive 2016 The Joint Symposium on Computational Aesthetics and Sketch-Based Interfaces and Modeling and Non-Photorealistic Animation and Rendering* (pp. 59-68). The Eurographics Association.

Daisey, P. (2016). *OGC® GeoPackage Encoding Standard.* (J. Yutzler, Ed.) Retrieved from Open Geospatial Consortium: http://www.opengeospatial.org/standards/geopackage

ESRI. (1998). ESRI Shapefile Technical Description. *An ESRI White Paper*.

ESRI. (2016a). *What is the difference between a shapefile and a layer file?* Retrieved from ESRI Technical Support: http://support.esri.com/en/technical-article/000011516

ESRI. (2016b). *What information is stored in a layer (.lyr) file?* Retrieved from Technical Support: http://support.esri.com/en/technical-article/000004904

ESRI. (2016c). *Is it possible to save a layer file into a file geodatabase?* Retrieved from Technical Support: http://support.esri.com/en/technical-article/000012097

GDAL. (2016). *GeoPackage vector.* Retrieved from GDAL - Geospatial Data Abstraction Library: http://www.gdal.org/drv_geopackage.html

GeoPackage SWG. (2014). *GeoPackage Standard Working Group Charter.* (P. Daisey, Ed.) Retrieved from Open Geospatial Consortium.

GeoServer. (2016). *GeoPackage Extension - A plugin to read and write GeoPackage files in GeoServer.* Retrieved from GeoServer: http://docs.geoserver.org/latest/en/user/community/geopkg/

MaCGDI. (2016). *Malaysia Geospatial Data Infrastructure (NSDI) Overview.* Retrieved from Malaysian Centre for Geospatial Data Infrastructure (MaCGDI): http://www.mygeoportal.gov.my/mygdi-overview

Mapbox. (2016). *Mapbox Style Specification.* Retrieved from Mapbox: https://www.mapbox.com/mapbox-gl-js/style-spec/

Masó, J., Diaz, P., Riverola, A., Díaz, D., & Pons, X. (2013). Exchanging the Status between Clients of Geospatial Web Services and GIS applications using Atom. *Proceedings of the International MultiConference of Engineers and Computer Scientists, 1.*

McBride, B. (2015). *GeoJSON Feature Styling in geojson.io.* Retrieved from Fulcrum mobile location leverage: http://www.fulcrumapp.com/geojson-feature-styling/

OGC. (2007). *Styled Layer Descriptor profile of the Web Map Service (Implementation Specification).* (M. Lupp, Ed.) Retrieved from Open Geospatial Consortium Inc.: http://www.opengeospatial.org/standards/sld

OGC. (2017). *An Open Format for Geospatial Information.* Retrieved from GeoPackage: http://www.geopackage.org/

OGC Network. (2016). *GeoPackage.* Retrieved from GeoPackage Information and Data Models: http://www.ogcnetwork.net/geopackage

Ordnance Survey. (2015). *Cartographic Stylesheet: Instructions for using Ordnance Survey's cartographic stylesheets.* Southampton: Ordnance Survey © Crown. doi:D11976 1015

Pierce, E. (2014). *Esri Supports OGC GeoPackage Encoding Standard.* Retrieved from ESRI ArcGIS: http://www.esri.com/esri-news/releases/14-2qtr/esri-supports-ogc-geopackage-encoding-standard

Safe Software. (2016). *Integrate OGC GeoPackage Using FME.* Retrieved from Safe Software: https://www.safe.com/integrate/ogc-geopackage/

Singh, R., & Bermudez, L. (2013). Emerging Geospatial Sharing Technologies in Earth and Space Science Informatics. *American Geophysical Union, Fall Meeting*.

Zhang, C., Sun, Z., Heo, G., Di, L., & Lin, L. (2016). Developing a GeoPackage Mobile App to Support Field Operations in Agriculture. *Fifth International Conference on Agro-Geoinformatics (Agro-Geoinformatics)*, pp. 1-4. doi:10.1109/Agro-Geoinformatics.2016.7577656

Zhao, T., Li, W., & Zhang, C. (2015). Geospatial Data Interoperability, Geography Markup Language (GML), Scalable Vector Graphics (SVG), and Geospatial Web Services. *Geospatial Semantic Web*, Springer International Web. doi:10.1007/978-3-319-17801-1_1