WHAT3WORDS GEOCODING EXTENSIONS AND APPLICATIONS FOR A UNIVERSITY CAMPUS

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August 2018

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August 2018

PREFACE

This technical report is a reproduction of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Department of Geodesy and Geomatics Engineering, August 2018. The research was supervised by Dr. Emmanuel Stefanakis, and support was provided by the Natural Sciences and Engineering Research Council of Canada.

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Jiang, Wen (2018). *What3Words Geocoding Extensions and Applications for a University Campus.* M.Sc.E. thesis, Department of Geodesy and Geomatics Engineering Technical Report No. 315, University of New Brunswick, Fredericton, New Brunswick, Canada, 116 pp.

ABSTRACT

Geocoded locations have become necessary in many GIS analysis, cartography and decision-making workflows. A reliable geocoding system that can effectively return any location on earth with sufficient accuracy is desired. This study is motivated by a need for a geocoding system to support university campus applications. To this end, the existing geocoding systems were examined. Address-based geocoding systems use address-matching method to retrieve geographic locations from postal addresses. They present limitations in locality coverage, input address standardization, and address database maintenance. These limitations have recently sparked an interest in developing alternative geocoding systems that apply alphanumeric codes as a reference to locations, such as Geohash, Google's Open Location Code, and what3words to name a few. Among them, what3words drew attention. It uses a simple combination of three words as a code to represent the location within a 3-meter square on the earth surface. The codes of what3words are less error-prone in communication, efficient to encode and decode, easier to memorize, and multiple languages are supported. The advantages of w3w geocoding system makes it a suitable geocoding method for university campus applications. However, the fixed 3 by 3 meter resolution and lack of consideration of three-dimensional encoding may limit its applicability. To better support geographic applications with special requirements, the what3words geocoding system was extended. This research proposes a series of what3words geocoding extension models in two aspects: variable-resolution and third dimension support. To satisfy the needs of applications for both indoor and outdoor environments, the extensions provide a variety

of finer and coarser resolutions of w3w cells. They also enable the three-dimensional encoding.

An RESTful application programming interfaces (API) implementing one of the w3w extensions—QTEM model, was designed and tested in order to perform the two-way transformation between the extended code and the geographic coordinates. This API was used as the geocoding processing component in the development of three application prototypes for a university campus, which are indoor facility management, indoor navigation, and outdoor navigation.

ACKNOWLEDGMENTS

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Stefanakis for his continuous support, guidance and mentorship throughout this project. His encouragement provided me many opportunities to explore and learn more in this field. Thank you more than I can say.

I am also thankful to Professor Bateman and Professor Bidlake for their support and help in Java programming.

Thanks to David Fraser, for his help in providing the data for this study.

Special thanks to Mike Bremner, for his encouragement, support, insights, and advises on this research. I want to acknowledge and appreciate the help and mentorship he provides me up until this day.

I am deeply grateful to my family, for their love, support and understanding throughout my life.

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1. INTRODUCTION

Geocoding is the process of converting descriptive locational information into geographic representations (Goldberg, 2013). This process is widely used to transform postal addresses into geographic coordinates for mapping, visualization and analysis purposes. With the recent advancement of location-based services, the demand for location data has dramatically increased (Jiang & Stefanakis, 2018). Geocoded locations have become essential component for GIS analysis and decision-making. As such, a variety of geocoding systems have been created to support specific applications, each with its own purpose and accuracy. This study is motivated by a need for a geocoding system to support university campus applications. A reliable geocoding system that can effectively return any location in the campus, with sufficient accuracy, is desired. For this purpose, an investigation on existing geocoding systems was performed.

Conventional geocoding systems based on the address-matching method have been used for decades. This method has several limitations, such as: the coverage, the required database maintenance, and the need for standardizing input address (Lee, 2009; Karimi et al., 2011; Zandbergen, 2008). Despite efforts made to improve the address-based geocoding systems, the limitations involved have not been completely resolved (Lee, 2009).

Alphanumeric code geocoding schemes provide alternatives to overcome some of the constraints of address-based geocoding. The mechanism of alphanumeric code

geocoding systems is the division of the earth surface into layers of cells with variable resolutions and the assignment of a unique code to each cell. Each implementation of alphanumeric code geocoding utilizes its own geocoding algorithms to transform between alphanumeric codes and the corresponding coordinates (Jiang & Stefanakis, 2018). With alphanumeric code geocoding, the static code assigned to each cell does not change over time, whereas a postal address may be changed to reflect real world changes. The code is also simple to encode and decode and is efficient for communication.

Among the alphanumeric code geocoding systems, what3words (w3w) is of particular interest to this study. It partitions the earth surface into homogeneous squares each very close to 3m by 3m in size (Barr, 2015). The code assigned to each cell is a distinct three-word combination. Instead of using a string of pseudo-random numbers and letters to describe a code, what3words uses words because they are easier to remember. In addition, the communication of distinct word sets is less error-prone than long codes mixing numbers and letters. It also supports multiple languages (w3w, 2018). The advantages that w3w presents have been widely recognized. It has been used in many applications (w3w, 2018), such as: mobility, delivery, unmanned aerial vehicle (UAV), assets management, and emergency response worldwide.

Despite the advantages the w3w has, it still presents limitations. The fixed 3 by 3 meter resolution and lack of consideration of three-dimensional encoding may hinder its adoption in specific applications. For instance, a finer resolution with elevation information may better support applications for indoor activities. Likewise, a coarser

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resolution may be preferable for applications that serve outdoor environment such as emergency evacuation. For this reason, this study is focusing on extending the what3words geocoding system to address the previously mentioned limitations. These extended w3w models can be applied to support geographic applications in a micro-scale area such as a university campus.

1.1 Research Questions

The invention of w3w geocoding system provides an new approach of location encoding. It overcomes the limitations of address-based geocoding. However, the w3w geocoding still has limitations, impeding its implementation in many applications. Therefore, the primary question of this thesis is how the w3w geocoding could be extended to better meet the needs of both outdoor and indoor applications for a university campus. To this end, a series of w3w geocoding extensions were proposed. The following question is how the w3w geocoding extensions can be utilized in applications. Thereby, a RESTful API implementing one of the extension was developed and employed by the applications.

1.2 Research Objectives

The overall objective of this study is to develop a geocoding system to support university campus applications. The specific research objectives are:

- Determine the aspects that the w3w geocoding need to be extended;
- Develop the extended models of the w3w geocoding;
- Develop the extended w3w geocoding RESTful API;
- Apply one of the w3w geocoding extensions to support university campus applications.

1.3 Thesis Structure

This research is presented as a five chapter, article-based thesis (Figure 1.1). Chapter 1 introduces the background, motivation, and objectives of this research. Chapter 2 to Chapter 4 present three peer-reviewed or under review, research papers. Chapter 5 provides the conclusions of the research.

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Chapter 1 Introduction:
Background; Research Questions; Research Objectives;
Thesis structure; Chapter Summaries
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Chapter 2: Paper 1
what3words Geocoding Extensions
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Chapter 3: Paper 2
A RESTful API for The Extended what3words Encoding
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Chapter 4: Paper 3
Applications of what3words Geocoding Extensions in
University Campus Environments
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Chapter 5 Conclusions and Future Research:
Conclusions; Recommendation for Future Work
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Figure 1.1 Thesis Structure

1.4 Research Papers

This is an article-based Master Thesis. From Chapter 2 to Chapter 4, the thesis is presented and supported by the following papers:

- Paper 1 (Peer Reviewed)

Jiang, W., & Stefanakis, E. (2018). What3words Geocoding Extensions. *Journal of Geovisualization and Spatial Analysis, (2018) 2:7*, 1-17. doi: 10.1007/s41651-018-0014-x

- Paper 2 (Peer Reviewed and Accepted)

Jiang, W., & Stefanakis, E. (2018). A RESTful API for The Extended what3words Encoding. *International Society for Photogrammetry and Remote Sensing (in print)*

- Paper 3 (Under Review)

Jiang, W., & Stefanakis, E. (2018). Applications of what3words Geocoding Extensions in University Campus Environments. *THE CANADIAN GEOGRAPHER.*

1.5 Chapter Summaries

Chapter 1 introduces the research motivation, questions, objectives and the thesis structure. Additionally, the research background regarding the development and limitations of the existing geocoding systems has been presented.

In Chapter 2, the extended w3w geocoding models are proposed. These models were extended from w3w geocoding towards two aspects—variable resolution and three-dimensional information encoding. To achieve finer resolutions, the original w3w square was respectively divided into 9 or 4 sub-squares, resulting in finest resolution cell sizes of 0.11m by 0.11m and 0.09m by 0.09m respectively. To achieve a coarser resolution, the original w3w square was enlarged by using the square itself as the basic spatial expansion unit (Jiang & Stefanakis, 2018). The w3w code was extended by a fourth

word to encapsulate the new cell size in a finer or coarser resolution. A fifth word can also be attached to the extended code to encode the third dimension and represent a variety of elevation types.

Chapter 3 examines the two-way transformation between the extended code and the geographic coordinates through an application programming interfaces (API), that support one of the w3w extensions—the QuadTree Extension Model (QTEM). The QTEM model recursively subdivides the original cell in quadrants to obtain resolutions of 1.5-meter, 0.75-meter, 0.375-meter, 0.1875-meter and 0.09-meter (Jiang & Stefanakis, 2018). The development of the API conforms to the constraints of Representational State Transfer (REST) network architecture. The extended w3w geocoding RESTful API provides the functions of (i) forward and reverse geocoding; (ii) encoding single line and polygon feature; (iii) encoding arrays of cells for a given area.

Three application prototypes utilizing the extended w3w RESTful API are presented in Chapter 4. These prototypes include indoor facility management, indoor navigation, and outdoor navigation. Each application used a grid of QTEM squares in the resolution of 0.75-meter as location reference. Such that, any location can be represented by its cell. The extended w3w geocoding API as a fundamental component of these applications is responsible for the transformation between the four-word or five-word code of each cell and the corresponding coordinates. This chapter demonstrates how the extended w3w geocoding can be used in applications that support indoor and outdoor activities.

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Chapter 5 presents the conclusions of this research. Details pertaining to the assumptions and limitations of the proposed w3w geocoding extensions and the application prototypes as well as suggestions for future research are included in this chapter.

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    doi:10.1016/j.compenvurbsys.2007.11.006

2. WHAT3WORDS GEOCODING EXTENSIONS

Abstract

With the advent of location-based services, the demand for location data has dramatically increased. Geocoded locations have become necessary in many GIS analysis, cartography and decision-making workflows. A reliable geocoding system that can effectively return any location on earth with sufficient accuracy is desired. This study is motivated by a need for a geocoding system to support university campus applications. Address-based geocoding systems have been used for decades. However, they present limitations in address resources, address standardization, and address database maintenance. These limitations have recently sparked an interest in developing alternative geocoding systems that apply alphanumeric codes as reference to locations, such as Geohash, Google's Open Location Code, and what3words to name a few. Comparing to other geocoders, what3words (w3w) has many advantages. It uses a simple format of code consisting of three words; it is less error-prone; codes are easier to memorize; and multiple languages are supported. However, its fixed resolution (consisting of 3 meter by 3 meter square cells) and lack of consideration of the third dimension may limit its applicability. In order to better support geographic applications with special requirements, w3w geocoding system needs to be extended. This paper proposes extensions of w3w in two aspects: variable-resolution and third dimension support. A geocoding processing tool that implements these extensions is

being developed to support the need of a university campus' facility management, emergency evacuation and route navigation planning, student survey data management, and other location-based services.

2.1 Introduction

Methods to determine a location on a digital map or find the optimal paths to get there are becoming increasingly relevant to everyday life. Location encoding (also known as geocoding) is an approach that transforms an address, postal code, place name or another geographic reference to geographic coordinates (Goldberg, 2011; Lee, 2009; Karimi et al., 2011). This allows spatial analysis, mapping, and other geolocation related processes to be performed in GIS software packages. As such, a variety of geocoding systems have been created to support specific applications including, but not limited to, marking locations on a map, route finding and navigation, and local searching. A geocoding system consists of three components: (i) the input data – address, the name of a place, or code; (ii) the geocoder – the processing algorithm; and (iii) the output data – the location coordinates corresponding to the input data. Reverse geocoding functions perform the opposite task and convert coordinates into the address, name, or code of the location.

Address-based geocoding, which refers to "address matching" including a postal code and place's name, has been dominant for decades. Numerous efforts have been

made to improve address-based geocoding. However, they were not able to completely restrain all limitations involved (Lee, 2009). Alphanumeric code geocoding systems have emerged more recently. These systems provide alternative methods to overcome the problems with address-based geocoding.

An alphanumeric code geocoding uses codes as a reference to locations. It partitions the earth surface into arrays of cells, often in layers of variant resolution, and assigns each cell a unique alphanumeric code. Codes can then be converted into the centroid coordinates of the cells. Examples of these geocoding schemes include Geohash, MapCode, c-Squares, WMO squares, Open Post Code, Google's Open Location Code, and what3words (Barr, 2015; Stefanakis, 2016). The latter one is of particular interest to this study.

what3words (w3w) divides the earth's surface into a grid of 3 meters by 3 meters squares; each assigned a unique code consisting of three dictionary words separated by periods, e.g., the entrance to the CN Tower in Toronto, Canada is located at "select.threaten.shelters" (Barr, 2015). This method allows for easier memorization of locations and is supported in multiple languages. Meanwhile, the three-word code is efficient to encode and decode. w3w provides a website, apps for iOS and Android, and an API that enables bidirectional conversion between the three dictionary words assigned to the grid cells and latitude/longitude coordinates (Barr, 2015).

w3w has demonstrated some advantages over the traditional address-based geocoding. It is estimated that over 4 billion people on Earth are physically disconnected because of lack of a reliable street address (Barr, 2015). But even when street addresses

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are available, they are very often unable to describe the location. For example, locations inside parks or large facilities (e.g., stadiums or hospitals with multiple entrances) may be hundreds of meters away from the nearest address. The use of directions (such as "behind the main building find a storehouse; deliver the package to the right door facing the park") instead of address has become a common practice. However, this is usually ambiguous as it relies on local knowledge, while it cannot be interpreted automatically (Stefanakis, 2016).

Apparently, the w3w grid can meet the fundamental need of addressing people and places no matter the existence of a reliable street address. The opportunities, that w3w presents, have been widely recognized around the globe. Governments of at least five nations with poor addressing systems have already adopted w3w for their postal services, while w3w has been recently used as an addressing mechanism in disaster relief missions and emergency response (The Ethicalist, 2017).

Besides the opportunities, w3w presents limitations that complicate its usefulness to certain geographic applications. Specifically, w3w has a fixed resolution of 3 m x 3 m and provides no consideration of elevation. How can the what3words geocoding system be extended to address these limitations? How could these extensions be applied to support geographic applications such as a micro-scale area of a university campus? To answer these questions, this study has established three main objectives: (a) to design alternative w3w geocoding extension models; (b) to implement geocoding algorithms for the extended models; (c) to apply the extended models and associated algorithms in

various applications relevant to a university campus. This paper focuses on the first

objective.

The w3w geocoding system was extended towards two aspects: variable resolution

and elevation. A potential application using a finer-resolution extension of the w3w

geocoding system is to locate a geographic entity (e.g., a desk) in a building room, as

demonstrated in Figure 2.1. The location of the desk can be represented by an extended

model involving a code consisting of four words with a resolution of 33cm by 33cm. On

the other hand, a coarser resolution extension would be required for an evacuation

planning application. As shown in Figure 2.2, an open space in a university campus

covered by square cells of a size that exceeds the 3m x 3m could be represented by an

extended model involving the central 3m x 3m cells accompanied by a number

describing the size of these cells.

(a)

(b)

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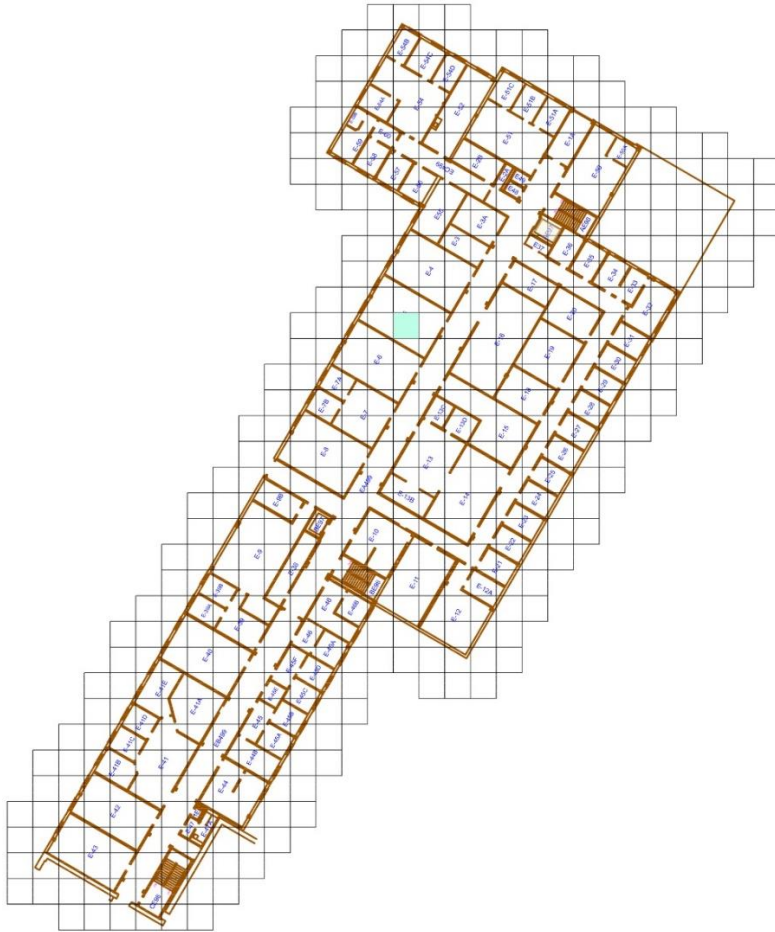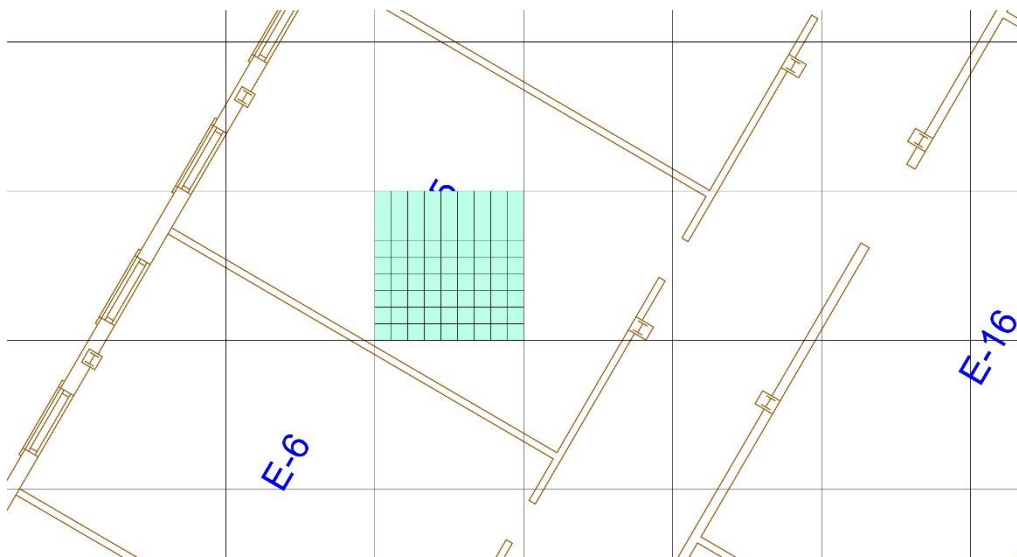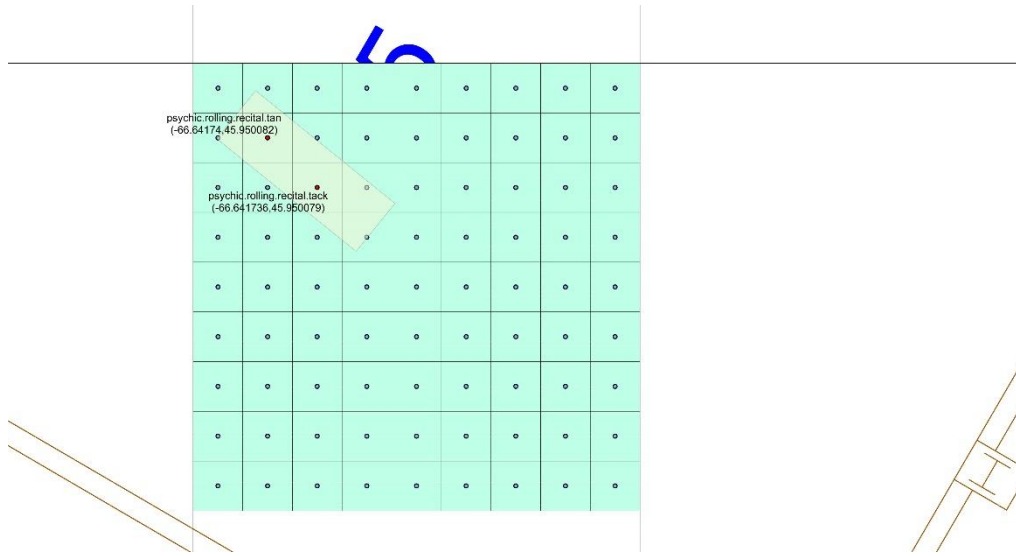
(c)

Figure 2.1 Example application of a w3w extension that considers a finer resolution: (a) Level E of Head Hall building and the w3w grid of 3m x 3m squares; (b) one w3w square within room E5 sub-divided into cells of 33cm x 33cm; and (c) the same cells in larger scale and the encoding of two cells covering a desk
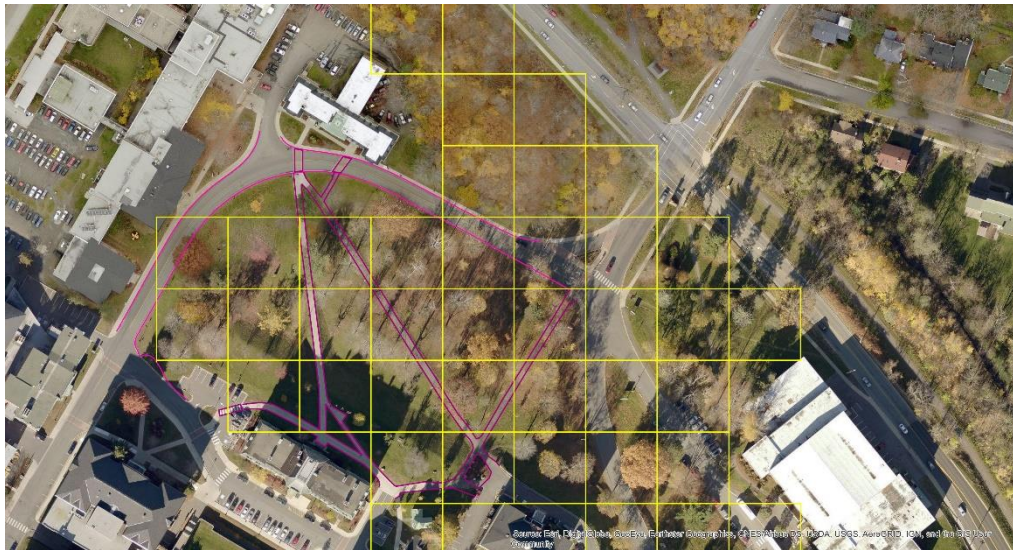
Figure 2.2 An example application of a w3w extension that considers a coarser resolution (cell size: 30m x 30m)

An elevation extension of the w3w geocoding system can be beneficial for locating entities in three-dimensional space. In the example of Figure 2.1, the desk is located on the fifth floor of a building. Its relative height (above the ground) is 13 meters (i.e., each floor is 3 meters high, and the desk is 1 meter high). Hence, the location of the desk can be described by three words supplemented by a code that provides its relative height, e.g., "psychic.rolling.recital.tan.RH7". A reverse geocoding process would turn the above code into the location of the desk expressed in (x, y, z) coordinates, i.e., (-66.64174, 45.950082, 13).

It is believed that the development of the extensions above could facilitate various geographic applications in a university campus such as campus navigation, emergency evacuation, facility management, and student survey data management.

The paper content is organized into five Sections. Section 2 provides the state-of-the-art of geocoding systems including a discussion on the advantages and disadvantages of these systems. Section 3 introduces the models to extend the w3w geocoding system to support variable resolution and elevation. Section 4 discusses some potential applications and example scenarios of the extended w3w geocoding system. Section 5 presents the forward and reverse transformations between extended w3w codes and the corresponding geographic coordinates. Section 6 summarizes the proposed extensions and presents some future developments.

2.2 Geocoding Systems and what3words

Geocoding is one of the basic geospatial operations that convert addresses, postal codes, place names or other geographic references to geographic coordinates (Goldberg, 2011; Lee, 2009; Karimi et al., 2011). It plays a vital role in the spatial analysis as geocoding technology has been utilized in many application areas such as epidemiology, environmental science, emergency management, marketing, planning and location-based services. These applications involve a broad range of disciplines including, but not limited to: geography; geographic information science; computer science; digital libraries; history; and economics (Goldberg, 2011; Karimi et al., 2011). Geocoded data provides a basis for subsequent spatial analysis and mapping. Errors associated with the geocoded data are likely to propagate through subsequent processing, analysis, modeling, and decision making (Goldberg, 2011; Karimi et al., 2011). Therefore, it is important to obtain accurate locations from geocoding processes.

There are two categories of geocoding schemes adopted by geocoding systems: address-based and alphanumeric code based. The address-based geocoding scheme makes use of two main models: street network geocoding and rooftop geocoding (also known as address-point geocoding), which have been widely used for decades (Lee, 2009; Karimi et al., 2011; Zandbergen, 2008).

Address-based geocoding systems have many constraints including coverage, standardization, maintenance, and precision. The coverage issues occur because these systems are unable to geocode locations with no official address (Barr, 2015). It is

estimated that, worldwide, over two billion people live at locations with no official street name or house number (Geelen, 2015). Standardization is an issue because address-based systems require properly formatted input, whereas address formats vary from location to location (Lee, 2009). Also, these systems require high maintenance as address databases must be updated regularly to reflect real-world changes for the entire coverage area (Lee, 2009). Last but not least, precision can be a major concern. Geocoding in rural areas is often offset-prone (Kellison, 2012). Even in urban areas, where geocoders are typically more precise, they use as a reference the centroid of structures or parcels. Entire university buildings, business parks, and farms are abstracted to single points that do not carry sufficient precision for many applications (Chen et al., 2016; Goldberg et al., 2007; Karimi et al., 2011).

Alphanumeric code geocoding scheme provides an alternative way for describing a geographic location. It assigns systematic alphanumeric labels to locations (polygons) over the earth, which are converted to geographic coordinates using mapping formulas, instead of graphs and an address database (Barr, 2015). Alphanumeric code geocoding systems share several advantages: (i) every cell is assigned a unique and static code, (ii) codes are simple to encode and decode; (iii) codes are efficient for communication (Chen et al., 2016).

w3w, compared to other alphanumeric code geocoding systems, has three significant advantages. First, it is the cleanness of the coding scheme as the use of dictionary words is less error-prone than a code mixing letters and numbers. Secondly, it is easier to remember (Barr, 2015). Finally, it supports multiple languages. Other alphanumeric

code geocoding systems provide a code combining random Latin characters with numbers, which can be as long as 10-characters for a high resolution. The codes provided by these systems are hard to remember, while they are not language or culture-independent (Rhind, 2015). On the other hand, as opposed to other alphanumeric geocoding systems, w3w has a fixed resolution of 3m x 3m. This may impede an efficient modeling in applications, such as in indoor environments where a finer resolution is required, or in outdoor environments where a coarser resolution is preferable.

Meanwhile, none of those mentioned above geocoding systems considers the third dimension, i.e., elevation (Stefanakis, 2016). 3D geocoding and 3D reverse geocoding services are still a challenge (Gartner, 2007). An address-based 3D geocoding system for the indoor environment was proposed by Lee (2009). However, this method inherits the limitations of address-based geocoding systems and does not offer an appropriate solution for 3D location-based services.

Therefore, to overcome the above limitations of w3w, this study introduces a series of extensions of the w3w geocoding system.

2.3 Extensions of what3words

This Section describes how w3w geocoding system can be extended to support variable resolutions as well as the integration of elevation data into the alphanumeric

code. In the original w3w system resolution is fixed to 3m x 3m. With a variable

resolution extension, w3w grid cells may have a smaller or larger size to satisfy the

needs of a finer or coarser resolution, respectively. The finer resolution model could be

used to represent any spatial points that fall into the same square beside the cell's

centroid (Figure 2.1). The coarser resolution model could be used to represent areas with

an extent larger than 3m x 3m, using a single code. The elevation could be described by

absolute height values, relative height values (i.e., above or below the ground), or even

floor labels and relative heights within the floor for indoor application purposes. The

above models need to be combined as shown in Figure 2.3 to represent specific areas or

locations at variable resolutions in 3D space.
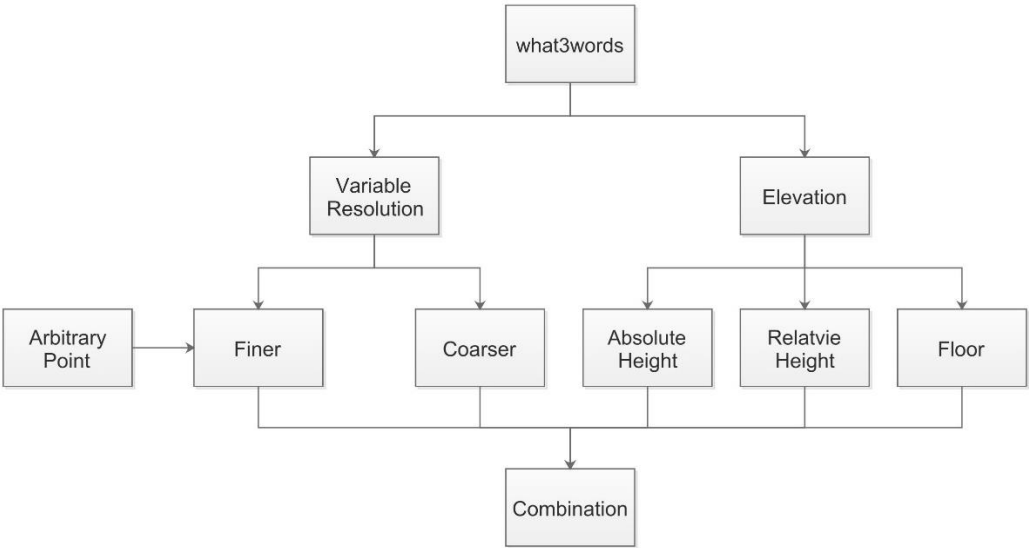
Figure 2.3 Alternative w3w geocoding extension models

2.3.1 Variable Resolution Extension Models – Finer Resolution

Two methods to increase the resolution of the grid cells are considered (Figure 2.4): Ternary-Tree (Stefanakis, 2014) Extension Model (TTEM), and Quadtree (Stefanakis, 2014) Extension Model (QTEM). The w3w square is divided into 9 or 4 sub-squares, respectively. Each square is recursively divided into sub-squares, resulting in a cell size at the finest resolution equal to 11cm by 11cm and 9cm by 9cm, respectively.
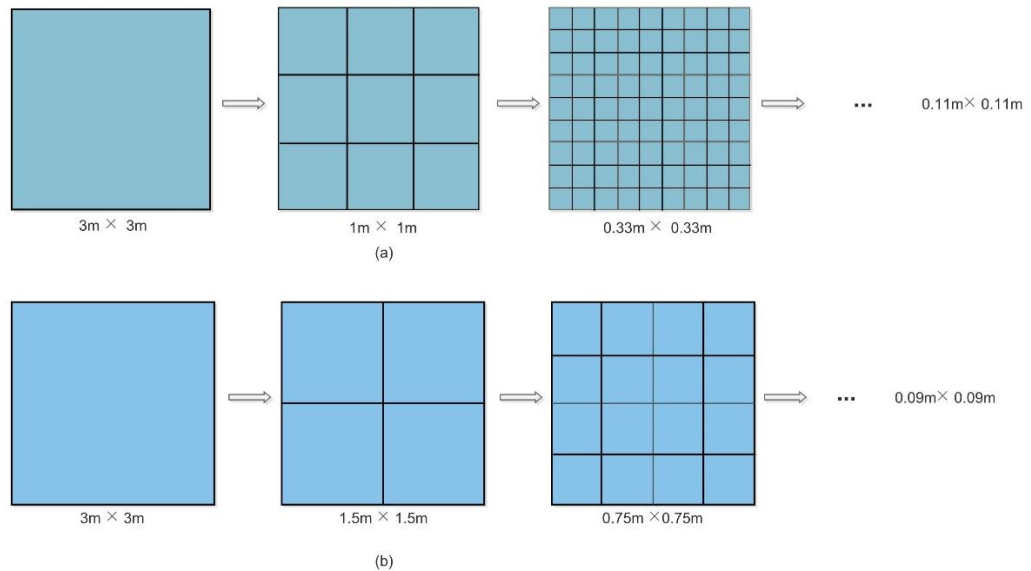
Figure 2.4 Finer resolution extension models: (a) Ternary-Tree Extension Model (TTEM), and (b)Quadtree Extension Model (QTEM)

The extended variable resolution model is represented by attaching a fourth element (a new word) to the w3w code, as shown in Figure 2.5. At each resolution level, all new words start with the same letter so that the resolution level can implicitly be determined

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from the code (Figures 2.6 and 2.7). This way, the fourth word conveys information about both the sub-cell size and location in the original w3w's 3m x 3m square. The spatial relations between two cells can also be partially extracted from their codes.
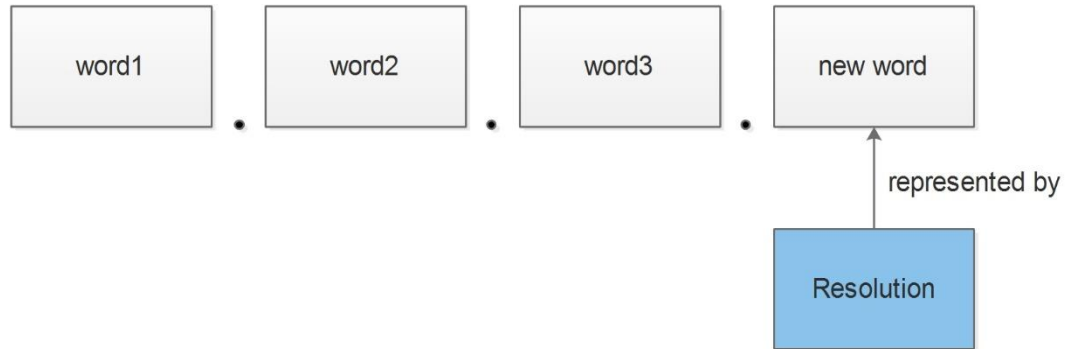
Figure 2.5 w3w resolution extension by adding an extra word
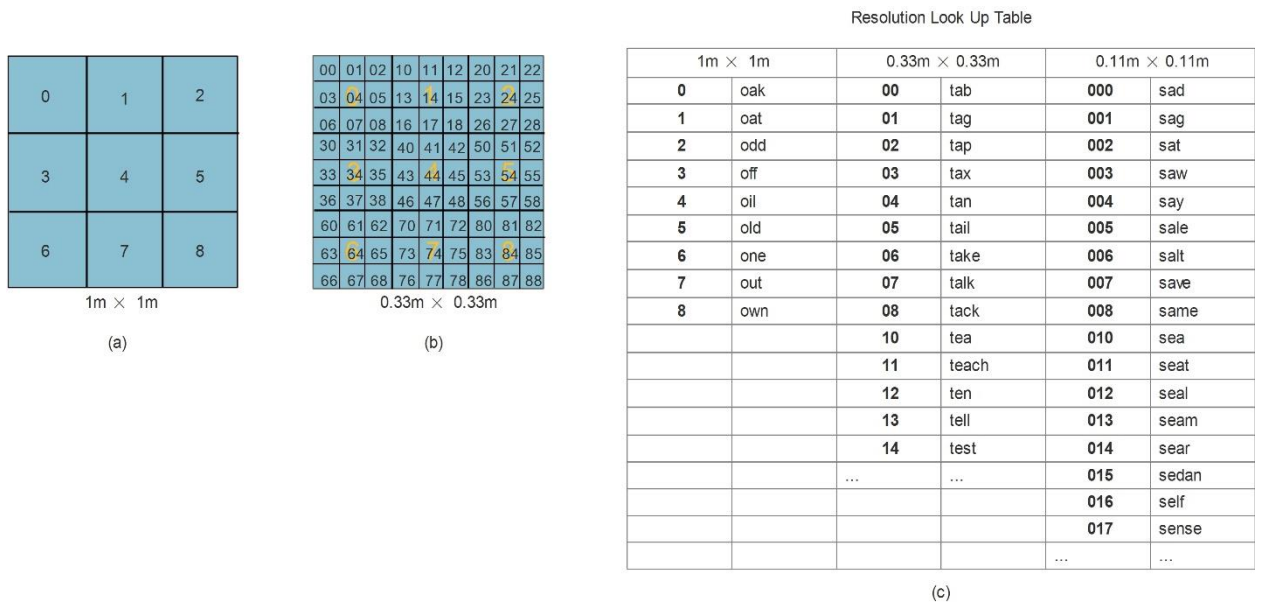
Figure 2.6 Ternary-Tree Extension Model (TTEM): (a) resolution of 1m×1m; (b) resolution of 33cm×33cm; (c) the fourth word for each sub-cell at three different resolution levels

Resolution Look Up Table

1.5m × 1.5m		0.75m × 0.75m		0.375m × 0.375m	
0	quad	00	fan	000	cat
1	queen	01	far	001	cap
2	quick	02	fat	002	car
3	quite	03	fax	003	caw
		10	fee	010	clan
		11	few	011	clap
		12	fear	012	claw
		13	feat	013	clay
		…	…	…	…

(c)
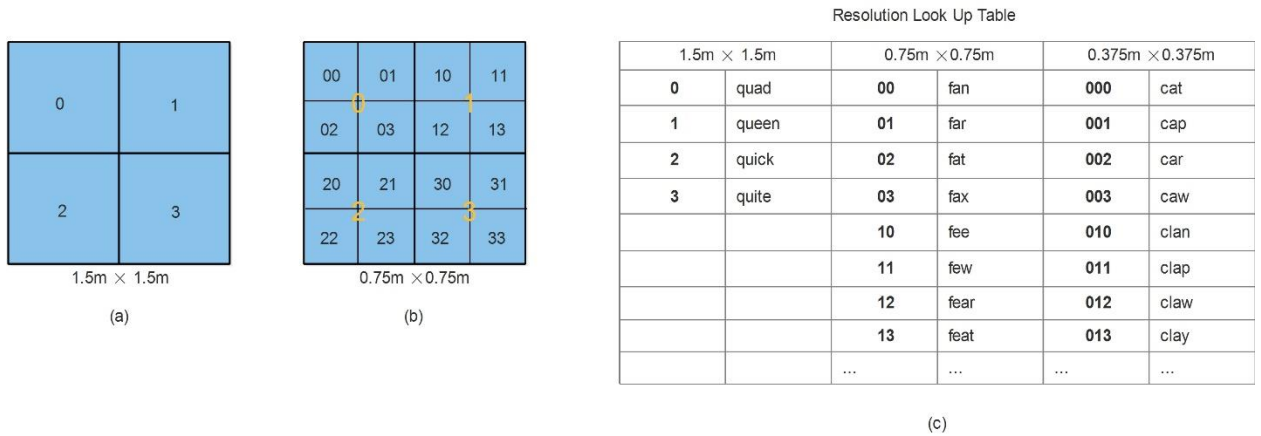
Figure 2.7 Quadtree Extension Model (QTEM): (a) resolution of 1.5m×1.5m; (b) resolution of 75cm×75cm; (c) the fourth word for each sub-cell at three different resolution levels

According to the nature of English vocabulary, the quantity of word starting with the letter "t", "s", "f" or "c" is greater than words starting with "o" or "q" (Figure 2.8). Therefore, these words were used for the sub-cells at the finer resolutions, where more words are demanded. Furthermore, when words starting with a certain letter are inadequate for a specific resolution (e.g., if words starting with "s" are not enough for TTEM at resolution 11cm ×11cm), words starting with another letter such as "p" could be utilized.

A fundamental principle of the w3w geocoding system is that the words assigned to a square give no clue as to the words of adjacent squares (Barr, 2015). In other words, the w3w geocoding system is non-hierarchical and non-topological. In TTEM and QTEM models, though, the fourth word conveys some locational semantics as it corresponds to a given sub-square within each 3m by 3m square.
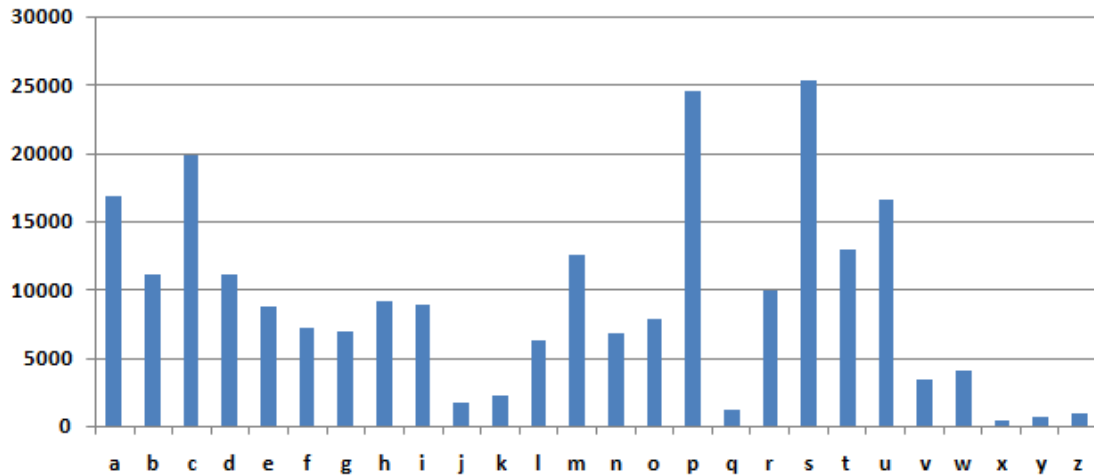
Figure 2.8 The number of English dictionary words starting with each letter (from http://whichenglish-letter-has-maximum-words.html)

TTEM and QTEM models could be used to represent any point location. The accuracy of the point's location increases with an increase in resolution. Given point A in Figure 2.9, the four-word code for the sub-square including point A could be used to represent point A's location through the cell's centroid. The maximum offset from A's actual location is 23 centimeters at resolution 0.33m x 0.33m in the TTEM model. The higher the resolution level, the smaller the maximum offset is.
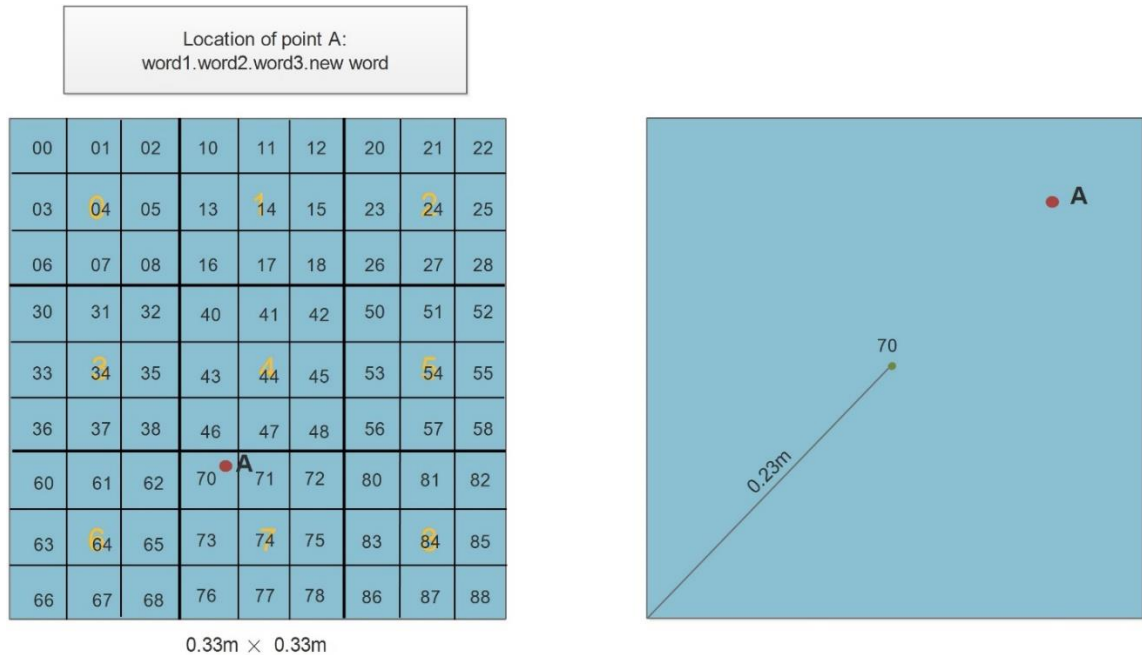
Figure 2.9 Using Ternary-Tree Extension Model (TTEM) to represent an arbitrary point A

An alternative model to represent a point location is the binary code extension model (BCEM). This model was inspired by Geohash geocoding system (Geohash, 2017), which recursively bisects the earth's sphere along latitude and longitude. A binary code was then created for both coordinate values, while the location could be encoded by interleaving the binary representations of these coordinate values. BCEM recursively divides a w3w square in a quadtree fashion, with two binary digits (0 or 1) appended to each division to determine the quadrant. The divisions could continue until the error tolerance of the point is reached. Then, the string of appended binary digits is encoded into letters to form the fourth (new) word. Notice that the sequence of letters does not necessarily form a dictionary word. Figure 2.10 illustrates the process and results of the extension through the BCEM model. BCEM binary code can be expanded or truncated

in pairs to achieve higher or lower precision respectively (Table 2.1). The spatial relation of two points in the same w3w square could be partially retrieved by detecting the fourth word.
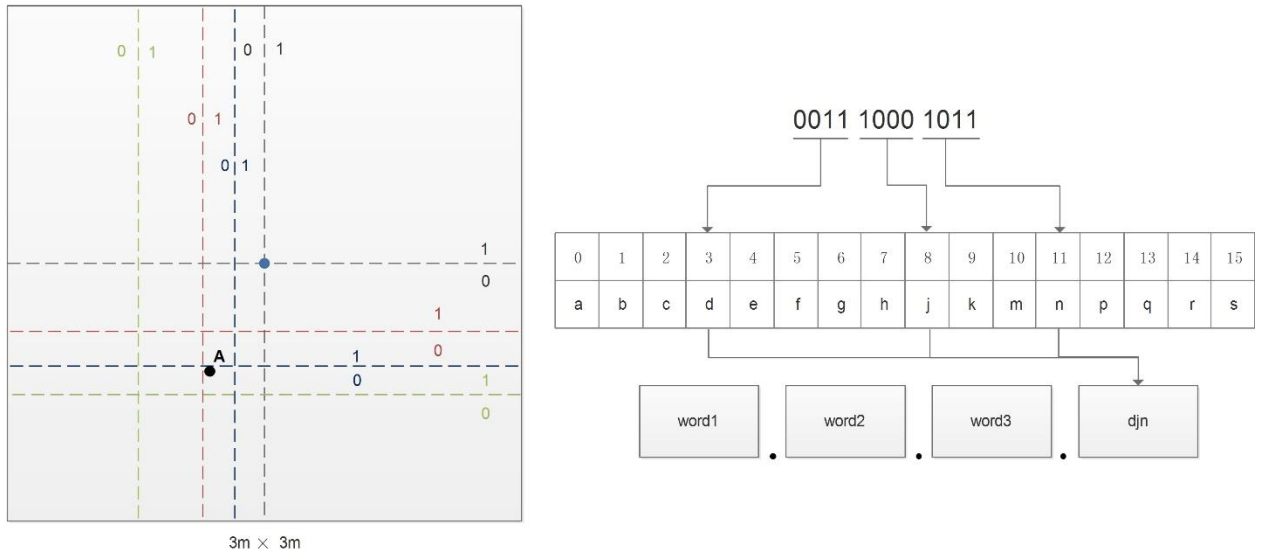
Figure 2.10 Binary code extension model (BCEM). Modelling location A with three words plus a sequence of Latin characters

Table 2.1 The location precision for a point under BCEM.

the 4th element length (number of letters)	code bit	max_vertical offset (m)	max_horizontal offset (m)
1	4	0.75	0.75
2	8	0.1875	0.1875
3	12	0.0469	0.0469
4	16	0.0117	0.0117

2.3.2 Variable Resolution Extension Models – Coarser Resolution

Three methods of coarser resolution extension are provided in this study. The first

two methods use a w3w square as a reference to decrease the resolution by expanding

the size of the square. The first method, called radial expansion extension model

(REEM), enlarges the square's size by applying a radial expansion as shown in Figure

2.11a. The second method, called diagonal expansion extension model (DEEM), uses a

diagonal expansion as shown in Figure 2.11b. Instead of adding another word to w3w

code to represent the lower resolution square, the fourth element for these models would

be a label of a representative letter and a number that defines the resolution itself (Table

2.2). Notice that the diagonal expansion could have four directions. Thus, the

abbreviations for these directions need to be attached to the label.
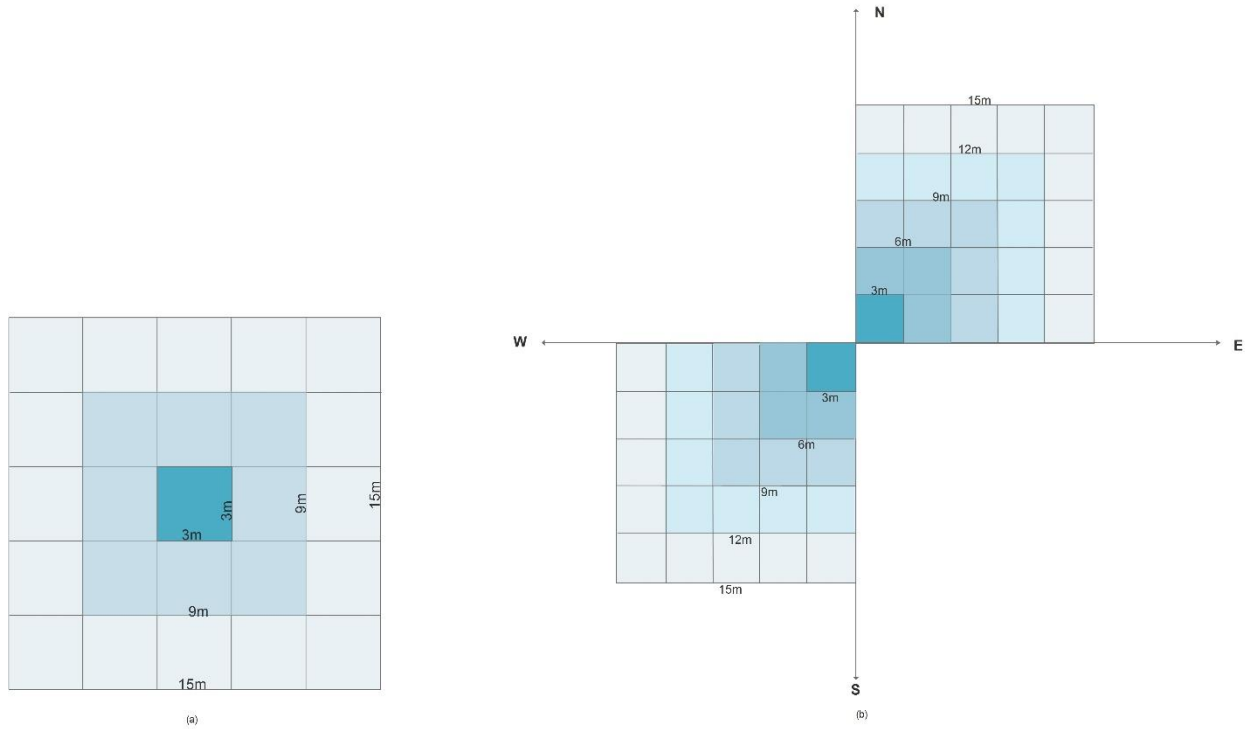
Figure 2.11 Coarser resolution extension models; (a) radial expansion extension model (REEM); (b) diagonal expansion extension model (DEEM)

Table 2.2 Alternative coarser resolution representations

DIRECTION	RESOLUTION REPRESENTATION			
Radial	R 9 R 15 …			
Diagonal	D NW6 D NE9 D NE12 D NE15 …	D NW6 D NW9 D NW12 D NW15 …	D SE6 D SE9 D SE12 D SE15 …	D SW6 D SW9 D SW12 D SW15 …
New code	word1 . word2 . word3 . R(D) Num.			

The third method of coarser resolution extension, named rectangle extension model (RECTEM), can map the square into a rectangle of any size with dimensions denoted as *m* and *n* (Figure 2.12). The new code is constructed by taking the centroid of a w3w square, considering it as the center point of a rectangle, and using the length and width parameters delimited by a letter 'v' to form the fourth element of the extended code (Table 2.2). Hence the area covered by the rectangle could be computed by the fourth element as a product on *m* x *n*.
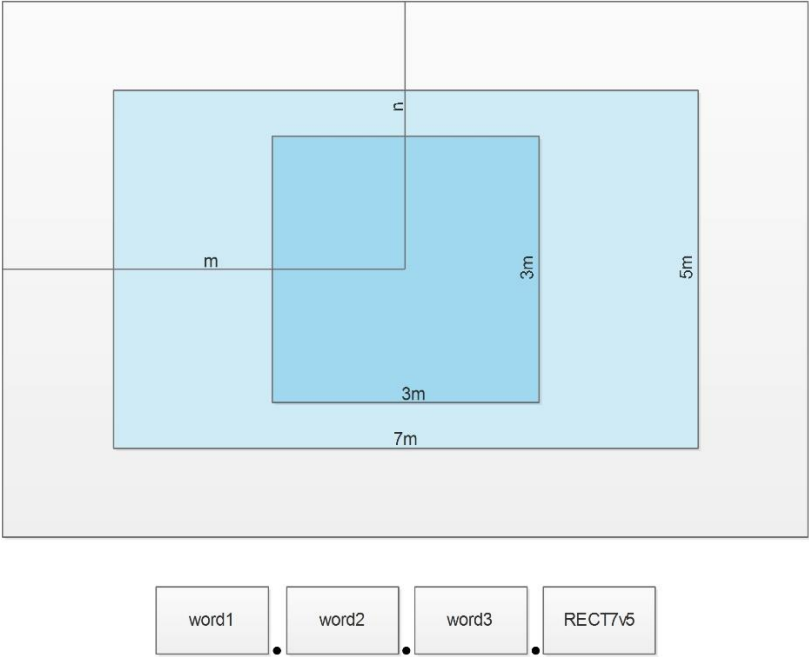
Figure 2.12 Coarser resolution extension model using a rectangle (RECTEM)

2.3.3 The Third Dimension Extension Models – Elevation

Like many of the other geocoding systems, w3w does not consider the third dimension. Therefore, this study proposes an extended model for w3w that can distinguish between locations of different elevation. The elevation can be described in three ways: absolute height, relative height (ground reference; above or below the ground), and floor (floor label and relative height within the floor) for indoor applications. To represent the elevation, a label combining letters and numbers is attached to the w3w code (Table 2.3).

Table 2.3 Alternative extension models for the third dimension

Elevation	Representation	Example
Absolute Height	H	H 34.05
Relative Height	RH	RH 3.5
Floor Number	F	F 1
New Code	wordA . wordB . wordC . H(RH/F) Num.	

The letter(s) H, RH, and F represent the diverse types of elevation, i.e., absolute, relative, and floor, respectively. The number following the letters H and RH describes height values in units of meters. Letter F is followed by the floor label (e.g., 3, 0, -2, or E), a period, and optionally a number describing the relative height from the surface of the floor in meters. Various types of floor description (i.e., Ground Floor, Floor C, etc.) need to be considered and standardized.

2.3.4 Combination of the Extension Models

To describe a precise location in space, the extension models addressing both variable resolution and elevation, need to be integrated. Therefore, the full description includes five elements as shown in Figure 2.13. A delicate balance exists between the descriptiveness and complexity of the code. While this new description loses some of the memory friendliness of the original w3w model, it retains many of the original aspects.
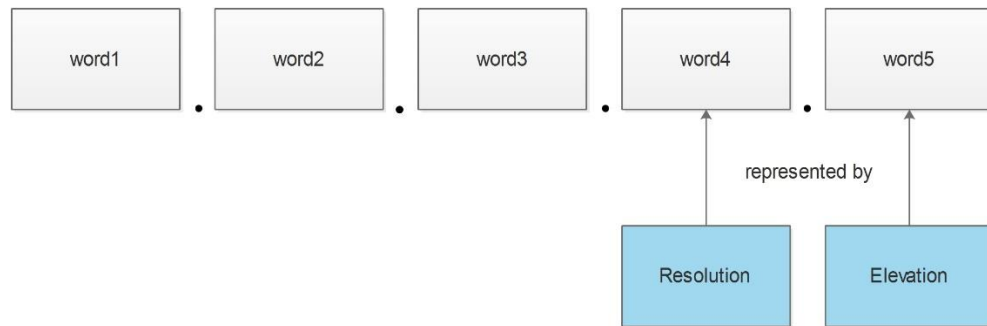
Figure 2.13 Alternative extension models for the third dimension

2.4 Applications

The proposed extensions were able to accommodate a variable resolution and elevation, while still utilizing the w3w square as a basic unit. By adding a word and/or a label to a w3w code, these extensions retain a simple format and remain compliant with

the advantages of the w3w geocoding system. Some potential applications that make use

of the extension models for a university campus are listed in Table 2.4.

Table 2.4 Applications of the proposed geocoding extension models to a university
campus

Location	Application
Indoor	(1) describe a path between rooms and support navigation; (2) label rooms and important sites, such as Exit, Entrance, extinguisher; (3) track equipment, books, and personnel; (4) locate facility management points of interest (POI) for maintenance or repair.
Outdoor	(1) find safety area for emergency evacuation (2) navigation in campus (3) student survey points management

Provided that a university campus extends in a relatively small and local area

consisting of up to a few hundred thousands of 3m x 3m squares, a single word (e.g.,

word1 in w3w) may turn out to be sufficient for encoding these squares. This way the

combined code in Figure 2.13 may be abbreviated to three words:

"word1.resolution.elevation" for local use. Obviously, a search must be done to make

sure that no two w3w squares in the campus share the same word1 of the original w3w

code.

The following two example scenarios demonstrate how what3words and the extended

models may enhance geocoding. The first scenario involves a mail delivery on a

university campus. Specifically, a package must be dropped off at the desk of a person in

room E5, which is located on the 5th floor (floor E) of Head Hall complex. The street

address of Head Hall is "15 Dineen Drive, Fredericton, NB, E3B5A3". As shown in

Figure 2.14, neither the street address nor the place name (i.e., "Head Hall, UNB

Campus") is very helpful to the postman, as they both fail to indicate an entrance to the building complex.
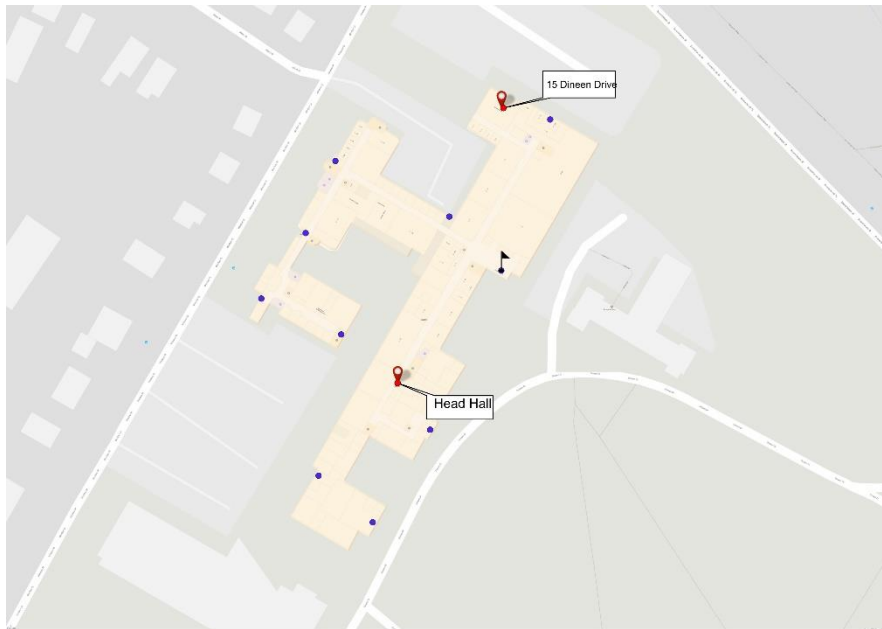
Figure 2.14 The Head Hall Complex. The red markers indicate the geocoding results based on street address and place name. The blue markers represent the entrances to the building complex, while the black flag indicates the main entrance

As explained in Section 2, address-based geocoding systems may fail to represent large structures, such as a building complex, as they assign a single or a limited number of addresses to each structure. To overcome this limitation, the what3words geocoding system provides a unique address made up of three dictionary words to identify each 3m by 3m square on the earth's surface. As shown in Figure 2.15, the main entrance to Head Hall complex falls into the w3w square cell indexed by the three words code: "tram.sullen.registration". The centroid of this cell is located at -66.641686 W, 45.949803 N. Obviously, the w3w address code may help the postman locate the

entrance to the building and reach out the delivery spot more efficiently. The navigation

in the outdoor space will be supported by satellite positioning systems.

Figure 2.15 The original what3words grid over Head Hall complex. The annotated 3m x 3m square is used to encode the location of the main entrance

The package must be dropped off at the desk of a person in room E5, which is located

on the 5th floor (floor E) of Head Hall complex. Hence, the postman needs additional

information to navigate within the building complex. As shown in Figure 2.16, the

horizontal location of room E5 is indexed by the three words code:

"psychic.rolling.recital". However, the room is located on the 5th floor (or floor E;

according to the floor numbering scheme of this complex). Hence, the extended code for

room E5 is either "psychic.rolling.recital..FE" when using the floor number or

"psychic.rolling.recital..RH12" when using the relative height (see Table 2.3; for a floor height equal to 3m). The latitude and longitude of the square cell can be retrieved from the first three elements (w3w code), while the height value can be retrieved from the 5th element. The extended code may better assist the postman to reach out the delivery spot. The navigation within the building will be supported by indoor positioning systems.
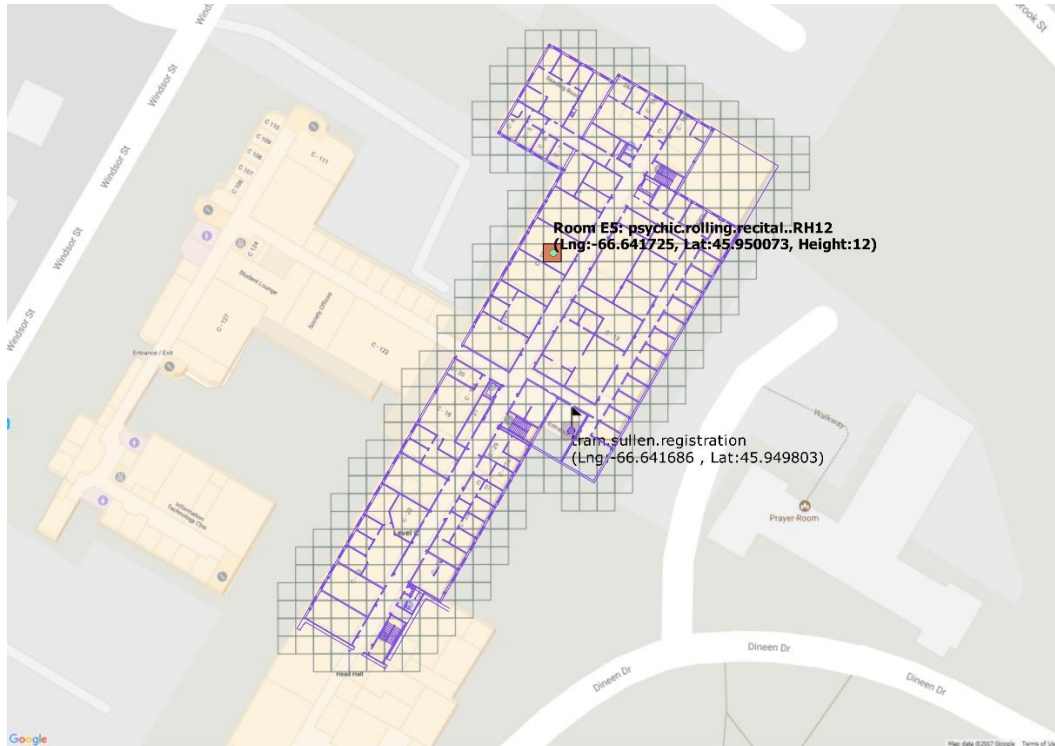
Figure 2.16 The plan of floor E in Head Hall complex and the location of room E5. The red 3m x 3m square corresponds to one w3w square cell full contained in the horizontal extent of room E5

Notice that there is no 4th element included in the latter two codes. The postman can only locate the right desk in E5 to drop off the package at, if the 4th element became available. As shown in Figure 2.17, a finer resolution can be achieved by subdividing the

3m x 3m square into 81 33cm x 33cm sub-squares. Those sub-squares will be identified through the 4th element (see Figure 2.6). Two alternative extended (5-word) codes for the desk surface are: "psychic. rolling.recital.tan.RH13" and "psychic.rolling.recital.tack.RH13". Notice that the relative height is increased by 1m compared to the floor height of 12m in Figure 2.16, to include for the height of the desk itself. Obviously, the extended 5-word code may assist the postman to reach out the delivery spot accurately.
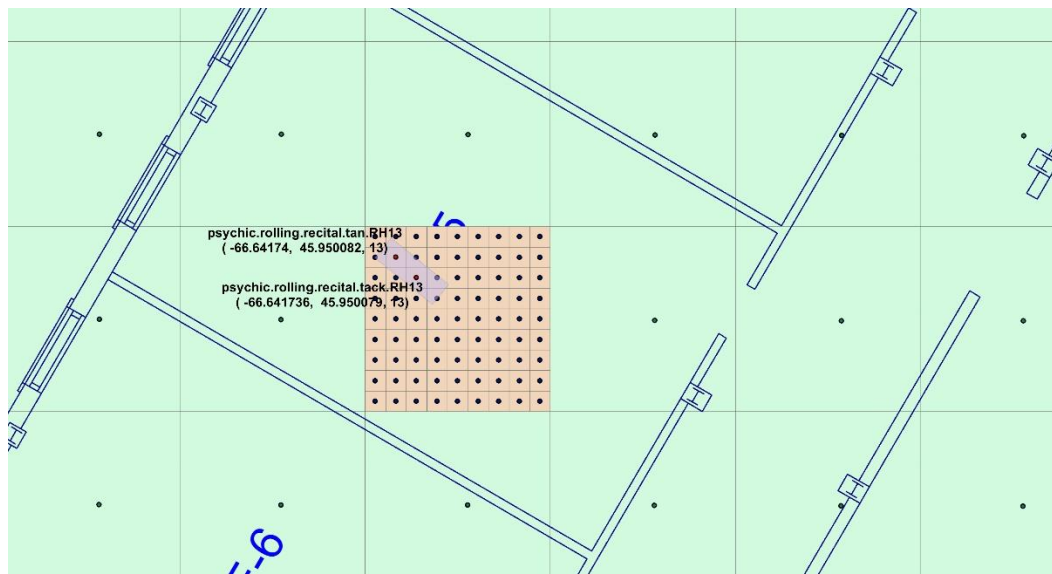
Figure 2.17 A 3m x 3m square in room E5 further subdivided into 33cm x 33cm sub-squares. A desk in the room encoded with an extended 5-word code

The second scenario handles the definition of an evacuation zone within a university campus. The evacuation zone is an open space that has accessibility to roads and is intended to accommodate students, staff, faculty, and visitors in case of emergency. Figure 2.18 shows an example evacuation zone. The size of the zone is such that

encloses hundreds or thousands of 3m by 3m square cells. Hence, this zone may be encoded with too many different w3w codes, while none of them convey the extent of the zone. By introducing a coarser resolution, the evacuation zone can be encoded more efficiently. The rectangular zone in Figure 2.18 can be explicitly described through the extended code "nurse.marginally.animation.RECT76.5v34.5" and according to Figure 2.12. Notice that the area covered by the rectangle is embedded in the code and can be extracted as the product of the two numbers reported in the fourth element.
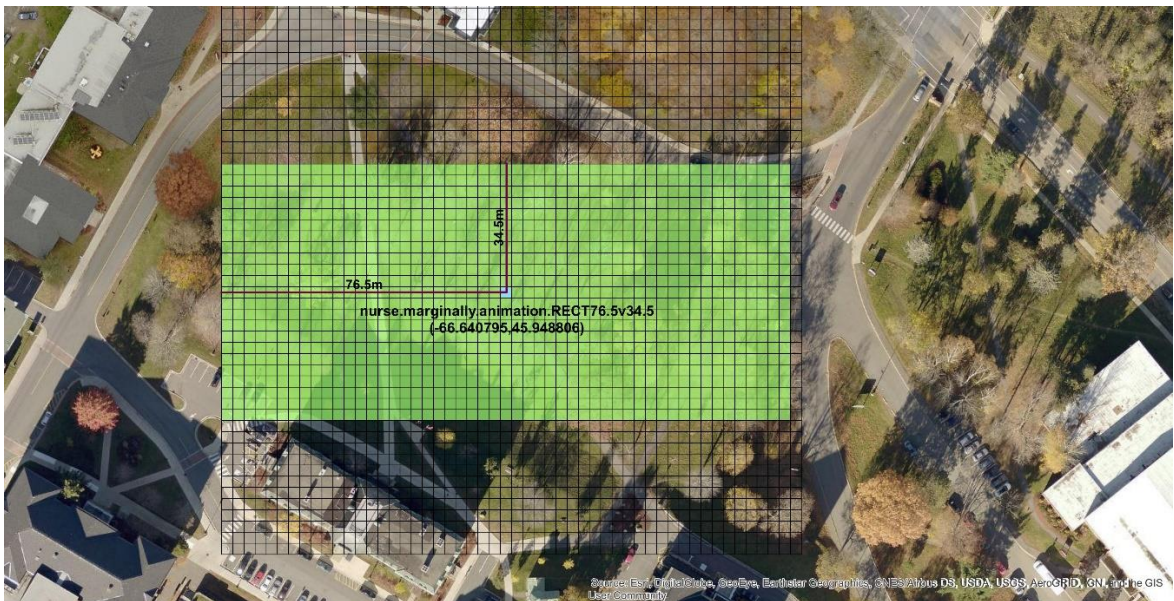
Figure 2.18 An extended rectangular area aligned to the w3w grid encoded using the coarser resolution extension model

Clearly, both the w3w encoding and the proposed extensions assume a positioning precision that goes beyond the capabilities of common outdoor or indoor positioning systems mounted to mobile devices, such as cell phones. There are, however, systems that can reach the required precisions, such as the relative kinematic positioning (RKP;

Teunissen and Montenbruck, 2017) using satellite systems, or the ultra-wideband

technology for 3D positioning (Pozyx, 2017). It is anticipated that systems like those

will be in wide use in the future.

A geocoder software tool is currently being developed. The tool will implement the

two-way transformation between five element codes (using the various w3w extension

models introduced in Section 3) and local or universal coordinates in 3D space for

individual locations. Also, it will support the two-way mapping of basic geometric

elements, such as lines, surfaces, and solids (used to model the entities of interest in

various university campus applications) to extended w3w codes (Table 2.4).

2.5 Forward and Reverse Geocoding Transformations

The following paragraphs describe the two-way transformation between an extended

code and the corresponding geographic coordinates. The forward geocoding converts an

extended code into geographic coordinates including elevation. The reverse geocoding

converts geographic coordinates and elevation into an extended code. Both

transformations make use of the what3words API (Application Programming Interface;

w3w API, 2017) as an integral component.

Figure 2.19 presents the flowchart of the forward transformation. The input value is a

code consisting of three, four or five words (or elements). After parsing the code and

depending on its content, one or more of following three procedures will be performed:

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(1) If a three dictionary words code were provided, the geographic coordinates of the centroid point (Lng, Lat) for the corresponding 3m by 3m square cell could be retrieved using the what3words API. These coordinates will be reported as a result of the transformation.

(2) If an extended code with the 4th element (word4) were provided, the first three words would feed the what3words API to retrieve the geographic coordinates of the centroid point (Lng, Lat) for the corresponding 3m by 3m square cell. Then, the fourth word or element will be used to calculate the offset from the centroid point (ΔX, ΔY). Depending on the extension model in use, the corresponding calculations will be carried out, and the geographic coordinates of the location will be retrieved and reported.

(3) If an extended code with the 5th element (word5) were provided, that element would be processed according to the adopted model for the third dimension and the height (Z) of the location will be retrieved to complement the horizontal coordinates.
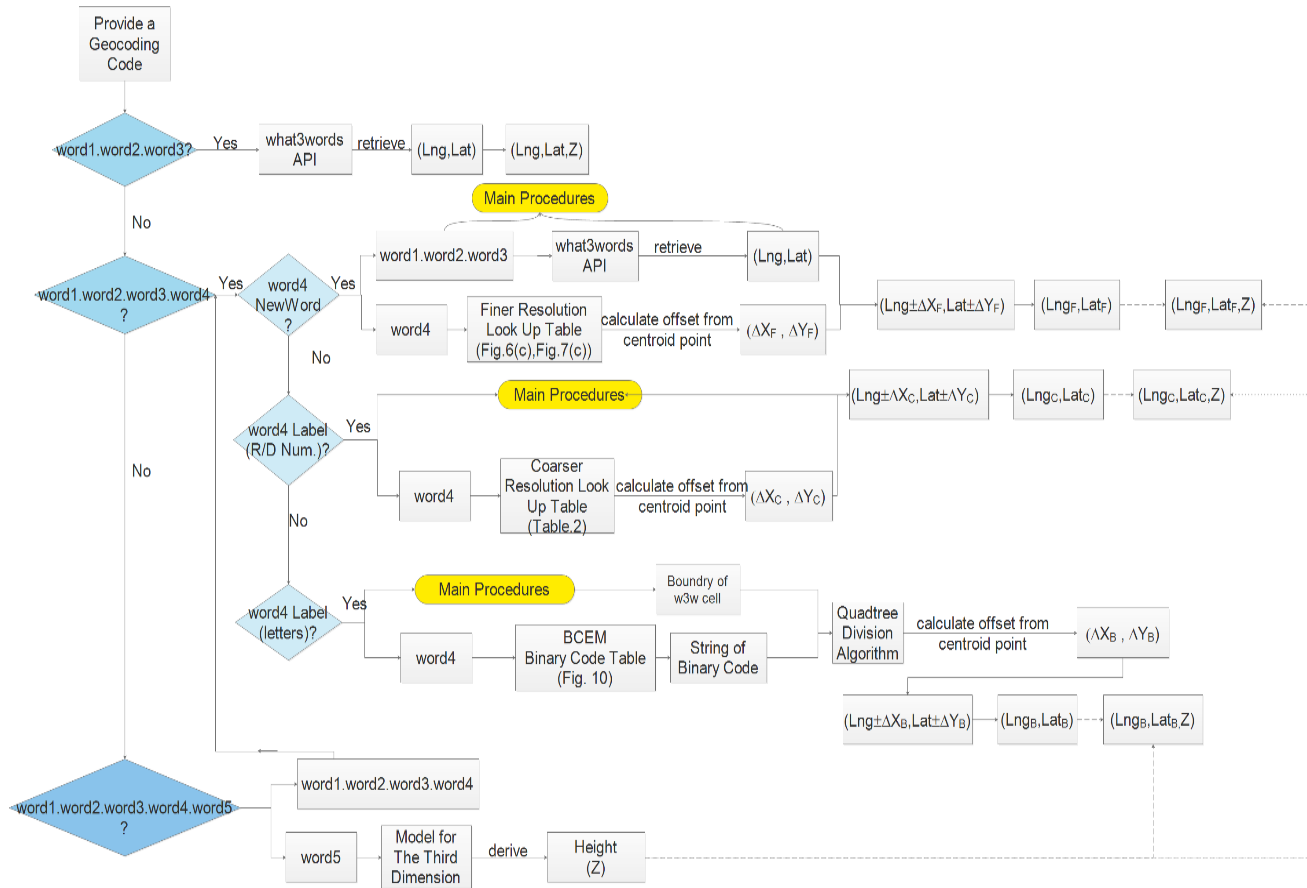
Figure 2.19 Flowchart of the forward geocoding transformation. The what3words API is adopted for the transformation between the three dictionary words and geographic coordinates (denoted as "Main Procedures"). The chart is not extensive as regards to the calculation

Figure 2.20 presents the flowchart of the reverse transformation. The input values of the reverse transformation include mandatory and optional items. The mandatory items are the geographic coordinates (Lng, Lat) of the location. The user-defined optional items are the resolution level (r) and the height (Z). By feeding the what3words API with the mandatory items, a three dictionary words code will be retrieved to identify the 3m by 3m square cell enclosing the geographic location. The optional item r takes a

value that determines the resolution level expressed in centimeters. If the value of $r <$ 300cm, a finer resolution is needed. A series of calculations will be applied to compute: the bottom left corner of the 3m by 3m square enclosing the location (denoted as LngMin and LatMin, respectively); the offset of the input location from that corner (denoted as ΔX and ΔY, respectively); and ultimately the sub-square that encloses the location at the requested resolution (identified by: Row and Column). A lookup table (see Figures 2.7 and 2.9) will be used to retrieve the fourth element (word4) that corresponds to that cell. If the value of r >300cm, depending on the actual value of r, the fourth element (word4) will be retrieved (see Table 2.2). If a code representing an arbitrary point is requested (e.g., for r = -1), the quadtree subdivision algorithm will be used to retrieve the string of binary code which will next be transformed into a letter code (Figure 2.10). That letter code composes the 4th element of the code (word 4).

The optional item Z takes a value that determines the height of the location. According to the adopted model for the third dimension, the height (Z) of the location will be transformed into the fifth element (word5) of the extended code.
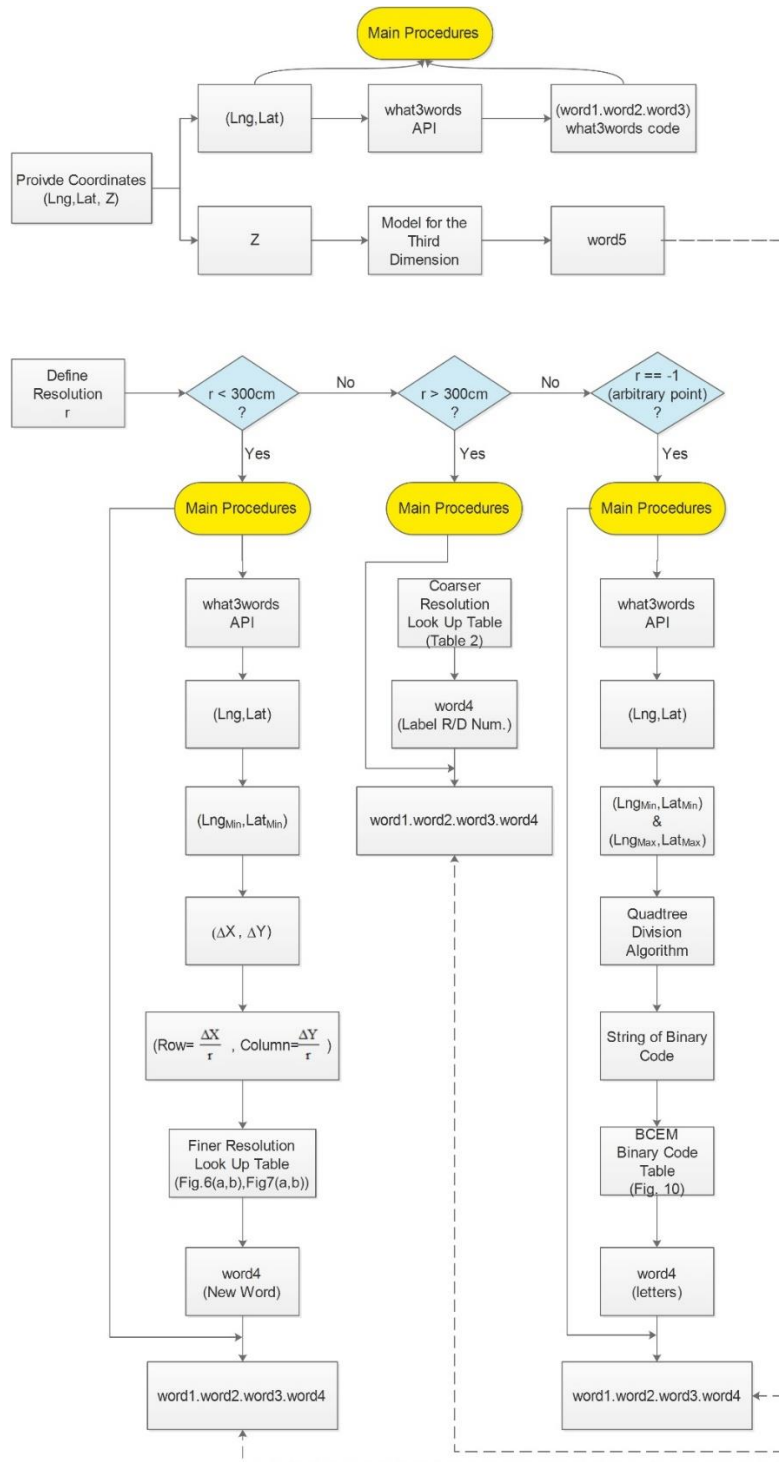
Figure 2.20 Flowchart of the reverse geocoding transformation. The what3words API is adopted for the transformation between the three dictionary words and geographic coordinates (denoted as "Main Procedures"). The chart is not extensive as regards to the calculation

The computational complexity of the above transformations is anticipated to be in the magnitude of the algorithm complexity of w3w API. The processing of the fourth and fifth elements involves very simple mathematical operations and/or a search in a lookup table of a few hundred of words at most (the number depends on the resolution level; see lookup tables in Figures 2.6 and 2.7), which can easily be ordered and indexed so that a logarithmic performance is achieved. After the implementation and validation of the geocoder software tool, a series of experiments will be carried out to prove the above argument and extract solid formulas describing the computational complexity of both the forward and reverse transformations.

The storage complexity is driven by the needs of the w3w API. The w3w system uses a proprietary algorithm in combination with a database that stores the triplets of dictionary words for all 3m x 3m square cells. The w3w core technology is contained with a file around 10 MB in size that can be run even when an internet connection is not available (Barr, 2015). To support some of the extended models introduced in this study, some additional space is also required to store the corresponding look up tables (e.g., Figures 2.6 and 2.7). Obviously, this space is minimal compared to the one needed for the w3w core database.

2.6 Conclusion

The address-based geocoding systems have been used for decades. However, these are not universally applicable in large-scale GIS applications. Alternative geocoding systems have been developed to overcome some of the constraints of address-based systems. Alphanumeric code geocoding systems divide earth surface into cells and assign each cell unique alphanumeric codes to represent the location. Each implementation of alphanumeric code geocoding utilizes its geocoding algorithms to transform between alphanumeric codes and the corresponding coordinates.

The w3w geocoding system has several advantages over other geocoding systems. However, due to its limitations, it needs to be extended, so that it can better support geographic applications. To support indoor applications, a finer resolution of squares is required, and elevations must be supported. For outdoor applications, a coarser resolution may also be needed. Therefore, this study proposes a series of extension models to the w3w geocoding system focusing on two main aspects, variable-resolution, and elevation.

The variable-resolution and elevation extension models are represented by the addition of elements to the standard three elements (words) used by the w3w model. The first three elements of the extended code are still the three words provided by the w3w geocoder. The fourth element is a word representing a variant resolution or an offset from the centroid of the standard w3w square. The fifth and final element is a label to

representing elevation. These extensions comply with and retain the advantages of the w3w geocoding system.

The extension models proposed in this study may further enhance the w3w geocoding system to better support geographic applications ranging from business and marketing to social and economic development of countries. The level of extension required in each application is variable and subject to the application needs as well as the decisions taken by both developers and end-users.

Notice that, the first four elements (words) in the combined code refer to locations on the earth's surface and their values are considered static. However, the fifth element refers to elevation, and its value (except the absolute height) depends on changes in infrastructure (e.g., building or road construction). For this reason, a sixth element could be added to provide a temporal reference. The extension of the combined five-word code with a sixth word representing time may also serve in modeling spatiotemporal applications. This is another direction for future research.

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3. A RESTFUL API FOR THE EXTENDED WHAT3WORDS ENCODING

Abstract

Geocoding is a fundamental task of Geographic Information System (GIS) processing and analysis. It allows the transformation between a location reference (i.e., an address or an alphanumeric code) and coordinates, which is often an essential step when performing spatial analysis, mapping, and other geolocation related processes. Providing software functionality through RESTful APIs is a common practice in geospatial applications. Client programs are able to access or process geospatial data easily through a lightweight and scalable RESTful web service. Existing geocoding RESTful API providers include Google Maps Geocoding API, ArcGIS Geocoding REST API, MapQuest Open Geocoding API and what3words (w3w) Geocoding API. Extensions of what3words geocoding system have recently been proposed to overcome its limitation of fixed resolution and lack of consideration of the third dimension. This paper considers one of the extensions, the Quadtree Extension Model (QTEM) and introduces a RESTful API that provides operations for forward geocoding, reverse geocoding, single line and polygon encoding, and centre points encoding for a given area. The resources published by the web service could be implemented by software programs performing indoor and outdoor location referencing, location marking and path finding. This API could facilitate various geographic applications such as facility management, emergency

evacuation, navigation and student survey data management in a university campus environment.

3.1 Introduction

Methods to determine a location on a digital map or find the optimal path to get there are becoming increasingly relevant to everyday life. Location encoding (also known as geocoding) is an approach that transforms an address, postal code, place name or another geographic reference to geographic coordinates (Goldberg, 2011; Lee, 2009; Karimi, Sharker, & Roongpiboonsopit, 2011). This allows spatial analysis, mapping, and other geolocation related processes to be performed in GIS software packages. Reverse geocoding functions perform the opposite task and convert coordinates into the address, name, or code of the location. Address-based geocoding methods have been applied for decades. Despite numerous efforts to improve address-based geocoding, not all limitations have been resolved (Jiang and Stefanakis, 2018). Alphanumeric code geocoding systems have emerged more recently and provide alternative methods to overcome some of the problems. Example geocoding systems include: MapCode, c-Squares, WMO squares, Open Post Code, Google's Open Location Code. what3words (w3w) is one of them and of particular interest to this study.

3.1.1 what3words Geocoding and Extensions

w3w divides the earth's surface into a grid of 3-meter by 3-meter squares; each

assigned a unique code consisting of three dictionary words separated by periods, e.g.,

the entrance to the CN Tower in Toronto, Canada is located at "select.threaten.shelters"

(Barr, 2015). This method allows for easier memorization of locations and is supported

in multiple languages. The static and unchangeable code meets the fundamental need of

addressing people and places no matter the existence of a reliable street address.

However, w3w also presents limitations: it has a fixed resolution of 3 m x 3 m and

provides no consideration of elevation.

To overcome these limitations, Jiang and Stefanakis (2018) proposed a series of

extended models of w3w towards the two aspects mentioned above. With a variable

resolution, w3w grid cells could have a smaller or larger size to satisfy the needs of a

finer or coarser resolution respectively. The w3w code was extended by a fourth word to

present the new cell size in a finer or coarser resolution. The QTEM model recursively

subdivides the original cell in quadrants to obtain resolutions of 1.5-meter, 0.75-meter,

0.375-meter, 0.1875-meter and 0.09-meter (Figure 3.1). At each resolution level, all the

fourth words start with the same letter so that the resolution level can implicitly be

determined from the code (Table 3.1). A fifth element can also be attached to the

extended code to represent the variety of elevation types. The elevation can be described

in three ways: absolute height, relative height (ground reference; above or below the

ground), and floor (floor label and relative height within the floor) for indoor

applications (Table 3.1). The space can be regarded as a 3D grid of cubic blocks, where each block has assigned a five-word code referencing its geographic location. Figure 3.2 shows an example of blocks representing the occupied space in dark colour and the free space in light colour, in the resolution of 1.5-meter and 0.75-meter.
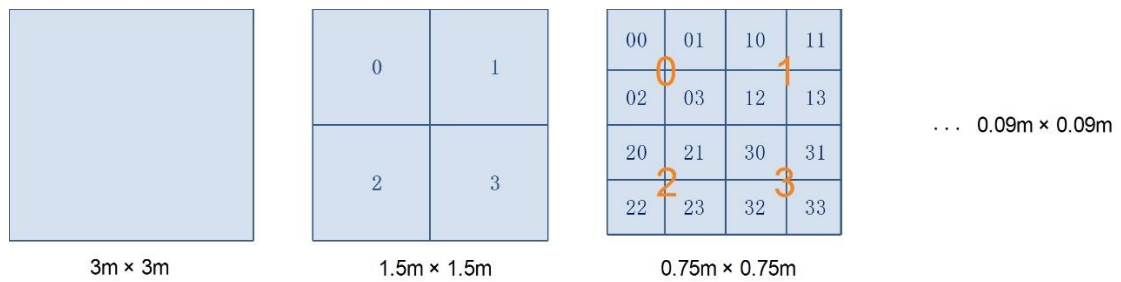
Figure 3.1 QTEM-a finer resolution extension model of w3w
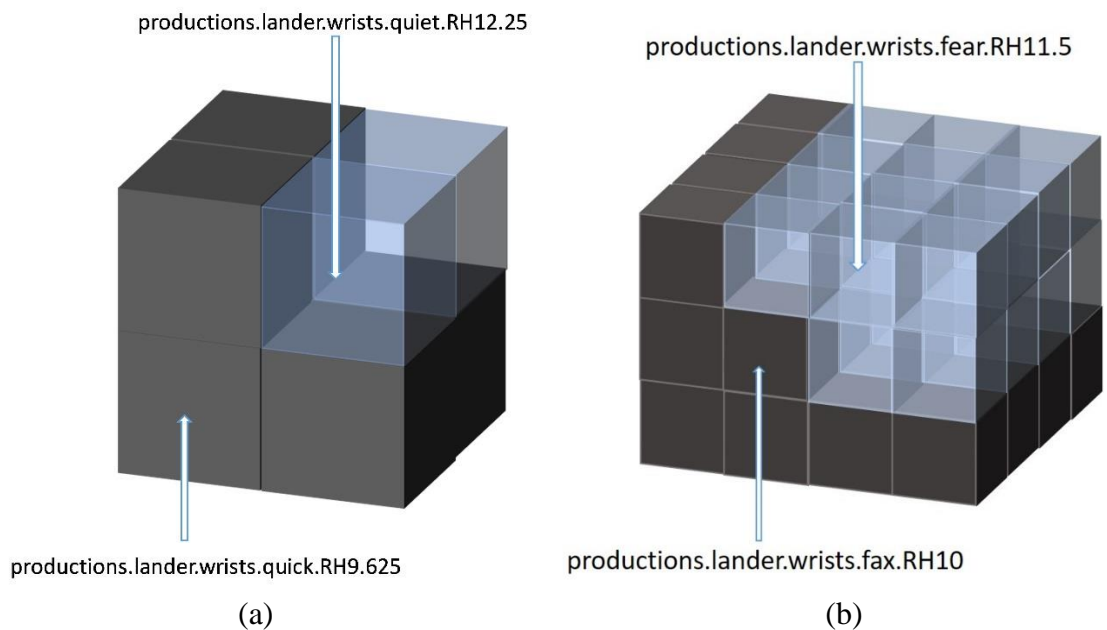
Figure 3.2 Blocks representing the 3D space. (a) blocks of 1.5m resolution; (b) blocks of 0.75m. (dark blocks represent occupied space, while light colour blocks represent free space)

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Table 3.1 Extended five-word code of w3w

Resolution (m)	Extended Code
3×3	word1.word2.word3..H(RH/F) 10
1.5×1.5	word1.word2.word3.**q**⋯.H(RH/F) 10
0.75×0.75	word1.word2.word3.**f**⋯. H(RH/F) 10
0.375×0.375	word1.word2.word3.**c**⋯. H(RH/F) 10
0.1875×0.1875	word1.word2.word3.**p**⋯. H(RH/F) 10
0.09×0.09	word1.word2.word3.**s**⋯. H(RH/F) 10

According to the resolution, the maximum residual offset of the geocoded location from the centroid of the cell is ranging from 1.06 meter to 0.06 meter. The w3w extensions provide higher precisions by simply adding one more word to the original three-word code. This coding scheme retains the advantage of w3w as being easier to remember (Barr, 2015). The MapCode provides precisions ranging from 5 meters to 0.16 meter by increasing the code from 5 digits to 8 digits with mixing numbers, letters, and symbols (Geelen, 2015). Similarly, Google's Open Location Code uses a 10-digit code to represent a square of 14-meter by 14-meter in size, which defines the precision to be roughly 10 meters. To increase the precision, the code needs to be lengthened (Open Location Code, 2015).

3.1.2 The RESTful API

To implement the two-way transformation between the extended code and the geographic coordinates, an application programming interface (API) for the extended w3w geocoding system was designed.

"Representational State Transfer" (REST) is an architectural style of network that commonly applied to API designs for web services (Masse, 2011). A Web API conforming to the constrains of the architectural style is considered RESTful. A client program can use the API to communicate with the web services. It can acquire data from the web service by sending a request to a specific Uniform Resource Locator (URL) through HTTP protocol. The RESTful API developed for this study implements the QTEM extension and provides the functions of (i) forward and reverse geocoding; (ii) encoding single line and polygon feature; (iii) encoding a section of centre points for a given area.

3.1.3 Scope and Structure of the Paper

The scope of this study is the development and testing of a HTTP-based RESTful API implementing the QTEM geocoding extensions of w3w.

The paper content is organized into five Sections. Section 2 provides a summary of existing geocoding systems including a discussion on the advantages and disadvantages

of these systems. It also reviews the definition and implementation of geographic RESTful APIs. Section 3 introduces the operations supported by w3w geocoding RESTful API. Section 4 demonstrates the development of the extended RESTful API and example results. Section 5 summarizes the geocoding operations provided by the extended RESTful API and lists some potential applications.

3.2 Literature Review

Geocoding is one of the basic geospatial operations. It converts addresses, postal codes, place names or other geographic references to geographic coordinates (Goldberg, 2011; Lee, 2009; Karimi et al., 2011). It plays a vital role in spatial analysis, as geocoding technology has been utilized in many application areas such as epidemiology, environmental science, emergency management, marketing, planning and location-based services. These applications involve a broad range of disciplines including, but not limited to: geography; geographic information science; computer science; digital libraries; history; and economics (Goldberg, 2011; Karimi et al., 2011). Geocoded data provides a basis for subsequent spatial analysis and mapping. Errors associated with the geocoded data are likely to propagate through subsequent processing, analysis, modelling, and decision making (Goldberg, 2011; Karimi et al., 2011). Therefore, it is important to obtain accurate locations from geocoding processes.

There are two categories of geocoding schemes adopted by geocoding systems: address-based and alphanumeric code based. Address-based geocoding systems have many constraints including coverage, standardization, maintenance, and precision. The coverage issues occur because these systems are unable to geocode locations with no official address (Barr, 2015). Standardization is an issue because address-based systems require properly formatted input, whereas address formats vary from location to location (Lee, 2009). Also, these systems require high maintenance as address databases must be updated regularly to reflect real-world changes for the entire coverage area (Lee, 2009). Last but not least, precision can be a major concern. Geocoding in rural areas is often offset-prone (Kellison, 2012). Even in urban areas, where geocoders are typically more precise, they are referenced to the centroid of structures or parcels. Entire university buildings, business parks, and farms are abstracted to single points that do not carry sufficient precision for many applications (Chen, Cheng, Tong, & Yuan, 2016; Zandbergen, 2007; Karimi et al., 2011).

The alphanumeric code geocoding scheme provides an alternative way for describing a geographic location. Multiple alphanumeric code based geocoding systems are already available to convert between alphanumeric codes and geographic coordinates: Geohash, MapCode, c-Squares, WMO squares, Open Post Code, Google's Open Location Code, and what3words (Barr, 2015; Stefanakis, 2016). These systems assign systematic alphanumeric labels to locations (polygons) over the earth, which are converted to geographic coordinates using mapping formulas, instead of graphs and an address database (Barr, 2015). Alphanumeric code geocoding systems share several advantages:

(i) every cell is assigned a unique and static code, (ii) codes are simple to encode and decode; (iii) codes are efficient for communication (Chen et al., et2016).

w3w, compared to other alphanumeric code geocoding systems, has three significant advantages. First, the cleanness of the coding scheme, as the use of dictionary words is less error-prone than a code mixing letters and numbers. Second, the codes are easier to remember (Barr, 2015). Finally, it supports multiple languages. Other alphanumeric code geocoding systems provide a code combining random Latin characters with numbers, which can be as long as 10-characters for high resolution. The codes provided by these systems are hard to remember, while they are not language or culture-independent (Rhind, 2015). However, w3w still has limitations, such as a fixed resolution and no consideration of elevation, which may impede efficient modelling in applications. Jiang and Stefanakis (2018) introduced a series of extensions of the w3w geocoding system to overcome these limitations. The Ternary-Tree Extension Model (TTEM) and Quadtree Extension Model (QTEM) proposed would extend the w3w grid to provide variable resolutions. These models in conjunction with elevation extension models support indoor applications where a finer resolution and height value are desired. These extensions require attaching a fourth-word and a fifth-word to original w3w codes to represent the resolution and elevation respectively.

Geocoding as a basic geoprocessing tool is commonly implemented by geographic applications (Zhao, Foerster, & Yue, 2012). Providing its functionalities through RESTful web service is an increasing trend in industry. The REST architecture, as a new paradigm on Web service is now a favorite method of designing web services that

process and deliver geographic data (Foerster, Bruhl, & Schaffer, 2011). The lightweight

and scalable properties of the RESTful APIs meet the needs of simplicity and flexibility

for many applications. It is beneficial for non-computer science researchers as it can be

easily implemented in existing applications (Mazzetti, Nativi, & Caron, 2009). Many

RESTful APIs have been developed for geospatial applications to publish geospatial

resources over a network for client programs' access (Sun et al., 2017). The standardized

interfaces allow for the interoperability between client programs and web services.

Examples of geocoding RESTful APIs are Google Maps Geocoding API, ArcGIS

Geocoding REST API, MapQuest Open Geocoding API and what3words Geocoding

API.

3.3 W3W RESTful API

W3w RESTful API, like many other geocoding APIs, provides programmatic access

to transform a three-word address into coordinates (forward geocoding) in the WGS84

spatial reference system and to convert coordinates to a three-word address (reverse

geocoding). It also provides access to a geographically bounded section of 3m x 3m

what3words grid which is comprised of multiline features. The delivery of the resources

is in XML, JSON and GeoJSON format. Other non-spatial operations such as obtaining

suggestions based on a full or partial three-word address (AutoSuggest and

StandardBlend) and retrieving a list of supported languages are provided as well

(what3words API, 2017).

Each of the API resources can be accessed from a specific URI that consists of an

endpoint https://api.what3words/com/v2, a path (i.e. /forward?, /reverse?, /grid?) and a

set of query options. Examples in Table 3.2 (a) demonstrate the URIs of w3w RESTful

API.

Table 3.2 (a) Example URIs of w3w RESTful API

Operations	URI
forward geocoding	https://api.what3words.com/v2/forward?addr=index.home.raft&key=MY-API-KEY&lang=en&format=json&display=full
reverse geocoding	https://api.what3words.com/v2/reverse?coords=51.521251%2C-0.203586&key=MY-API-KEY&lang=en&format=json&display=full
grid	https://api.what3words.com/v2/grid?bbox=52.208867%2C0.117540%2C52.207988%2C0.116126&key=MY-API-KEY&format=json

Each URI consists of both required and optional queries (Table 3.2 (b)). The

parameters of the queries are the input that will be passed to the web server when a

request has been made. The optional queries can be left blank and they will be assigned

default values designed by w3w RESTful API.

Example representations of the resources of w3w forward and reverse geocoding

were shown below (Figure 3.3). The requested format is JSON, and the "display"

parameter in the URIs were determined as "minimal".

Table 3.2 (b) Example URIs' parameters of w3w RESTful API

Operations	Queries	Parameters
forward geocoding	addr key lang (optional) format (optional) display (optional)	three-word address; API key of w3w; language it supports; return data format type; return data display type;
reverse geocoding	coord key lang (optional) format (optional) display (optional)	coordinates; API key of w3w; language it supports; return data format type; return data display type;
grid	bbox key format (optional)	the northeast and southwest corner; coordinates of the specified grid; API key of w3w; return data format type.

URI
https://api.what3words.com/v2/forward?
addr=basks.lenses.rugged&key=myAPIkey&lang=en&
format=json&display=minimal

Result

```
{
  "words":"basks.lenses.rugged",
  "geometry":{
    "lng":66.642151,
    "lat":45.949237
  },
  "language":"en",
  "status":{
    "reason":"OK",
    "status":200
  }
}
```

URI
https://api.what3words.com/v2/reverse?coords=
45.92222%2C-66.67777&key=myAPIkey&lang=en
&format=json&display=minimal

Result

```
{
  "words":"muddy.finishes.sued",
  "geometry":{
    "lng":-66.677771,
    "lat":45.922232
  },
  "language":"en",
  "status":{
    "reason":"OK",
    "status":200
  }
}
```

(a)   (b)

Figure 3.3 (a) Result of w3w forward geocoding API request in JSON format, (b) Result
of w3w reverse geocoding API request in JSON format

The w3w API is utilized by the extended w3w API, to provide forward and reverse geocoding of the first three words of each extended code.

3.4 Extended w3w RESTful API

The development of the extended RESTful API for the QTEM model is presented. Like the w3w RESTful API, the extended RESTful API also provides forward and reverse geocoding operations. Operations of single line and polygon feature encoding and multi-points encoding are implemented as well.

3.4.1 Development

3.4.1.1 URI Structure and HTTP Method

A RESTful API exposes a set of resources over the network that are identified by URIs (Balani & Hathi, 2009). Each unique URI directs to a specific resource. The accessibility of URI is essential for web applications. Therefore, the architecture structure of URI needs to be clearly formed. The generic syntax of a URI is defined as URI= scheme "://" authority "/" path ["?" query] ["#" fragment] (RFC 3986). The scheme "https" is used for the interaction with the resource through Hypertext Transfer

Protocol (HTTP) over Secure Sockets Layer (SSL). HTTP provides a uniform interface and a set of methods such as GET, POST, PUT, DELETE to manipulate the resource. The extended w3w RESTful API was developed exclusively using the GET method, which retrieves the representation of the resource. "gaia.gge.unb.ca" host was used for the authority portion to identify the owner of the RESTful API. It can only be accessed within UNB network at this time. Based on the requested resource the path and query parameters vary. Table: 3.3-3.7 demonstrate URI templates of the extended w3w RESTful API.

The operations can be performed by four-word and five-word extensions, denoted as "w4w" and "w5w" respectively in the URI path. The following word (i.e., forward, reverse, line, polygon, area) indicates the operation of the API. The format parameter can be assigned "xml", "json" or "geojson" to obtain the specific format of the resource.

Table 3.3 Extended w3w forward geocoding API reference

Operation	Forward Geocoding
URI Root	https://gaia.gge.unb.ca
URI Path	/WebService1/geocoding/w4w/forward
	(/WebService1/geocoding/w5w/forward)
Parameters	addr — extended four-word (five-word) code lang — supported language format — supported format
HTTP method	GET
Format	XML, JSON, GeoJSON

Table 3.4 Extended w3w reverse geocoding API reference

Operation	Reverse Geocoding
URI Root	https://gaia.gge.unb.ca
URI Path	/WebService1/geocoding/w4w/reverse
	(/WebService1/geocoding/w5w/reverse)
Parameters	lat — latitude of the coordinates lng — longitude of the coordinates (h — elevation of the coordinates) resolution — resolution of the extended square lang — supported language format — supported format
HTTP method	GET
Format	XML, JSON, GeoJSON

Table 3.5 Extended w3w line encoding API reference

Operation	Line Encoding
URI Root	https://gaia.gge.unb.ca
URI Path	/WebService1/geocoding/w4w/line
	(/WebService1/geocoding/w5w/line)
Parameters	start — four-word (five-word) code of endpoint end — four-word (five-word) code of the other endpoint lang — supported language format — supported format
HTTP method	GET
Format	XML, JSON, GeoJSON

Table 3.6 Extended w3w polygon encoding API reference

Operation	Polygon Encoding
URI Root	https://gaia.gge.unb.ca
URI Path	/WebService1/geocoding/w4w/polygon
	(/WebService1/geocoding/w5w/polygon)
Parameters	vertices — an array of four-word (five-word) codes separated by "%" lang — supported language format — supported format
HTTP method	GET
Format	XML, JSON, GeoJSON

Table 3.7 Extended w3w centre points encoding API reference

Operation	Centre Points Encoding
URI Root	https://gaia.gge.unb.ca
URI Path	/WebService1/geocoding/w4w/area
	(/WebService1/geocoding/w5w/area)
Parameters	bbox — the coordinates of southwest and northeast corner for a given area resolution — resolution of the extended square format — supported format
HTTP method	GET
Format	XML, JSON, GeoJSON

3.4.1.2 Resources Design

The resource is the data returned to the client. The information the resource conveys

is determined by the geocoding operations. For the QTEM model, the operation

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algorithms were implemented on the JAVA programming platform. The extended w3w forward and reverse geocoding algorithms are the basic procedures, utilized by the algorithms of line, polygon and centre points encoding.

Algorithm 1 demonstrates the forward geocoding operation that transforms a four-word code to a pair of coordinates (φ, λ) (Table 3.8 (b)). An array of the fourth words, representing the positions, in the second level QTEM model is displayed in Table 3.8 (a).

The algorithm can be mapped to a work flow (Figure 3.4) in which the extended four-word code as input were separated into two parts—the original w3w address code and the fourth word. The first three words are transformed to the corresponding coordinates of the w3w square by using w3w RESTful API. By finding the fourth word with the 2D array, the position of the sub-square is located. The latitude and longitude offsets between these two points are calculated and applied to obtain the coordinates of the sub-square.

Similarly, for the five-word implementation, the first four words were processed using Algorithm 1 to obtain latitude and longitude. The fifth word was processed separately to retrieve the height value. Figure 3.5 shows the work flow of the transformation from five-words code to coordinates with elevation.

Table 3.8 (a) An example 2D array of the fourth words of QTEM model in resolution of 0.375m; (b) Algorithm of transforming four-word code to coordinates

fan	far	fee	few
fat	fax	fear	feat
file	film	flag	flam
fire	five	flap	flat

(a)

Algorithm 1: Forward geocoding, from four-words code to position
Input:
An array of string data type of four words
Output:
Corresponding coordinates of latitude φ' and longitude λ'
Steps:
1. Create a new array to store the first three words of the four-word code;
2. Retrieve coordinates φ, λ of the center point of the original what3words square through what3words API by providing the new array;
3. Determine resolution based on the fourth word:
i. If it starts with letter 'q', resolution r = 1.5 m
ii. If it starts with letter 'f', resolution r = 0.75 m
iii. If it starts with letter 'c', resolution r = 0.375 m
iv. If it starts with letter 'p', resolution r = 0.1875 m

v. If it starts with letter 's', resolution r = 0.09375 m

4. find its position in the two-dimensional array [row, column]

5. find the offset distance value

    i. calculate the x, y distance between the center point of the sub-square and the center point of the original square

        x = f (row, column, r)

        y = f (row, column, r)

    ii. convert the x, y value into $\Delta\lambda$, $\Delta\varphi$ respectively

        $\Delta\varphi = y \div M^{1}$

        $\Delta\lambda = x \div (N^{2} \cdot \cos\varphi)$

6. Add offset $\Delta\varphi$, $\Delta\lambda$ to φ and λ respectively

        $\varphi' = \varphi + \Delta\varphi$

        $\lambda' = \lambda + \Delta\lambda$

End

(b)

---

[1] $M = \dfrac{a(1-e^{2})}{(1-e^{2}\sin^{2}\varphi)^{\frac{3}{2}}}$,

[2] $N = \dfrac{a}{(1-e^{2}\sin^{2}\varphi)^{\frac{1}{2}}}$, a is the semi-major axis, e is the numerical eccentricity of the ellipsoid (Torge & Muller, 2012).
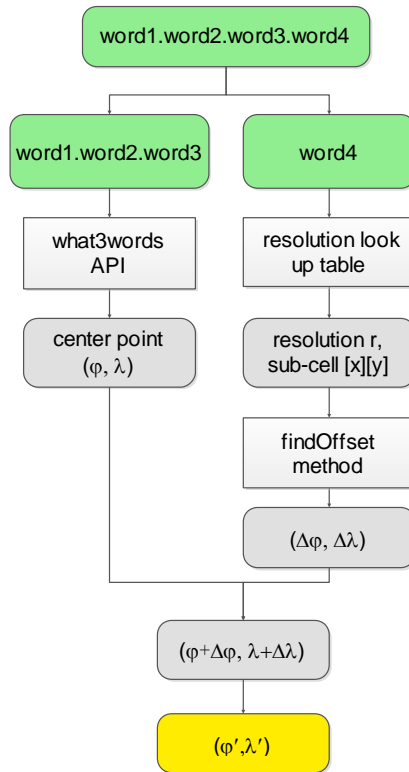
Figure 3.4 Work flow of extended forwarding geocoding with four-word code
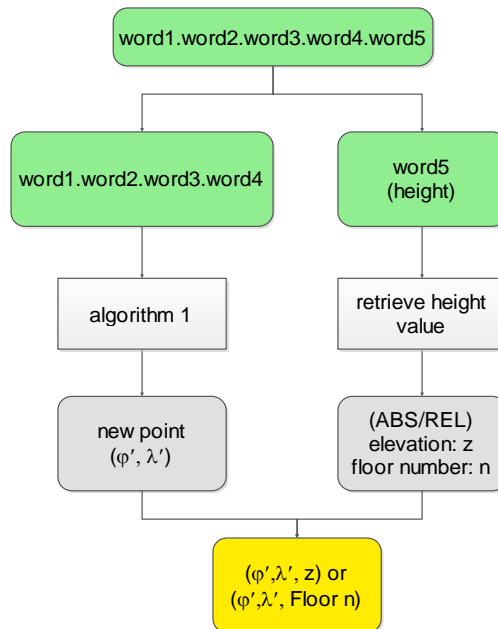
Figure 3.5 Work flow of extended forward geocoding with five-word code

Algorithm 2 demonstrates the reverse geocoding operation that converts a pair of coordinates (φ, λ) to a four-word code given a specific resolution (r) (Table 3.9). The work flow in Figure 3.6 illustrates the process of Algorithm 2, in which the coordinates (φ, λ) and resolution (r) in darker blocks were passed as input parameters. The output four-word code was obtained by combining the original three words retrieved from w3w API and the fourth word retrieved from the "find Sub-square" method. To convert coordinates with elevation value to a five-word code, the above work flow was utilized to obtain the first four words. The elevation was processed separately and converted to the corresponding symbol as the fifth word (Figure 3.7).

Table 3.9 Algorithm of converting coordinates to four-word code

Algorithm 2: Reverse geocoding, from position to four-words code

Input:

    1.   Coordinates of latitude φ and longitude λ

    2.   Resolution r

Output:

    Corresponding four-words code

Steps:

    1. Retrieve original what3words code [word1.word2.word3] through what3words API by providing coordinates (φ, λ);

2. Retrieve the coordinates of the center point of the what3words square φ_c, λ_c through what3words API by providing the code [word1.word2.word3] from step 1;

    3. Find the Sub-square method

       i. Calculate the latitude and longitude offset between input point and the center point of what3words

$$\Delta\varphi = \varphi - \varphi_c$$

$$\Delta\lambda = \lambda - \lambda_c$$

       ii. Convert $\Delta\varphi$, $\Delta\lambda$ into horizontal and vertical distance

$$y = M \times \Delta\varphi$$

$$x = (N \cdot \cos\varphi) \times \Delta\lambda$$

    4. Resolution categorized:

If r <=2m and r >=1m, resolution r = 1.5 m

search the words start with letter "q"

If r <1m and r >=0.5m, resolution r = 0.75 m

search the words start with letter "f"

If r <0.5m and r >=0.25m, resolution r = 0.375 m

search the words starts with letter "c"

If r <0.25m and r >=0.125m, resolution r = 0.1875 m,

search the words starts with letter "p"

If r <0.125m and r >0m, resolution r = 0.09375 m search

the words starts with letter "s"

5. Find the fourth word in the array

row = f (x, y, r)

column = f (x, y, r)

6. Add the fourth word to the words tuple [word1.word2.word3]

retrieved from step 1.

End
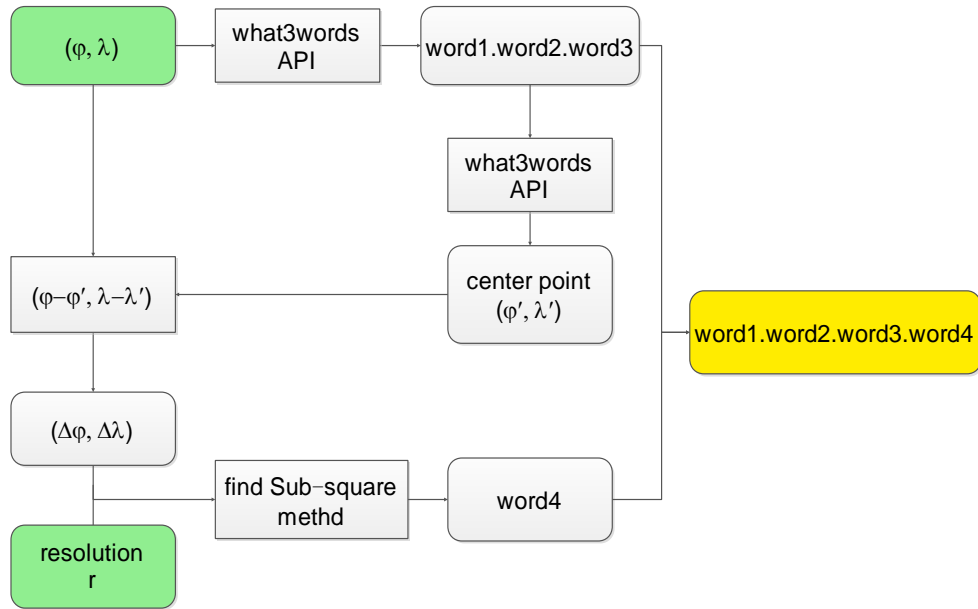
Figure 3.6 Work flow of extended reverse geocoding with four-word code
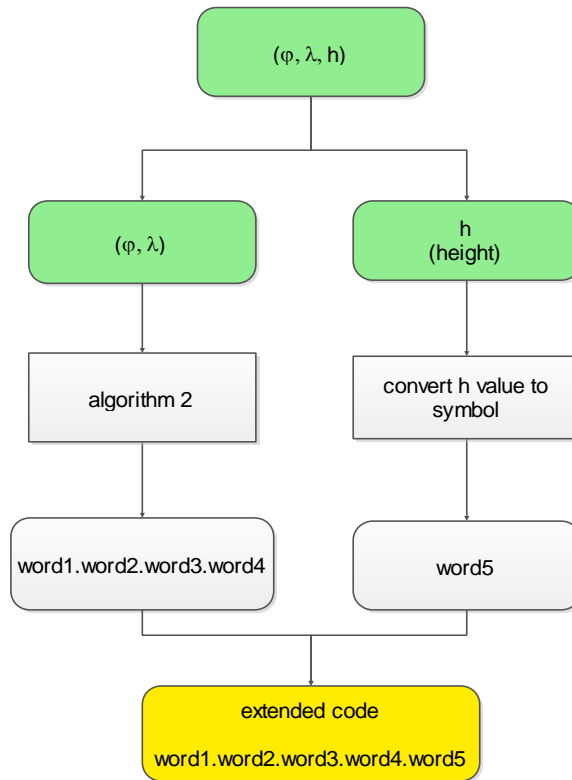
Figure 3.7 Work flow of extended reverse geocoding with five-word code

3.4.2 RESTful API Request Results

Table 3.10 lists the operations the extended w3w RESTful API provides, associated

with example URIs.

Table 3.10 Extended w3w RESTful API operations and example URIs

Operation	URI
forward geocoding	https://gaia.gge.unb.ca/Webservices1/geocoding/w4w/forward?addr=handlebars.overlooks.pitch.fat&lang=en&format=xml
	https://gaia.gge.unb.ca/Webservices1/geocoding/w5w/forward? addr= handlebars.overlooks.pitch.fat.RH13&lang=en&format=xml
reverse geocoding	https://gaia.gge.unb.ca/Webservices1/geocoding/w4w/reverse?lat=45.949803&lng=-66.641686&resolution=0.75&lang=en&format=json
	https://gaia.gge.unb.ca/Webservices1/geocoding/w5w/reverse?lat=45.949803&lng=-66.641686&h=RH13&resolution=0.75&lang=en&format=json
line encoding	https://gaia.gge.unb.ca/Webservices1/geocoding/w4w/line?start=breathless.trains.machine.far&end=rituals.munched.cheater.flap&lang=en&format=geojson
	https://gaia.gge.unb.ca/Webservices1/geocoding/w5w/line?start= breathless.trains.machine.far.RH13& end= rituals.munched.cheater.flap.RH13&lang=en&format=geojson
polygon encoding	https://gaia.gge.unb.ca/Webservices1/geocoding//w4w/polygon?vertices=vendetta.invocation.dairy.few%clay.risk.lockup.flag%ungreased.thumbnail.glitters.flat%faithless.term.breakdown.fat&lang=en&format=geojson
	https://gaia.gge.unb.ca/Webservices1/geocoding//w5w/polygon? vertices=vendetta.invocation.dairy.few.F5%clay.risk.lockup.flag.F5%ungreased.thumbnail.glitters.flat.F5%faithless.term.breakdown.fat.F5&lang=en&format=geojson
area encoding	https://gaia.gge.unb.ca/WebService1/geocoding/w4w/area?bbox=45.94925049480924, -66.64216067341889,45.94928,-66.64219&resolution=0.75&format=xml
	https://gaia.gge.unb.ca/Webservices1/geocoding//w5w/area?bbox=45.948479,-66.641608, 45.948430,-66.641590&h=35.5&resolution=0.75&format=xml

The following examples display some of the results of the extended RESTful API

requests. The four-word code "handlebars.overlooks.pitch.fat" representing a sub-square in

resolution 0.75m (Table 3.8 (a)) was passed on to the web server. The coordinates of the

sub-square associated with the bounding coordinates and the latitude and longitude

offsets from the centre point of the 3m square (in meters) were returned in XML format

as determined in the URI (Figure 3.8). Similarly, the five-word address containing

elevation information can be transformed to the corresponding coordinates (Figure 3.9).

URI
https://gaia.gge.unb.ca/WebService1/geocoding/w4w/forward?
addr=handlebars.overlooks.pitch.fat&lang=en&format=xml

Result

```
<response>
   <bound>
      <northeast>
         <latitude>45.95010674780873</latitude>
         <longitude>-66.64177367334382</longitude>
      </northeast>
      <southwest>
         <latitude>45.95010000019127</latitude>
         <longitude>-66.64178334665617</longitude>
      </southwest>
   </bound>
   <geometry>
      <latitude>45.950103374</latitude>
      <longitude>-66.64177851</longitude>
   </geometry>
   <offset>
      <delta_x>-1.12500244212281</delta_x>
      <delta_y>0.3750212596528374</delta_y>
   </offset>
</response>
```

Figure 3.8 Forward geocoding a four-word code

URI
https://gaia.gge.unb.ca/WebService1/geocoding/w5w/forward?
addr=handlebars.overlooks.pitch.fat.**RH13**&lang=en&format=xml

Result

\</response>
            ...
  \<geometry>
    \<latitude>45.950103374\</latitude>
    \<longitude>-66.64177851\</longitude>
    \<elevation>relative 13\</elevation>
  \</geometry>
            ...
\</response>

Figure 3.9 Forward geocoding a five-word code

The coordinates retrieved from the forwarding geocoding API in GeoJSON format

was uploaded to ESRI ArcGIS Online platform and presented in Figure 3.14 (a).

The reverse geocoding that converts coordinates into extended codes were also tested

(Figure 3.10). The resolution parameter from the client input may differ. However, it

will be classified to fit the specific resolution supported by the QTEM extensions.

The single line encoding operation using four-word code was tested by sending the

following request (Figure 3.11). The GeoJSON object was mapped as a line feature

following along the hallway of Head Hall Building in UNB (Figure 3.14 (b)). The

polygon encoding API provides the function of retrieving a simple polygon by inputting

the codes of its vertex (Figure 3.12). The centre points encoding for a defined area return

a collection of points that represent the sub-squares (Figure 3.13).

The features of the polygon and the multi-points obtained from the above API

requests were visualized in Figure 3.14 (c). To demonstrate the corresponding four-word

code for sub-squares, four example points were selected from each original square. The

fourth word in each code indicates the position of the sub-square inside the original cell

(Table 3.8 (a)).

URI
https://gaia.gge.unb.ca/WebService1/geocoding/w4w/reverse?
lat=45.949803&lng=-66.641686&resolution = 0.75&
lang=en&format=json

Result

{
        "first":"tram",
        "second":"sullen",
        "third":"registration",
        "fourth":"flag"
}

Figure 3.10 Reverse geocoding coordinates to four-word code

URI
https://gaia.gge.unb.ca/WebService1/geocoding/w4w/line?
start=breathless.trains.machine.far&end=rituals.munched.cheater
.flap&lang=en&format=geojson

Result

{
  "type": "LineString",
  "coordinates": [
    [
      -66.641651837,
      45.950083121
    ],
    [
      -66.641565163,
      45.950197879
    ]
  ]
}

Figure 3.11 Encoding with four-word code

77

URI
https://gaia.gge.unb.ca/Webservices1/geocoding//w4w/polygon?vertices= vendetta.invocation.dairy.few%
clay.risk.lockup.flag%ungreased.thumbnail.glitters.flat%
faithless.term.breakdown.fat&lang=en&format=geojson

Result
{
  "type": "Polygon",
  "coordinates": [
   [
     [-66.64174949, 45.950137121],
     [-66.641720163, 45.950177626],
     [-66.64163249, 45.950143879],
     [-66.64166151, 45.950103374],
     [-66.64174949, 45.950137121]
   ]
  ]
}

Figure 3.12 Polygon encoding by providing the codes of vertex

URI
https://gaia.gge.unb.ca/WebService1/geocoding/w4w/area?
bbox=45.94925049480924,-
66.64216067341889,45.94928,-66.64219&resolution=
0.75&format=xml

Result
{
  "type": "FeatureCollection",
  "features":[
      { "type": "Feature",
        "geometry": {
            "type": "Point",
            "coordinates":
                  [-66.64216551,45.949280879]
          },
         "properties": {
            "words": "newsstands.ulcer.scored.fire"
          }
      },
      { "type": "Feature",
        "geometry": {
            "type": "Point",
            "coordinates":
                  [-66.6421558368284,45.949280879]
          },
         "properties": {
            "words": "newsstands.ulcer.scored.five"
          }
      },
      ......
  ]
}

Figure 3.13 Centre points encoding for a given area
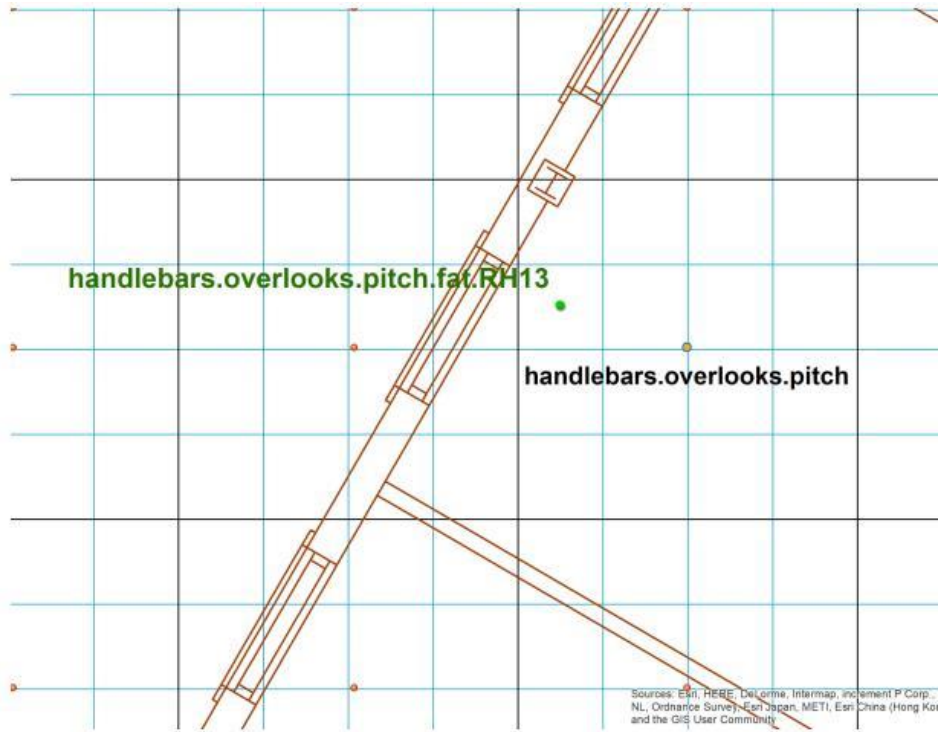
(a)

(b)
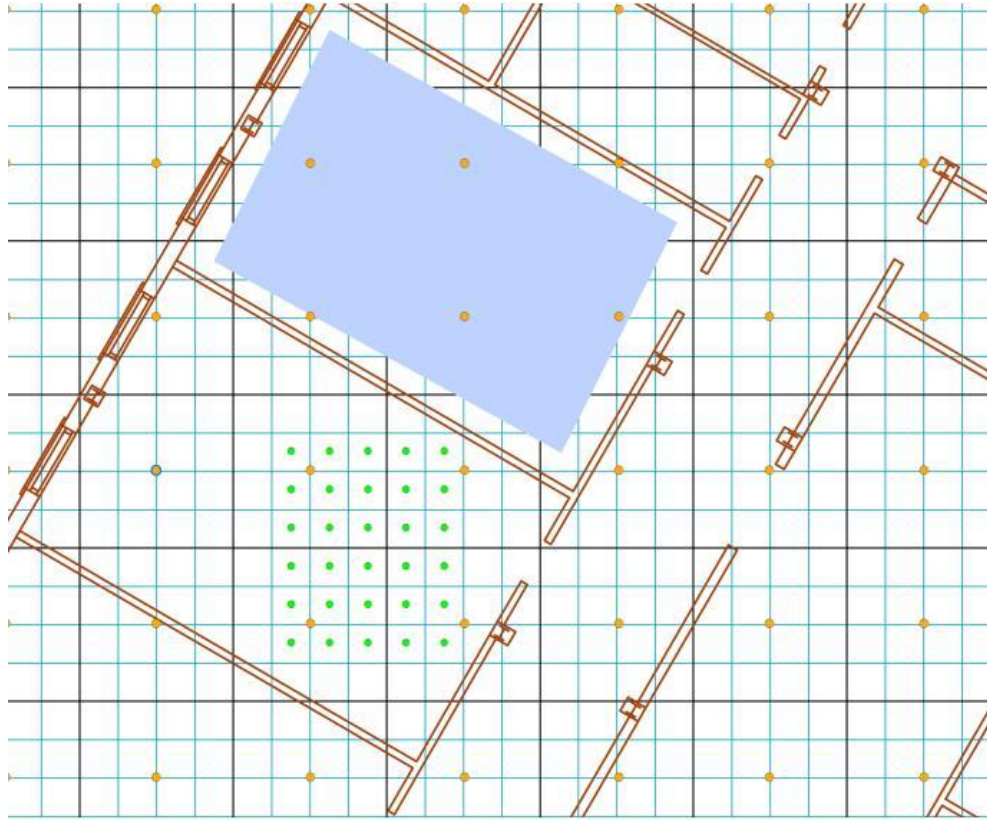
(c)

Figure 3.14 Visualization of (a) forward geocoding of a five-word code, (b) line encoding of Head Hall hallway, (c) polygon encoding of room E4 and centre points encoding of defined area in room E5

3.5 Conclusion

The extended w3w RESTful API implementing QTEM extensions has been designed and tested in order to validate the extensions and provide a web service for client geographic applications. The extended geocoding API provides operations for (i)

forward geocoding, that transforms the extended four-word or five-word code to corresponding coordinates; (ii) reverse geocoding, that converts a set of coordinates into the extended code; (iii) line and polygon encoding, that retrieve single line or polygon feature; and (iv) centre points encoding, that retrieve a section.

The URIs of the developed API were designed in the pattern with a clear architectural structure that is human-readable and easy to understand. The requested resources can be obtained by identifying the URI path and the corresponding parameters. XML, JSON and GeoJSON format of the resources are supported by the API. The algorithms that perform forward and reverse geocoding were tested by implementing the API requests of centre points for a given area.

The extended w3w RESTful API is a lightweight and scalable application. The resources published by the web service could be implemented by software programs performing indoor and outdoor location referencing, location marking and path finding. For this reason, the performance evaluation of the API including the efficiency, errors and satisfaction needs to be investigated before its implementation. This is another direction for the future research.

ACKNOWLEDGEMENTS

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4. APPLICATIONS OF WHAT3WORDS GEOCODING EXTENSIONS IN UNIVERSITY CAMPUS ENVIRONMENTS

Abstract

Geocoding is a process for transforming descriptive formats of location data into geographic coordinates. It is a fundamental component of spatial analysis which is commonly used in many geographic information system (GIS) applications. With the advancement of location-based technologies, the demand for geocoding systems with increasing accuracy and coverage in outdoor and indoor spaces has been rising. A variety of geocoding systems have been developed and are available for developers, each with its own purpose and accuracy. Amongst them, what3words (w3w) provides a novel approach for location encoding. Any place on the earth surface can be located using a three-word address code, with a maximum 2.12 meters residual. However, the limitations of w3w, i.e., a fixed resolution and no consideration of third-dimension, hinder its adoption in many applications. Extensions of w3w geocoding have been proposed to overcome these limitations. With various resolutions and encoding the third-dimension, these extensions could facilitate the development of applications for both outdoor and indoor environments. This paper proposes three application prototypes utilizing one of the w3w extensions: Quadtree Extension Model (QTEM). This model divides the original w3w squares into sub-squares at a resolution of 0.75-meter. The third-dimension (elevation) is also considered. These prototypes include indoor facility

management, indoor navigation, and outdoor navigation for university campus
environments.

4.1 Introduction

A wide range of geographic information systems (GIS) software providing location-based services has been developed to meet the increased demand for location data in a variety of industry sectors ranging from mobility, transportation, and asset management to insurance and robotics. Geocoded locations are essential for many GIS analysis, cartography and dicision-making workflows (Jiang & Stefanakis, 2018a). Geocoded locations have become necessary for many spatial analysis tasks such as locating objects (assets or people) and caculating optimal paths for navigation or evacuation purposes. Geocoding is a fundamental geoprocessing tool that has been commonly used in geographic applications to obtain location data (Goldberg, 2013). It is the approach that transforms the reference of a place such as an address, postal code, place name or other alphanumeric code to geographic coordinates. Typically this is done so that the location of the place could be retrieved and displayed, allowing the spatial analysis, mapping, and other geolocation related processes to be performed in GIS software packages (Jiang & Stefanakis, 2018a).

Motivated by a need for a geocoding system to support applications for the University of New Brunswick (UNB) campus, this paper presents representative

applications utilizing one of the extended what3words (w3w) geocoding models –

Quadtree Extension Model (QTEM). QTEM is one of several w3w extensions that were

developed based on the original w3w geocoding system in Jiang and Stefanakis (2018a).

w3w geocoding system is different from the conventional address-matching geocoding

in that it partitions the earth's surface into a grid of 3-meter by 3-meter squares. Each

square is assigned a unique code consisting of three dictionary words separated by

periods. For example, the entrance to the CN Tower in Toronto, Canada is located at

"select.threaten.shelters" (Barr, 2015). This method is supported in multiple languages

and allows for easier memorization of locations. The static and unchangeable code

allows for the addressing of places no matter the existence of a reliable street address.

However, it also presents limitations: a fixed resolution of 3 m x 3 m and no

consideration of elevation. To address this Jiang and Stefanakis (2018a) proposed a

series of extended models of w3w. With a variable resolution, w3w grid cells could have

a smaller or larger size to satisfy the needs of a finer or coarser resolution, respectively.

By attaching a fourth word starting with a certain letter to the original three-word code,

the four words tuple represents the location and the resolution of the new square. A fifth

word can also be attached to the extended code to represent the variety of elevation

types. For example, the entrance of Head Hall building of UNB is located at

"tram.sullen.registration.flag.RH0"- a 75cm edge length square with a height value

equals to 0 meter relative to the ground.

   A RESTful API of the w3w extensions has been built to facilitate the development of

geographic applications (Jiang & Stefanakis, 2018b). This API extends the original w3w

RESTful API by utilizing the w3w API Java library (what3words API, 2018). The extended API provides the operations of forward and reverse geocoding for client programs, allowing them to communicate with the web server to retrieve either the coordinates or the corresponding address code of each square. In this paper, three application prototypes utilizing the RESTful API associated with other goeprocessing tools in the GIS software are proposed. These applications include indoor facility management, indoor navigation, and outdoor navigaton for UNB campus.

The paper content is organized into four Sections. Section 2 illuminates the role of geocoding in application development and lists example applications implementing geocoding function. Section 3 demonstrates the development of three application prototypes for UNB campus utilizing the w3w geocoding extension. Finally, Section 4 concludes the discussion.

4.2 Geocoding Implementation

The process of geocoding forms a fundamental component of spatial analysis in a wide variety of research disciplines and application domains (Goldberg et al., 2007). Geocoding has been commonly used in many geographic applications including web GIS and standalone GIS software. These applications are used in many industries such as asset management, emergency services, navigation and mobility, robotics, crime and health care.

A web-mapping application is a simple example of geocoding. The web page may accept an address as input and pass it to a web server for geocoding processing. The resulting coordinates may then be displayed on the map embedded in the web page. Google Maps platform provides a geocoding API to developers, and its association with other Google Maps APIs makes it a good source for building web GIS applications (Akanbi & Agunbiade, 2013). The rapid evolution in wireless communication and location positioning technologies has facilitated the development of many mobile GIS applications. Geocoding plays a critical role in supporting Location-Based Services (LBS) (Kushwaha & Kushwaha, 2011; Goldberg, 2013). GPS-enabled technologies are not the only way to determine the user's geographic location. A user may submit a textual or spoken query describing their location in diverse formats such as an address, postal code or place name to request location information and services relevant to that location. Geocoding is the process responsible for translating the expression into geographic representations supported by the LBS (Goldberg, 2013). Another common form of LBS is the travel routing application. An LBS providing route computing service must employ a geocoding system to determine the location of the origin, destination and/or waypoints in circumstances where the user inputs locations in the form of descriptive addresses (Goldberg, 2013).

GIS applications have been progressively extending from outdoor to indoor environments over the past few years (Li et al., 2010). The demands for indoor space information for: indoor positioning, indoor path planning, emergency evacuation, indoor and outdoor integrated navigation, etc. are steadily increasing (Lin et al., 2017).

Geocoding systems that support indoor and 3D spatial location encoding is currently a major challenge (Goldberg, 2013). Lee (2009) proposed an indoor 3D geocoding prototype based on address-matching method. This method inherits the limitations of address-based geocoding systems as it still relies on an address with a specific unit number (Jiang & Stefanakis, 2018a). Therefore, it is not suitable for applications that serve large-scale regions. Another attempt, using a character matching method for indoor geocoding, was made by Lee and Lee (2013). It required a database to store semantic and spatial information for each unit in the building. By matching the textual data (i.e., store name or business phone number) from user input with the attributes of each record, the result can be retrieved and visualized. However, the database needs to be maintained and the information needs to be updated regularly. There are a variety of geocoding systems available for application developers, each with its own accuracy, accessibility, advantages and disadvantages. The conventional address-based geocoding systems have many constraints including coverage, standardization, maintenance, and precision (Jiang & Stefanakis, 2018a). Alphanumeric code geocoding scheme provides an alternative way for describing a geographic location. Among the alphanumeric code geocoding systems, w3w has gained attention because it has three significant advantages over the others. First, it offers the cleanness of the coding scheme as the use of dictionary words is less error-prone than a code mixing letters and numbers. Secondly, it is easier to remember. Finally, it supports multiple languages. w3w geocoding has been applied in many industries such as navigation, delivery, UVAs and asset management (what3words, 2018).

However, w3w still has limitations such as a fixed resolution and no consideration of elevation. Jiang and Stefanakis (2018a) proposed a series of extensions of the w3w geocoding system to address these limitations. A variable resolution extension could facilitate applications for both outdoor and indoor environments. For indoor applications, a finer resolution and three-dimensional information is required. Three example applications utilizing the w3w extensions are presented in the following section to illustrate that the extended w3w geocoding models are viable for supporting geographic application development.

4.3 Applications for UNB campus

There are several potential applications that make use of the w3w extensions for a university campus (Table 4.1). Each application would implement one of the w3w extensions with either finer or coarser resolution, and may consider three-dimensional information.

Table 4.1 Example applications of w3w geocoding extension models to a university campus.SOURCE: Jiang & Stefanakis (2018a)

Location	Application
Indoor	(1) describe a path between rooms and support navigation; (2) label rooms and important sites, such as Exit, Entrance, extinguisher; (3) track equipment, books, and personnel; (4) locate facility management points of interest (POI) for maintenance or repair.
Outdoor	(4) define safety area for emergency evacuation; (5) describe paths between various locations (buildings) on campus; (6) manage student survey data.

In this study, the Quad Tree Extension Model (QTEM) with 0.75-meter resolution is applied to applications for both indoor and outdoor environment. Three application prototypes are demonstrated below: facility management, indoor navigation and outdoor navigation.

4.3.1 The Creation of the Grid of QTEM Squares

To support the applications and provide the location reference, the first step was to create a grid of QTEM squares in resolution of 0.75-meter, simulating the partition of the earth surface. The grid was generated using Fishnet tool (ArcGIS Desktop, 2018), which is a common processing function supported by GIS software like ArcGIS and QGIS (Li et al., 2016). Figure 4.1 shows the parameters required for the creation of the grid that covers Head Hall building. To fill the form the following steps were carried out.

Figure 4.1 The form to specify the parameter values for generation the grid

(1) Acquire the Fishnet Origin Coordinates and Opposite corner coordinates: The

building data in this study was provided by Geodesy and Geomatics Engineering (GGE)

department, UNB. The floor plan of Head Hall building E floor (level 5) was originally

in DWG format (CAD file). It was extracted to ArcGIS and georeferenced for further

processing. The coordinates of the bounding box of the building layout were known

from the layer property. The bottom-left coordinates are -66.642284W, 45.949443N, and the top-right coordinates are -66.641234W, 45.950390N. These two coordinate pairs were passed to the extended w3w center points encoding API (Jiang & Stefanakis, 2018) as input parameters to retrieve the coordinates of the centroids of all the squares. The result as in JSON was imported to ArcGIS and visualized. The coordinates of the bottom-left corner are -66.642281W, 45.949442N (2488969.104W, 7438817.1065N in meter) and the top-right corner are -66.641229W, 45.950388N (2489050.854W, 7438922.1065N in meter). To obtain the Fishnet Origin coordinates both the latitude and longitude values of the bottom-left corner need to decrease 0.375m (i.e., 0.75m/2). Likewise, the top-right corner needs to shift by 0.375m in both axes to acquire the coordinates of the Opposite corner.

(2) Obtain the Y-Axis Coordinate: The Y-Axis Coordinates are required because they define the rotation angle of the grid (Figure 4.1). The azimuth from the origin point to the Y-Axis coordinates point is used as the rotation angle, where the rotation is a clockwise angle from the y axis of the coordinate system. For instance, the Fishnet Origin Coordinate = (0, 0); the Y-Axis Coordinates point = (6.9, 4). The line from origin to the defined point creates a 60-degree angle, so that the final position of the grid is rotated by 60-degree from North.

In this study, for the creation of the grid no rotation is applied, because w3w is aligned to geographic graticule. The shape of the 3m by 3m squares may vary slightly towards the poles. Also, the studied area coved by the created grid is in small scale.

Therefore, the x coordinate value of the Y-Axis Coordinate parameter retained the same as the Fishnet Origin, and the y coordinate can be any value along the Northing axis.

(3) Define the Cell Size: The QTEM model recursively subdivides the original w3w cell in quadrants to obtain resolutions of 1.5-meter, 0.75-meter, 0.375-meter, 0.1875-meter and 0.09-meter (Jiang & Stefanakis, 2018a). The sub-cells in each resolution are squares with equal length in width and height (Figure 4.1). For applications in this study, the 0.75-meter resolution was applied. So that the Cell Size Width and Height parameters were set to 0.75m.

(4) Determine the Geometry Type: There are two options of the output geometry types, polyline and polygon (Figure 4.1). In order to be able to use cells to represent entities (i.e., objects or routes), a polygon feature class is needed.

According to these parameters, the grid of QTEM squares coving Head Hall building and facilities was automatically generated (Figure 4.2). The procedures were performed again to create the grid that covers a side of the hill in campus, in order to support outdoor application.

Figure 4.2 A grid of QTEM squares in resolution of 0.75-meter that covers Head Hall building and facilities

Other w3w extensions can also be applied by defining the specific parameters accordingly. Such as Ternary-Tree Extension Model (TTEM), which obtaining finer resolutions by dividing the w3w square into 9 sub-squares, and Radiational Expansion Extension Model (REEM), which providing coarser resolution cells.

4.3.2 Indoor Application: Facility Management

The objective of this application is to support facility management tasks through indoor positioning in a facility. Each of the QTEM squares that cover the building

footprint were assigned unique address codes individually. These codes represent the geographic locations of the squares. A facility covered by specific square(s) is automatically assigned the corresponding code(s). Thus, the location of the facility can be retrieved. Instead of using coordinates to locate a facility, a four-word or five-word code is less error prone and could easily be transformed into coordinates.

The application prototype for indoor facility management was developed on ArcGIS platform using a 2D plane layer. However, with the three-dimensional information provided by the extended w3w geocoding, the facility can be analyzed and visualized in 3D space. There are three components of the application: the interface, the database, and the w3w extension geocoding RESTful API.

The client interface offers viewing and exploring capabilities. It displays geographic layers of the grid, the floor plan and the facilities. The viewing window allows zooming in and out, dragging and selecting operations. The cell(s) representing the selected facility will be highlighted and an information window will pop up. The information window lists detailed attributes of the facility. To search for a specific facility, the user can input the corresponding w3w extension code through the searching operation supported by the interface. The result will then be displayed.

A database was built for the storage and retrieval of facility information. The database interacts with user input queries and parses the required object. The database schema consists of two relations: cells and facilities (Table 4.2 (a)). Take a desk and a shelf in room E5 as examples (Figure 4.1), the corresponding data instances are shown

in Table 4.2 (b). Notice that the desk mainly covers thirteen cells, only a few are listed in the table for demonstration.

Table 4.2 (a) The database schema of Indoor facility management application

FACILITIES

object_id	name	room_name	floor_number	floor_name	elevation

CELLS

object_id	latitude	longitude	status	facility *(foreign key)*
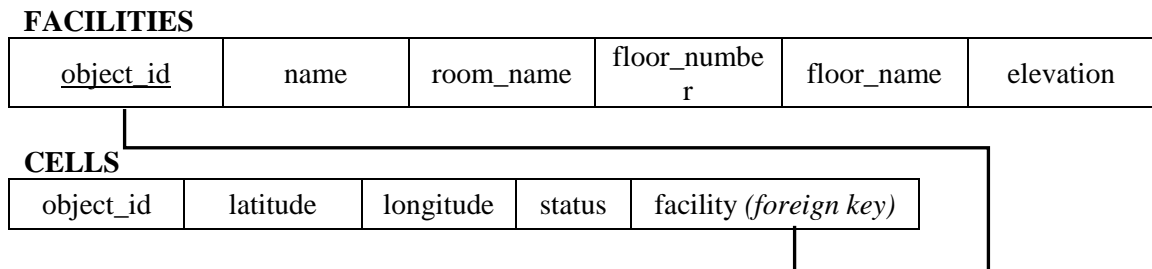
Table 4.2 (b) The database instances

FACILITIES

object_id	name	room_name	floor_number	floor_name	elevation
1	E5 desk	E5	5	E	relative 13
2	Alice shelf	E5	5	E	relative 14

CELLS *foreign key*

object_id	latitude	longitude	status	facility
…	…	…	…	…
10982	45.95005644	-66.64173151	occupied	2
…	…	…	…	…
11224	45.95006996	-66.64171219	occupied	1
11225	45.95006998	-66.64170252	occupied	1
11342	45.95007669	-66.64173156	occupied	1
11343	45.95007670	-66.64172188	occupied	1
…	…	…	…	…

The height of E5 desk and Alice's shelf are 13-meter and 14-meter relative to the ground, respectively. Because the height of each floor is 3 meters so the height of the fifth floor where room E5 is located is 12 meters, and the relative height of the desk surface is 1 meter higher. Likewise, the relative height of the bottom of Alice's shelf hanging overhead is 2 meters higher.

Any location in the indoor space can be referred to by its cell. By the support of the

extended w3w geocoding API (Jiang & Stefanakis, 2018b), each cell's address code can

be retrieved using reverse geocoding process; given a code, the cell's location can be

obtained through forward geocoding operation and it can then be displayed on the map.

The mechanism of the API associated with the application workflow are presented in

Figure 4.3.
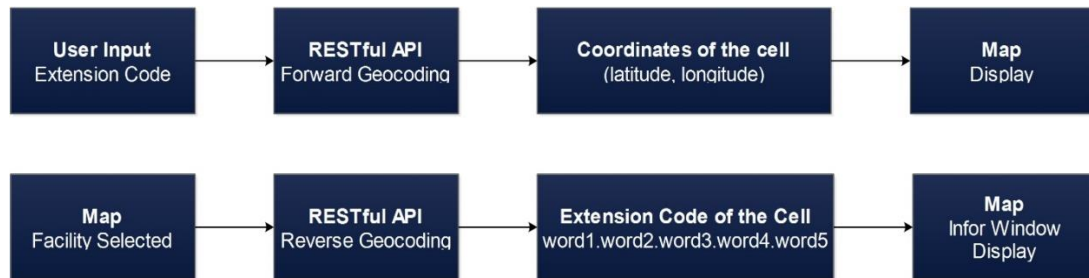
Figure 4.3 The mechanism of the API and the application workflow

Through the application interface, the user can type in one of the five-words codes,

and the extended geocoding process will transform the address into coordinates. So that

the cell representing the facility can then be marked on the base map included in the

application interface. The user can also select any cell on the map and the data

information of the selected cell will be displayed in the Information Window, in which

the extended w3w code is embedded.

Other indoor sites such as floor exits, building entrances, room doors, fire

extinguishers can be geocoded as well. With the encoded points of interest (POI), this

application can also be applied to mobile features to support indoor positioning. Instead

of using wireless network technologies such as WLAN, RFID or Bluetooth, this

application could derive user's location from the user's input address code of the current site. For example, if a user is standing in front of room E5, by typing the code of room E5's door - "breathless.trains.machine.file.RH12", her location could be retrieved and displayed on the map.

4.3.3 Indoor Application: Navigation within Buildings

In the last decade, much research focusing on indoor navigation has been carried out. Many indoor 3D network models and path finding algorithms have been presented (Jamali, Rahman, Boguslawski, Kumar, & Gold, 2017; Lin, Xu, Hu, Hu, & Li, 2017; Xiong et al., 2016). In this sub-section, an approach of indoor navigation implementing the extended w3w geocoding and the existing path finding algorithm in ArcGIS is presented.

This application consists of four components: the interface, the database, the ModelBuilder, and the w3w extension RESTful API. The interface displays feature layers of the floor plan, the building interior (i.e., facilities), the grid created from the previous sub-section 3.1 and the resulting route calculated by the path-finding algorithms. A list of cells representing the route as well as the corresponding geocoding codes are displayed in the direction pane included in the interface. The interface allows users to define the origin and destination using the extended w3w codes accordingly.

The geographic locations of the origin and destination will be retrieved using forwarding geocoding operation provided by the extended w3w RESTful API.

The grid of cells created in the previous sub-section was used as the referencing network. A database for the storage of the cells' occupancy was created. To determine each cell's occupancy status, the building data, including the line features of the floor plan and the facility layer were rasterized. The occupancy of each cell was defined by detecting the intersection of the raster layers and the grid. The occupied cells were assigned value 1, denoting an obstacle, and the empty cells were assigned value 0, denoting a free or an accessible space.

The grid network, the origin and the destination are three input parameters for route computing. To calculate the route, ModelBuilder (ArcGIS Desktop, 2017) provided by ArcGIS software was employed to automate the path-finding analysis. The ModelBuilder consists of (i) input rasters: grid network, origin, and destination; (ii) path finding algorithms: weighted distance analysis, cost distance, and cost path; (iii) output raster. The geoprocessing workflow is visualized in Figure 4.4.
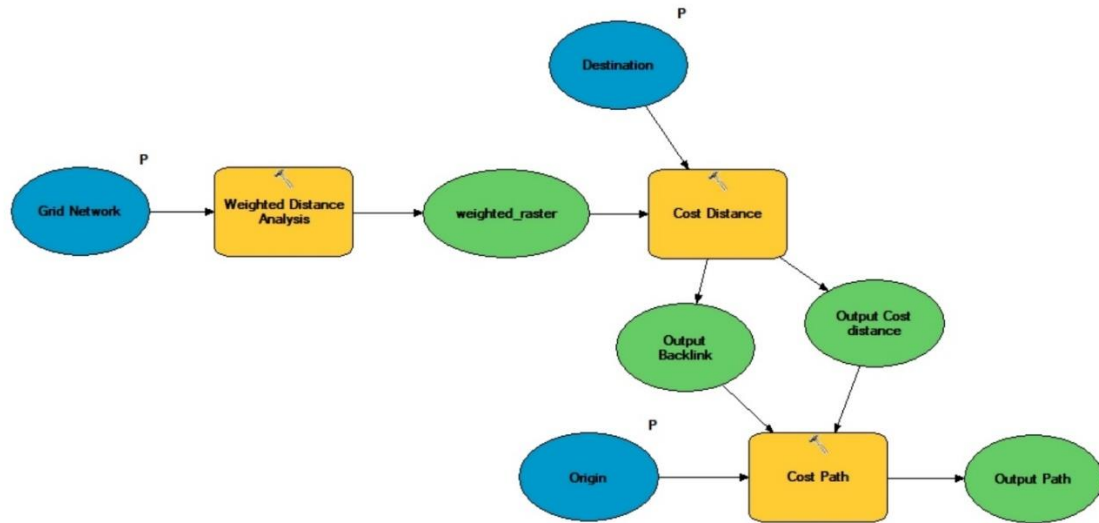
Figure 4.4 The geoprocessing workflow of route computing inside the ModelBuilder component

The weighted distance analysis function provides an approach of considering travel constraints such as terrain, slope, obstacle (Esri, 2018). A travel cost value for each type of constraint can be defined and assigned for each cell of an input raster data. Based on the influence ratio of these factors, this function will generate an output raster data with a total cost value for each cell. For this application prototype, the input raster data was created from the pre-generated grid. Each cell of the grid has been assigned a cost value representing free space or obstacle. Under the circumstance of indoor environment, this factor was considered to have full influence on the total cost. The step of total cost raster creation is followed by the cost distance analysis. The cost distance tool produces two results: (i) the cost distance, recording the accumulated travel cost of getting from each cell between the origin and destination locations; (ii) the backlink, returning a direction

raster data that identifies the route between the origin and destination. The cost path tool

uses these two results as input to determine the least-cost path from the origin to the

destination. The output path will then be displayed on the map included in the interface.

This produced a jagged path because the building foot print is unaligned with the grid.

To minimize the defect a finer resolution could be applied.

The path can be represented by a series of five-word codes describing the cells that

formed the route (Table 4.3). To achieve this, the reverse geocoding algorithm (Jiang &

Stefanakis, 2018b) was used to convert the coordinates of each cell into the

corresponding five-word code. In a following up step, the path can be simplified, in that

a straight segment of the path was represented by two endpoint cells. The new group of

cells associated with the corresponding codes were listed in the direction pane in the

interface to indicate the path (Figure 4.5).

Table 4.3 Representation of indoor path using w3w extension code

Cell_ID	Coordinates (lng, lat)	Geocoding	Code
origin	-66.64173154, 45.95006994		psychic.rolling.recital.film.RH12
waypoint_1	-66.64172185, 45.9500632		psychic.rolling.recital.flap.RH12
waypoint_2	-66.64171216, 45.95005647	extended	informants.steeps.costing.few.RH12
waypoint_3	-66.64170248, 45.95005648	w3w	herbal.song.latex.fan.RH12
waypoint_4	-66.64169283, 45.95006324	reverse	aired.snuck.recess.five.RH12
...	...	geocoding	...
destination	-66.6417128, 45.95030615		boils.adapted.testified.flat.RH12

Figure 4.5 The simplified path with a direction pane indicating the origin, destination and the waypoints

For indoor applications related to navigation and inventory management, both horizontal and vertical space need to be considered. The w3w geocoding extension provides three-dimensional information. The building interior space can be regarded as a 3D grid of cubic blocks where each block is assigned a five-word code referencing its geographic location. Using a 3D grid for indoor network generation is superior to graph-based method. Because the facilities within each block, such as desks, shelves, doors, free spaces and stairs can be identified by attributes embedded in each block. Meanwhile, their locations in space can be obtained through the process of geocoding as each block is assigned a unique five-words address code. This is critical to finding optimal path between different floors.

Many path-finding algorithms, supporting grid-based 3D network navigation, have been developed (Jamali et al., 2017; Tsiliakou & Dimopoulou, 2016). However, to implement these methods, a solid foundation with fine geometric and semantic descriptions of indoor space is necessary. The w3w geocoding extensions provide means to facilitate the indoor space representation and the generation of indoor 3D networks.

Nevertheless, there are still limitations impeding the adoption of the w3w geocoding extensions: (i) lack of building interior data; (ii) limited integration of geographic information systems (GIS) and the platforms used by architects including computer-aided design (CAD) and building information management (BIM) systems (Goldberg, 2013).

4.3.4 Outdoor Application: Navigation in Open Space

The previous sub-section utilized relative height value to represent the third-dimension of in-door locations. The w3w extensions support three types of elevation: absolute height, relative height (ground reference; above or below the ground), and floor (floor label and relative height within the floor). The outdoor navigation application demonstrates the use of absolute height information in the w3w extension.

The studied area for outdoor navigation is on the side of a hill. To calculate the route following the topography surface, a ModelBuilder similar to the previous sub-section was created. However, the slope of the surface needed to be considered. To identify the

gradient change in height value from each cell of a raster surface, a digital elevation

model (DEM) representing the terrain's surface was needed. Therefore, the

ModelBuilder input rasters included the DEM, origin, and destination. And the path-

finding algorithms are: slope, reclassify, weighted distance analysis, cost distance, and

cost path. A set of survey points with elevation values was provided by the GGE

department at UNB. The DEM was created using the surveying points and was input to

the Slope function. Such that, the output raster was assigned slope value to each cell. In

the following step, the slope value ranging from 0.00085 to 48.3778 degree was

classified into 10 grades using the reclassify operation. Each grade was assigned a new

slope value starting from 1 to 10 successively. Then, each cell from the raster was

assigned the new slope value accordingly, as the travel cost value for further analysis.

The following algorithms including weighted distance, cost distance and cost path

likewise were performed. The origin of the path was determined by the square

"regenerates.verily.seclusion.flag.H27.81", which is at the foot of the hill, and the

destination – "expert.hasty.princess.fee. H38.64" was on the top of the hill in front of the

Old Arts building.

　　This path can also be represented by a group of the extended codes assigned for the

cells. The elevation value for each cell was derived from the Add Surface Information

tool in ArcGIS. Thus, the fifth word referring to height can be encoded.

Table 4.4 Representation of indoor path using w3w extension code

Cell_ID	Coordinates (lng, lat, h)	Geocoding	Code
origin	-66.641526, 45.949504, 27.81	extended w3w reverse geocoding	regenerates.verily.seclusion.flag.H27.81
waypoint_1	-66.641516, 45.949497, 27.79		regenerates.verily.seclusion.flat.H27.79
waypoint_2	-66.641507, 45.949491, 27.78		supervises.stops.lads.fan.H27.78
waypoint_3	-66.641507, 45.949484, 27.79		supervises.stops.lads.fat.H27.79
waypoint_4	-66.641507, 45.949477, 27.81		supervises.stops.lads.file.H27.81
…	…		…
destination	-66.641221, 45.948357, 38.64		expert.hasty.princess.fee.H38.64

4.4 Conclusion

In this paper, three example applications, utilizing the w3w geocoding extension QTEM model, for UNB campus have been presented. Each application used a grid of QTEM squares in the resolution of 0.75-meter as reference data layer. QTEM can also provide finer resolutions for specific applications to achieve desired results. For the indoor facility management application, the extended w3w geocoding schema provides an approach to locate each asset with one or more five-word codes. The codes can be translated into coordinates through the RESTful API for w3w geocoding extensions. The location of the asset can then be displayed on the map. This application also provides an alternative method for indoor positioning. In the indoor navigation application, the w3w extension was used as 3D indoor network frame. Based on the identification of each block, the path-finding algorithm was applied to calculate the optimal route between user determined locations. The path, consisting of a group of cellular units can be represented by a series of five-words code accordingly. The outdoor navigation

application demonstrates that the absolute elevation is also supported by the extension. The height value can be encoded as the fifth word of the extended code.

This paper explores applications of QTEM model. However, there are other w3w extension models that can be applied for specific applications. The w3w geocoding extensions provide variable resolutions. They also support elevation encoding. Based on these advantages, the extensions could facilitate geographic applications for both indoor and outdoor environments.

Nevertheless, the greatest remaining challenges to indoor applications are: the lack of detailed indoor data and the deficiency of the integration between Geographic Information Systems and Building Information Management (BIM) systems.

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5. CONCLUSIONS AND FUTURE RESEARCH

This research was conducted to satisfy a need for a geocoding system to support university campus applications. The existing geocoding systems were investigated and a comparison between the geocoding systems reveals that w3w has many significant advantages that can be utilized to better support specific geographic applications. Further explorations of w3w disclosed limitations of this geocoding method, which could impede its utility in applications. Therefore, extensions to the w3w geocoding model were developed to better support applications for both indoor and outdoor environments. Applications, utilizing the extended models, were prototyped to demonstrate their potential value to support various university campus needs.

5.1 Conclusions

In this research, two categories of geocoding schemes, address-based and alphanumeric code based, were examined. The limitations inherited in address-based geocoding systems make them not universally applicable in large-scale GIS applications. Alphanumeric code geocoding systems were developed to overcome some of the constrains of address-based systems.

The advantages of w3w geocoding system makes it a suitable geocoding method for university campus applications. However, due to limitations of w3w geocoding,

extensions to the model are required. To support indoor applications, a finer resolution

of squares is needed, while elevation information must be incorporated. For outdoor

applications, a coarser resolution may also be desired. Therefore, Chapter 2 proposes a

series of extension models to the w3w geocoding system focusing on two main aspects,

variable-resolution, and elevation. To represent the extension models, additional

elements (words) were attached to the original w3w code. The fourth element is a word

representing a variant resolution, the fifth element is a label representing elevation. This

scheme complies with and retains the advantages of the w3w geocoding system.

Subsequently, an RESTful application programming interfaces (API) implementing

QTEM model was designed and tested in Chapter 3. This API extends the original w3w

RESTful API by using the w3w API Java library. The extended API provides a web

service for client geographic applications to access and utilize the w3w geocoding

extension. It supports the operations of (i) forward geocoding, that transforms the

extended four-word or five-word code to corresponding coordinates; (ii) reverse

geocoding, that converts a set of coordinates into the extended code; (iii) line and

polygon encoding, that retrieve single line or polygon feature and (iv) arrays of cells

encoding, that retrieve the locations of the cells' centroids, for a given area. The

extended w3w RESTful API was used as the geocoding processing component in the

development of the application prototypes, examined in Chapter 4.

Three example applications, utilizing the w3w geocoding extension QTEM model

for the UNB campus in Fredericton were explored in Chapter 4: indoor facility

management, indoor navigation, and outdoor navigation. These applications employed a

grid of QTEM squares in the resolution of 0.75-meter as location reference. In the

indoor facility management application, each facility was represented by one or more

squares. The location of the square(s) was encoded with a single or multiple four-word

or five-word codes. The transformation between the code and the corresponding

coordinates can be realized by using the extended w3w API. For indoor and outdoor

navigation applications, the w3w extension geocoder translated the codes of the user

determined origin and destination into locations, so that the shortest path could be

computed by a path-finding algorithm. The resulting path, consisting of a set of squares,

was also represented by a set of corresponding codes.

As discussed, geocoding system is a necessary component for many geographic

applications. To meet the need of a geocoding system to support applications for the

UNB campus, a series of geocoding models extending w3w were developed. With the

advantages of variable resolutions, and elevation encoding, these extensions could

facilitate applications for indoor and outdoor activities.

5.2 Limitations and Suggestions for Future Research

While a variety of w3w geocoding extensions have been proposed, this thesis mainly

focused on the implementation of one of the extensions presented in Chapter 2—the

QTEM model. The need to develop RESTful API for the rest of the w3w extension

models is still an outstanding goal in order to facilitate specific applications. For

instance, the coarser-resolution extensions can be utilized in applications providing emergency evacuation services for a university campus.

Additionally, the application prototypes presented in Chapter 4 were created using ArcGIS desktop platform. However, the w3w geocoding extensions could also be applied in mobile applications. The development of mobile applications utilizing these extensions supporting a university campus could also be part of the future works.

The extension models may further enhance the w3w geocoding system to better support geographic applications ranging from business and marketing to social and economic development of regions or countries. The level of extension required in each application is variable and subject to the application needs as well as the decisions taken by both developers and end-users.

In the word-combined code schema, the fifth word referring to elevation may alter over time due to the changes of natural or man-made processes. For this reason, a sixth element could be added to provide a temporal reference. The extension of the combined five-word code with a sixth word representing time may also serve in modeling spatiotemporal applications. This is another direction for future research.

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