



Master's Thesis

Introducing 3D representations as an advanced method for the case of the Hot-Warm-Cold zone model

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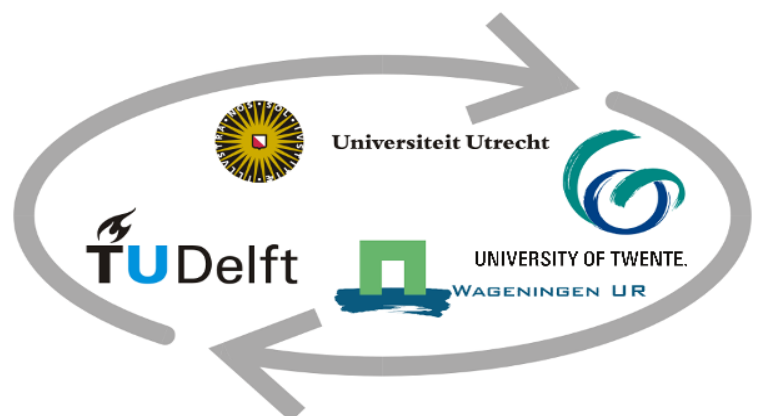
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The introduction of 3D representations

As an advanced method for the case of the Hot-Warm-Cold zone model

By

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ABSTRACT

The use and availability of 3D data and 3D applications is increasing every year. In this light, the Dutch National Police is trying to implement more 3D data for several cases. One of these cases is the Hot-Warm-Cold zone model, a safety model in which the 3 different zones represent differences in safety during calamities. Currently 2D data is used in this case, but the use of 3D data can increase safety, effectivity and efficiency. In this research a method has been created for the introduction of 3D representations for incidents requiring the Hot-Warm-Cold zone model.

A distinction has been made between 2 different kinds of incidents. 'Ad hoc' incidents concern incidents which happen quite unexpectedly and at locations not known by the police, while 'high risk' incidents happen at locations known by the police and thus are already observed and analysed prior to any incidents occurring. For the 'ad hoc' incidents a 3D representation has been developed in ArcGIS Pro, using a 3D city model and various visibility analysis and buffer tools. A 3D representation for 'high risk' incidents on the contrary, has been developed with 2D data in ArcGIS Pro as the foundation, while the more detailed 3D representation has been created in CloudCompare using a Hidden Points Removal algorithm on point clouds.

For the 'ad hoc' incidents as well as the 'high risk' incidents 2 different forms of 3D representations have been developed. The nature of the incident can differ, thus depending on the incident being related to explosions, chemical substances or violence, the shapes of the hot, warm and cold zone of the 3D representation differs. For chemical incidents the factor of the wind is of such significant importance that it needs to be included in the 3D representations. For these specific incidents an ovoid 3D representation is developed, as the wind can be depicted through this ovoid shape. Other incidents, for instance related to explosions and violence, are not influenced by the wind and therefore a sphered 3D representation is adequate where the hot, warm and cold zone are depicted through spheres.

Depending on the type of incident, a suitable 3D representation can be used within the operative police environment. These 3D representations make it easier to decide on the outlines of the hot, warm and cold zone and additionally ensure that more accurate and precise outlines can be created. This establishes a safer environment of the incident location as more information on the location is available. Besides, the information which is available is more understandable as the 3D representations stand closer to the real-life situation.

Keywords: Hot-Warm-Cold zone model; point clouds; ArcGIS Pro; CloudCompare; visualisation; Nijmegen; Dutch National Police; 3D data; Hidden Points Removal; 3D Buffers; visibility analysis; city model; 3D representation

LIST OF ABBREVIATIONS

AHN	Actueel Hoogtebestand Nederland (<i>Current DEM of the Netherlands</i>)
ALS	Airborne Laser Scanning
ATM	Automated Teller Machine
BAG	Basisregistratie Adressen en Gebouwen (<i>key registry addresses and buildings</i>)
BGT	Basisregistratie Grootchalige Topografie (<i>key registry large-scale topography</i>)
BIM	Building Information Models
BPZ	Basis Politie Zorg (<i>basic police care</i>)
CACO	Calamiteiten Coördinator (<i>calamity coordinator</i>)
CBRN	Chemisch, Biologisch, Radiologisch en Nucleair (<i>chemical, biological, radiological and nuclear</i>)
COPI	Commando Plaats Incident (<i>command place incident</i>)
CTER	Contra-Terrorisme, Extremisme en Radicalisering (<i>counter-terrorism, extremism and radicalisation</i>)
DEM	Digital Elevation Model
DSI	Dienst Speciale Interventies (QRF)
DSM	Digital Surface Model
DTM	Digital Terrain Model
EODD	Explosieve Opruimingsdienst Defensie (<i>explosive disposal services</i>)
GIS	Geographical Information Systems
HAZMAT	Hazardous Materials
HPR	Hidden Point Removal
IDLH	Immediately Dangerous to Life and Health
LiDAR	Light Detection and Ranging
LoD	Level of Detail
MLS	Mobile Laser Scanning
OC	Operationeel Centrum (<i>operations centre</i>)
OvD	Officier van Dienst (<i>duty officer</i>)
OvD-P	Officier van Dienst-Politie (<i>police duty officer</i>)
QRF	Quick Reaction Force
SGBO	Staven Grootchalig en Bijzonder Optreden (<i>staff large-scale and special performances</i>)
TEN	Tetrahedronised Irregular Network
TEV	Team Explosieven Verkenning (<i>team explosives reconnaissance</i>)
TIN	Triangular Irregular Network
UAV	Unmanned Aerial Vehicle
UAV-LS	Unmanned Aerial Vehicle – LiDAR Scanning
WBS	Work Breakdown Structure
WP	Work Package

TABLE OF CONTENTS

ABSTRACT	3
LIST OF ABBREVIATIONS.....	4
1. INTRODUCTION.....	7
1.1 Motivation and context	7
1.2 Problem statement.....	9
1.3 Relevance.....	10
1.4 Research objectives	10
1.5 Research scope.....	11
1.6 Research Approach.....	12
1.6.1 Type of scientific procedure	12
1.6.2 General research approach	13
1.7 Research outline	13
2. THEORETICAL FRAMEWORK.....	14
2.1 Conceptual model.....	14
2.2 The Hot-Warm-Cold zone model	14
2.2.1 Defining the Hot-Warm-Cold zone model.....	15
2.2.2 The Hot-Warm-Cold zone model for different emergency services	15
2.2.3 In depth use of the Hot-Warm-Cold zone model by the Dutch National Police.....	17
2.3 3D datatypes and 3D models	19
2.3.1 3D datatypes.....	20
2.3.2 3D data models.....	22
2.4 3D representations applied to the Hot-Warm-Cold zone model.....	24
2.4.1 Added value of 3D representations for hot, warm and cold zones	24
2.4.2 The applicable 3D model for the Hot-Warm-Cold zone model.....	24
2.4.3 The appropriate software packages	25
3. METHODOLOGY.....	28
3.1 Study area	28
3.2 Data collection.....	29
3.2.1 Literature review and interviews	29
3.2.2 Required software	30
3.2.3 Collected datasets.....	31
3.3 Data preparation and pre-processing	33
3.3.1 '3D Basisbestand'	33
3.3.2 BGT dataset.....	35
3.3.3 Point cloud dataset	35
4. ANALYSIS.....	37
4.1 Analysing an incident on an 'ad hoc' location.....	37

4.1.1	View dome	37
4.1.2	Line of sight	38
4.1.3	Viewshed.....	39
4.2	Analysing an incident on a 'high risk' location	41
4.2.1	Buffering operations on the BGT dataset	42
4.2.2	Point cloud visibility analysis.....	44
5.	RESULTS FOR 'AD HOC' INCIDENTS.....	48
5.1	The Hot-Warm-Cold zone model represented as spheres.....	48
5.2	The Hot-Warm-Cold zone model represented as ellipsoids	50
5.3	The Hot-Warm-Cold zone model represented as ovoids	51
5.4	Addition of street view images for 'ad hoc' incidents	54
5.5	Sub-conclusion for 'ad hoc' incidents	56
6.	RESULTS FOR 'HIGH RISK' INCIDENTS	59
6.1	Creating the outlines of safety zones for 'high risk' incidents	59
6.2	A comprehensive representation of the safety zones through point clouds.....	61
6.2.1	The camera setup for the point cloud visibility analysis	61
6.2.2	Setting the right octree level for HPR.....	63
6.2.3	Points visibility.....	65
6.2.4	Comparing the point cloud images to street view images	66
6.2.5	The advantages of using point clouds	67
6.3	Sub-conclusion for 'high risk' incidents	68
7.	CONCLUSION.....	69
7.1	Answering the research sub questions	69
7.1.1	The Hot-Warm-Cold zone model defined.....	69
7.1.2	The Hot-Warm-Cold zone model specified for the Dutch National Police.....	70
7.1.3	The different 3D datatypes and 3D models.....	70
7.1.4	The differences between 'ad hoc' incidents and 'high risk' incidents	71
7.1.5	The most suitable 3D model and software package for the Hot-Warm-Cold zone model	71
7.1.6	The establishment and visualisation of the hot, warm and cold zones in 3D.....	72
7.1.7	The added value of 3D for the Dutch National Police.....	73
7.2	Answering the main research question.....	73
8.	DISCUSSION AND FURTHER RESEARCH	76
8.1	Discussion.....	76
8.2	Future research.....	78
	REFERENCES.....	80
	LIST OF FIGURES	83
	APPENDIX I.....	86
	APPENDIX II.....	94
	APPENDIX III.....	95

1. INTRODUCTION

In this chapter the research topic will firstly be introduced and thereafter the outlines of the research are set. In paragraph 1.1 the motivation and context of this research are given. Secondly, in paragraph 1.2 and 1.3 the problem statement and relevance of this research are discussed. This leads to the research questions and research objectives in paragraph 1.4 and to the research scope in paragraph 1.5. Lastly, the research outline for the rest of this thesis research is explained in paragraph 1.6.

1.1 Motivation and context

3D data has been developed and used increasingly over the last few years. Technological developments provide quicker 3D data collection and a more realistic reconstruction of 3D models (Aleksandrov et al., 2019; Balsa-Barreiro & Fritsch, 2018). Therefore, the usage of 3D data in various applications has become more accessible for an increasing number of organisations. Within the Dutch National Police (*Nationale Politie*) some departments are already working with 3D data to support their tasks. For instance, by using 3D data to make reconstructions of certain crime scenes (Raneri, 2018). However, 3D data can be used up to a much larger extent within this organisation. The Dutch National Police is dealing with complex and risky situations on a daily basis and some cases can be alleviated by using 3D applications.

One specific case in which the National Police does not use 3D data yet is the case of 'Hot, warm and cold zones'. There does not exist a 3D representation of the Hot-Warm-Cold zone model up until now. The zones of the Hot-Warm-Cold zone model represent differences in safety during calamities. It is a model known in multiple countries and used by all emergency services, not solely the police (Park et al., 2020). Even though all emergency services use this model, the police are the only emergency service which lead the analysis of the threat and the subsequent declaration of the different safety zones (Park et al., 2020). Thus, an accurate analysis of the hot, warm and cold zone is essential since lives can depend on it. This analysis is not always easy as the different zones can be dynamic, e.g. with a terrorist attack. Therefore, a 3D representation can be beneficial to facilitate the analysis and division of the different safety zones. A 3D representation of hot, warm and cold zones will reduce the amount of cognition effort, since a real-life representation of the location is shown instead of a 2D map, and therefore improve the efficiency in deciding on the different safety zones (Kemec et al., 2009).

In figure 1.1 a 2D and 3D visualisation is shown of the exact same location, keeping in mind that the perspective of the 2 images is slightly different. Even though a relatively simple 3D visualisation is shown, e.g. it is a city model thus infrastructural objects are not represented in 3D, still the analysis of the environment is alleviated with this 3D visualisation compared to the 2D visualisation. In the right image it is instantly clear what buildings are, the differences in size and height of buildings, where the streets are located etc., while in the left image it is harder to instantly recognize the infrastructural objects. This difference in cognition effort will improve the efficiency in the decision making process of the Hot-Warm-Cold zone model, as the interpretation of the environment is easier and takes less time (Zlatanova, 2008). Furthermore, the 3D visualisation in figure 1.1 reveals information which cannot be found in the 2D visualisation. An example of this is the quay at the bottom of both images. In the left (3D) image the quay clearly changes in the middle of the image from a steep quay to a descending quay, while in the right (2D) image it is noticeable that the quay

changes, but not how exactly. When an incident would occur at this location, such information affects the decision on the safety zones.

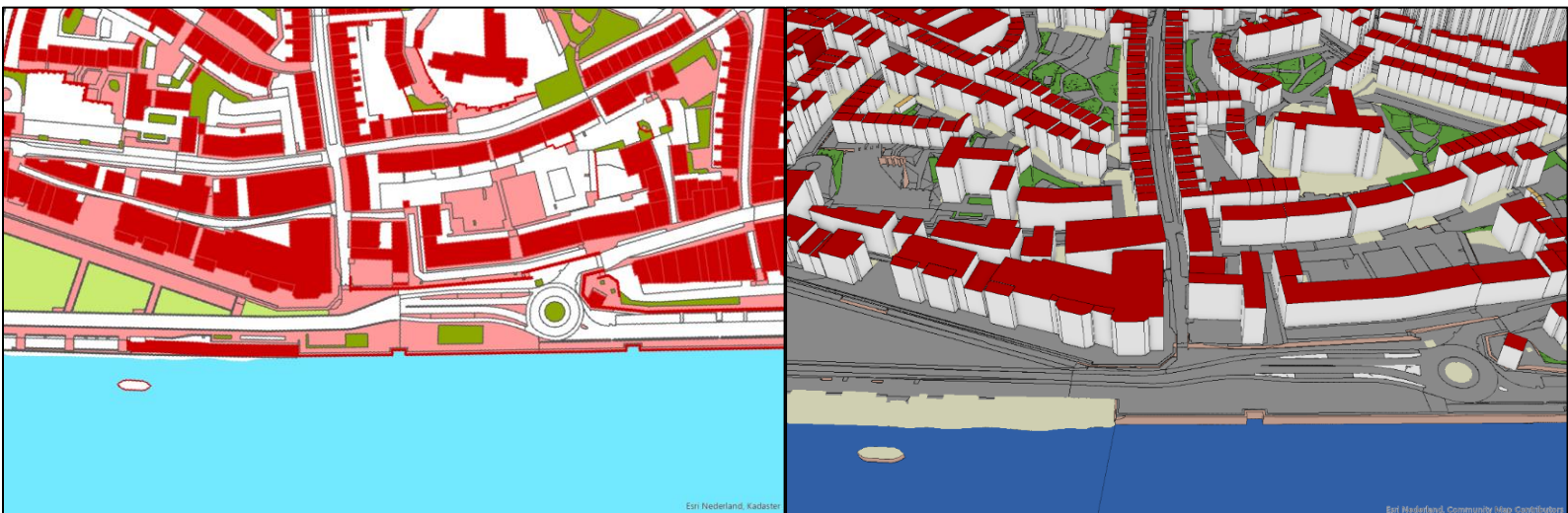


Figure 1.1: An example of a 2D visualisation (left) and 3D visualisation (right) located in the city centre of Nijmegen (BGT 2020; 3D Basisbestand 2020)

A prime example in which the necessity of adequately assessing the different zones comes forward, is a physical hazardous incident in an urban area. When dealing with toxic gasses the hot zone becomes a zone in which there is an immediate threat of exposure to these toxic gasses, which forms a direct danger to life and health. This also indicates that special chemical protective equipment needs to be used to function within this area (Caban-Martinez et al., 2018). Such an example stresses how important accurate outlines of the hot zone are, since there is an immediate threat to life within the hot zone. Since the police force is the only emergency service who declares the different safety zones, it is their responsibility to divide the zones correctly so that no one is exposed to a life-threatening danger.

Hence, real-world visualisation is of significant added value when it comes to hot, warm and cold zones. Using the third dimension in models allows people to adequately evaluate the potential impact certain developments can have on the living environment. This is the case because 3D data also provides the means to visualise the z-value and thus represent real-world elevation values (Heywood et al., 2011). As mentioned before, lives depend on the decision of the hot, warm and cold zones. The management, availability and presentation of the geospatial information plays a critical role in this final decision on the safety zones since a time-critical response is required (Lee & Zlatanova, 2008). When this geospatial information is 3D the response will be quicker, since the safety zones can be decided on more efficiently and easily due to the representation of real-world elevation values.

In a 3D representation of hot, warm and cold zones buildings will be required to be represented accurately. The representation of buildings in 3D can be performed through different Levels of Detail (LoD). The OGC CityGML standard defines 5 LoDs, see figure 1.2 for LoD0 until LoD3 (Open Geospatial Consortium, 2012). LoD4 and LoD5 are not included in this figure since they contain the interior of buildings, which is not included in the scope of this research (see paragraph 1.5 for further details). LoD0 marks the transition from 2D to 3D GIS (being a plane square), thereafter the LoDs become more detailed ending with LoD3.3 which is a detailed model of a house with windows, doors and façade details (Breunig et al., 2020; Biljecki et al., 2016a). For the Hot-Warm-Cold zone model it makes a significant difference whether a 3D representation has, for instance,

LoD1.0 or LoD1.3. When the details of facades and roofs of a building are known a completely different decision can be made in comparison to a decision based on LoD1.0.

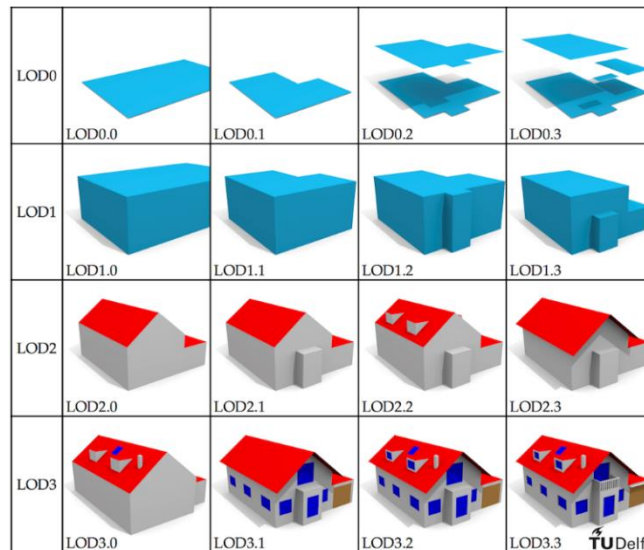


Figure 1.2: The different LoDs (Biljecki et al., 2016b)

1.2 Problem statement

General awareness of the benefits of using 3D data for various applications is growing, also amongst the Dutch National Police. As mentioned before, 3D data is already used in some departments of this organisation, however it does not live up to its potential yet. For the case of 'Hot, warm and cold zones', currently only 2D data is used to draw circles around the incident location, thus the analysis of assigning safety values to the hot, warm and cold zone can be executed more effectively and efficiently. The introduction of 3D data for this case could overcome this problem. At present the decision on the location of the hot, warm and cold zone is made by officers at location working together with officers of the operational centre. The introduction of 3D representations would support the officers at the operational centre better, who in their turn can then be of better support for the on-site officers.

Currently, the outlines of the zones, especially the hot zone, are drawn on paper or on a tablet. Thus, when an on-site officer is not familiar with that specific location, it can be hard to understand the outlines of the hot zone. The temporary creation of these outlines of the safety zones will be discussed in paragraph 2.2. Also, possible crucial details about the hot zone can be unknown at present, since there is no adequate (3D) representation available yet. With the introduction of such a 3D representation officers of the operational centre can help and direct on-site officers how to walk, what dangerous directions are etc., as they know what the officers can expect due to the 3D representation. So, the hot, warm and cold zones can be handled much more efficiently and effectively by using more advanced 3D area determination compared to the current use of 2D data.

1.3 Relevance

First of all, the work for police officers (on location) can become safer by using a 3D representation for the decision on hot, warm and cold zones. With more detailed information available on the location of the incident, possible risks will be reduced which makes it safer for the on-site officers. Besides, the bigger part of police deployment takes place in urban areas. In these areas 3D is indisputable looking at infrastructural objects and even more so looking at all of the different buildings. This indicates the possible added value of 3D data for the Dutch National Police.

Also, the addition of a 3D application could be used as a steppingstone towards an even greater use of 3D data and applications within the Dutch police force. At present within the National Police potential applications for 3D data are already being explored. However, it is challenging to implement such applications throughout the entire police organisation, due to organisational and financial reasons. The completion of this case will form a clear-cut example of the added value of 3D data and/or 3D representations, which could loosen the implementation process for more 3D applications.

For more emergency services, besides the National Police, the use of 3D data could be of added value, compared to not using any data at all, but also compared to the current use of 2D data, as is the case with the Hot-Warm-Cold zone model. All emergency services are using the Hot-Warm-Cold zone model for certain incidents, hence using 3D data for this model will increase efficiency for more services than solely the Dutch National Police. The output of this research is expected to be a contribution to the practical and theoretical knowledge of 3D data in general, but more particularly to 3D data and 3D representations regarding hot, warm and cold zones, and to stimulate the use of 3D data within the Dutch police force.

1.4 Research objectives

The main objective of this research is to provide insights into an advanced method of deciding on hot, warm and cold zones at the Dutch National Police, which could eventually replace the current method of dealing with these safety zones. This advanced method will focus on the use of 3D representations for this case. The Hot-Warm-Cold zone model already exists and is actively used within the Dutch police force, thus this research will further elaborate on that information. The current method for the Hot-Warm-Cold zone model will be compared with the developed method of this research to see whether the determination of the safety zones has improved with 3D data.

The main focus regarding the decision of the different safety zones is put on incidents related to the physical safety of the public living environment, making a distinction between 'high risk' locations and 'ad hoc' locations. 'High risk' locations being, locations known to the police which can be observed prior to any incidents, while 'ad hoc' locations are not known by the police and thus an analysis on the safety zones needs to be performed during an incident.

The sub-objectives of this research are:

- Gaining insight in the general possibilities of 3D data and 3D models
- Gaining insight in the possibilities of a 3D representation in regard to hot, warm and cold zones
- To analyse 'high risk' locations with 3D data
- To analyse 'ad hoc' locations with 3D data
- To study the outcomes of the location analysis together with the Dutch National Police

Completion of these sub-objectives will serve the main research question of this research, which is:

To what extent will the use of a 3D representation in the case of 'Hot, warm and cold zones' be conducive for the Dutch National Police?

This main research question will be answered by means of the following sub questions:

- How are the hot, warm and cold zones defined?
- How does the Dutch National Police currently establish the hot, warm and cold zones?
- What are the different existing 3D datatypes and 3D models?
- What are the differences in analysing a 'high risk' location compared to an 'ad hoc' location?
- Which 3D models and corresponding software packages are most suitable for the case of 'Hot, warm and cold zones' and why?
- How can the hot, warm and cold zones be established and visualised in 3D?
- What is the added value of 3D in the case of 'Hot, warm and cold zones' for the Dutch National Police and how can this be measured?

1.5 Research scope

This research has several limitations defining the scope:

- Since this research is completed as a master's thesis there is a time limit of 5 months, indicating that not every aspect related to the main research question can be investigated. These aspects are mentioned below. Furthermore, any other relevant aspects which came up during the research but could not be included anymore are discussed in chapter 8, the discussion.
- As mentioned in the research objectives, 2 different types of locations will be analysed; being the 'high risk' locations and 'ad hoc' locations. With these locations the focus is put on static incidents related to the physical safety of the public living environment. There are also other incidents in which 3D data can be of added value, for instance with a terrorist attack. However, these other incidents will not be addressed in this research.
- Such incidents can appear in the outdoor environment as well as the indoor environment. The indoor environment will not be discussed in this research. Including the indoor environment in this research will make it too complicated, as the indoor environment is a lot more detailed and has a lot of movable objects which will need to be taken into consideration, e.g. chairs, tables, lamps.
- Also, this research specifically addresses the division of hot, warm and cold zones. With a serious incident to the public safety, investigations need to be carried out during and after the incident. The hot, warm and cold zones only concern activities during or prior to the incident and thus this research will not discuss anything related to the aftermath of an incident.
- Another aspect which should be kept in mind is the software possibilities for the Dutch National Police. This research has been executed with specific and relatively advanced software packages, however these are not extensively used or available within the organisation of the National Police. It should be investigated what software packages are also able to create/deal with the final 3D representation developed in this research. However, this investigation is not a part of this research.

1.6 Research Approach

The complete research approach consists of an explanation of the scientific procedure in paragraph 1.6.1 and thereafter, the general research approach is discussed in paragraph 1.6.2.

1.6.1 Type of scientific procedure

In order to complete this research, the Work Breakdown Structure (WBS) will be followed and thus the entire research has been subdivided into individual Work Packages (WP) which will make the research more manageable and structured (Meredith, 2016). All individual WPs are listed in table 1 and further explained below.

WP 1	Literature study
WP 2	Developing a 3D representation for 'high risk' incidents and 'ad hoc' incidents
WP 3	Study with the Dutch National Police
WP 4	Analysing results and finalising the 3D representation (for the different incidents)
WP 5	Conclusion and discussion

Table 1: Work Breakdown Structure

WP 1

Before a 3D representation of hot, warm and cold zones can be created a thorough literature study is required for a better understanding of the different sorts of 3D data and models. Besides this, the hot, warm and cold zones will also be explored but it should be kept in mind that there is not an abundance of literature available in regard to this topic. Therefore, the main source of information for this part will come from interviews with police employees instead of information from a literature study. The main elements of the literature study (WP 1) consist of different types of 3D datatypes, different types of 3D models and the characteristics of hot, warm and cold zones.

WP 2 and WP 3

After conducting the literature study WP 2 can be started, being the development of a 3D representation. A 3D method will be used to display 3D data regarding hot, warm and cold zones. For the development of a 3D representation regarding hot, warm and cold zones the software packages of ArcGIS Pro and CloudCompare will be used. Alongside WP 2, WP 3 will also be conducted. It is important to involve the employees of the police during the development process. In that way it is possible to figure out the current criteria, the wished changes and what potential requirements are. The feedback given during this WP is important to see whether the designed 3D representation works.

WP 4 and WP 5

Thereafter, WP 4 can take place, consisting of analysing the results from WP 3, implementing these in the existing 3D representations and consequently applying the 3D representation on different areas, for the 'high risk' incident as well as the 'ad hoc' incident. With the finalised 3D representations it is also possible to move on to the final WP: WP 5, writing the conclusion and discussion. In other words, finalising the entire thesis research.

1.6.2 General research approach

In figure 1.3 a schematic overview is shown of the entire research workflow. This flowchart is based on the earlier mentioned work packages. All work packages will be completed consecutively, except for WP 2 and WP 3. These 2 work packages need to be executed simultaneously, as the input of WP 3 is required for WP 2 and vice versa the results of WP 2 need to be checked by WP 3. In the end, by completing all work packages a final thesis product will be created.

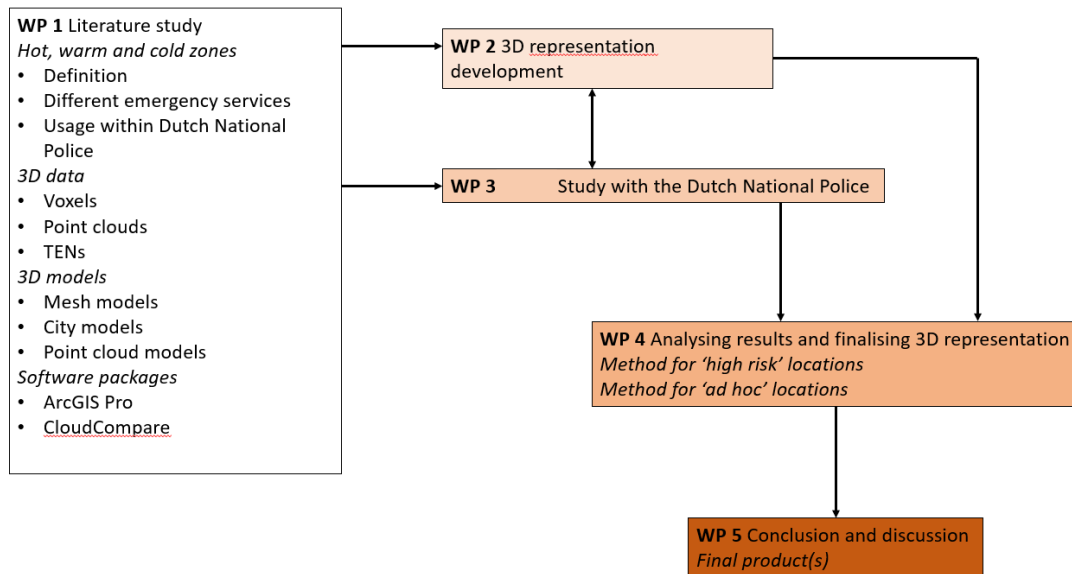


Figure 1.3: Research flowchart

1.7 Research outline

In this first chapter an introduction to this research has been given together with the set research objectives and questions. Also, the relevance of this research has been described together with the scope, which indicates what can be expected of the entire research paper.

Subsequently in chapter 2 the theoretical framework is set up. First the conceptual model is explained and thereafter the key concepts will be elaborately discussed, being the Hot-Warm-Cold zone model and 3D data and 3D models.

In the third chapter the methodology of this research is explained. In this chapter more detailed information on the study areas is given. Furthermore, the required software packages are discussed. Lastly, the used data is discussed together with all taken steps to pre-process the data for further analysis.

Chapter 4 consists of the analysis of the research. This chapter contains all steps which have been taken in order to get to an adequate 3D Hot-Warm-Cold zone representation. The final results for 'ad hoc' incidents are then discussed in chapter 5, whereafter in chapter 6 the final results for 'high risk' incidents are discussed.

Lastly, in chapter 7 the overall conclusions of the research are given by means of answering the composed sub-questions and main research question. This chapter is followed by the last chapter, chapter 8, which contains the discussion of this research and suggestions for future research, in the line of this research.

2. THEORETICAL FRAMEWORK

In this chapter the conceptual model will be explained firstly. This conceptual model forms the fundament of the entire theoretical framework. All mentioned concepts will then be discussed in the next paragraphs of this chapter. First the Hot-Warm-Cold zone model is discussed, in general and thereafter also more specifically for the Dutch National Police. Then, 3D datatypes and 3D models are discussed and lastly suitable 3D representations will be applied onto the Hot-Warm-Cold zone model.

2.1 Conceptual model

In figure 2.1 the conceptual model of this research is shown. All elements discussed further on in this chapter are represented here, together with elements which are examined further on in the research. The arrows indicate the links between the different elements. Eventually all these elements come together in the concept of 'Demarcation of hot, warm and cold zones' which forms the end product of this research.

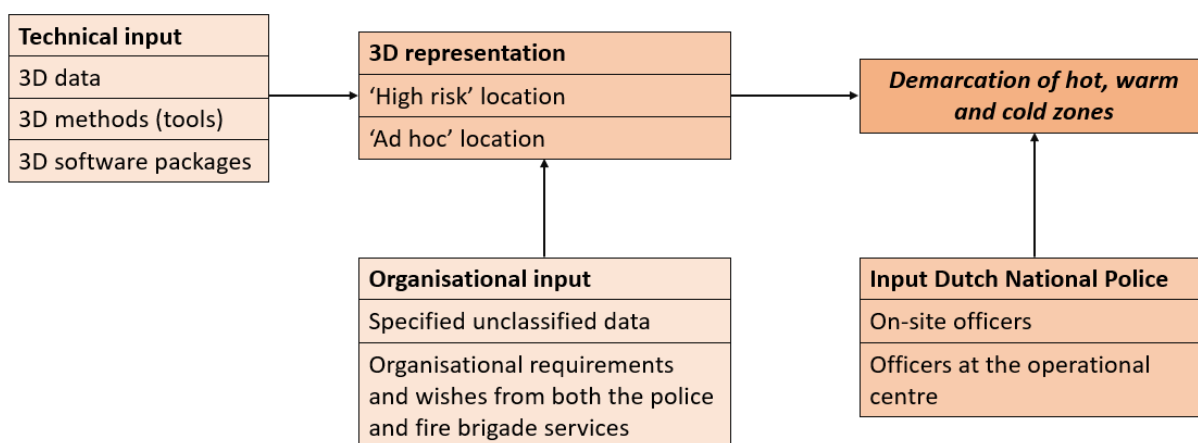


Figure 2.1: Conceptual model

2.2 The Hot-Warm-Cold zone model

The model of hot, warm and cold zones is used for a variety of different incidents within the Dutch National Police and also within other emergency services. All emergency services use the same model and principles, however the tasks differ for each emergency service. In this chapter the model of hot, warm and cold zones will be defined and explained thoroughly. Furthermore, the Hot-Warm-Cold zone model will be discussed through the eyes of all emergency services, with a more in-depth explanation regarding the role of the Dutch National Police.

2.2.1 Defining the Hot-Warm-Cold zone model

As discussed in the introduction, the Hot-Warm-Cold zone model consists of 3 different zones representing different safety levels during calamities. This model is a procedure which helps to identify the risk, and the exact location of the risk, during an incident in the public living environment (Power & Alison, 2017). As the 3 different zones of this model represent a different level of safety, the location and outlines of the risk can be established. The hot zone is a zone with a credible and ongoing threat to life, the warm zone is a zone in which there is still an identified threat, but the danger is not present or immediate, and lastly the cold zone is a zone far away enough from the incident so that there is only a small risk factor, for emergency workers as for civilians (Power & Alison, 2017; Park et al., 2020). In figure 2.2 the Hot-Warm-Cold zone model is illustrated.

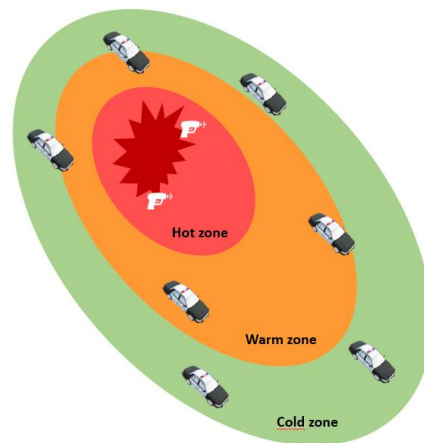


Figure 2.2: The Hot-Warm-Cold zone model

As shown in the figure above, the emergency services are mainly present in the warm and cold zone. The hot zone, where the immediate danger exists, can only be entered by trained emergency service workers and still it is not recommended (Pennardt & Schwartz, 2014). Which emergency service workers are required to enter the hot zone depends on the incident. For instance, during a physical hazardous incident only firefighters with special chemical protective equipment are allowed to enter the hot zone, since they will also be the only ones who will be able to function in this area during such an incident (Caban-Martinez et al., 2018). However, during a terrorist incident an armed police team will be the only ones allowed in the hot zone. Therefore, depending on the occurring incident a call can be made on the presence of the emergency services in different zones.

2.2.2 The Hot-Warm-Cold zone model for different emergency services

The Hot-Warm-Cold zone model is used by all emergency services. Working adequately together minimises the active risk of an occurring incident. Each emergency service occupies a different role during such an incident. These individual roles will be discussed in this paragraph, so that the entire outlines of the Hot-Warm-Cold zone model are transparent.

Ambulance services

The ambulance services are not active in the hot and warm zone during high-risk incidents. Their main occupation takes place in the cold zone. As said before, specialist trained emergency workers of all 3 emergency services are allowed in the warm zone, thus ambulance workers are fundamentally allowed too. However, besides evacuating people there is generally no evident role for the ambulance services in the warm zone, let alone the hot zone (Power & Alison, 2017). Thus, the cold zone is the main operating place for these

services where the casualty triage centres are located, when necessary. For ambulance services triage commonly encompasses making decisions about wounded patients from a high-risk incident, considering 3 key factors: survival, quality of life and resource consumption (Christian, 2019).

In other words, the main role of ambulance services is that of providing prehospital emergency medicine. This prehospital emergency medicine can be divided in the helicopter emergency medical team and in the ground based critical care team, which are standard ambulance services during high-risk incidents. Both of these teams are required to perform technical medical interventions, decision making and certain medical leadership (Park, 2020). Even though the casualty triage centres are situated in cold zones, these can still be seen as high threat environments, compared to the work of ambulance services in 'casual' incidents. However, ambulance services are not commonly trained and prepared for high-risk situations, but they still need to perform and save lives (Park, 2020). Even without an immediate threat, working in regards of the Hot-Warm-Cold zone model only complicates appropriate decision making for the ambulance services.

Fire brigade services

Incidents in which the Hot-Warm-Cold zone model is used do not always involve the fire brigade, an example of this are incidents which have to do with extreme violence. However, for certain incidents the fire brigade plays an important role, such as an incident with the exposure or explosion of hazardous gases or biohazard incidents. An incident which leads to a hazardous work zone, is only accessible for the fire brigade. In such a case, the hot zone is a zone with exposure to immediately dangerous to life and health (IDLH) conditions, thus this zone can only be entered by firefighters with special HAZMAT (*'hazardous materials'*) protective gear (Caban-Martinez et al., 2018). With such incidents, the warm zone is usually upwind from the fire so that multiple intervening activities can be performed by the fire brigade. The firefighters here are still in a health risk zone for respiratory hazards, e.g. CO or other chemicals found in smoke (Caban-Martinez et al., 2018). The cold zone is a zone where a safe space is created and a checkpoint for incoming crew exists and also where the co-operation with the ambulance services is most prevalent.

Hence, the fire brigade services are demanded with fire incidents or hazardous incidents. In case of a hazardous incident the 3 different zones have clear boundaries and accompanying activities. The hot zone, also called the exclusion zone, is the place of contamination. The warm zone, also called the contamination-reduction zone, is where the decontamination of responders and victims takes place. Lastly, the cold zone, also called the support zone, is the zone without contamination and here the victims will be transported to suitable medical care (Phelps, 2006). In such a case, the toxic hazard is located in the hot zone, indicating that the fire brigade services are the only ones allowed in the hot zone to extract casualties and possibly triage. Since the hot zone forms an immediate threat of exposure on toxic gasses, this is a dangerous role to perform (Byers et al., 2014). However, it is also a significant important role, otherwise the incident will only increase in danger and decontamination cannot take place.

Police force services

The police force is the only emergency service which is active during all incidents. With the exception of some incidents, e.g. hazardous and fire incidents, the police is always active within all 3 zones. The role of the police force in the hot zone entails threat suppression, preventing (more) casualties and extracting casualties from the hot zone. The rescue task forces are normally situated in the warm zone and as an identified threat still exists in this zone. Certain police teams are also allocated here to control and supervise the hot zone. In the cold zone the main activities are managing medical resources, transport resources and overseeing the entire situation (Pennardt & Schwartz, 2014). Even though the police force is responsible for certain aspects and activities in the hot zone, as mentioned above, this zone is limited to law enforcement forces. It should be kept

in mind that there is always a big, direct and immediate threat in the hot zone. Therefore, the police force will only act in this zone when it is inevitable (Atwater, 2012).

Besides the distinct role that police forces play in the different safety zones, there is also a decisive part in the Hot-Warm-Cold zone model which the police is responsible for. The prospective declaration of the zones is led by the police solely. They will ultimately make the final call on the outlines of the hot, warm and cold zones. This final call can be made in cooperation with other emergency services, but the police are the responsible emergency service regarding the final decision. When the safety zones are not demarcated accurately significant consequences could follow, indicating the importance of this task (Park, 2020). After the demarcation of these zones the police will also lead the following collaboration with the other emergency services. The police commanders will need to work closely together with the other agencies, in order to create a good response, rapid treatment of patients and a final good outcome of the incident (Park, 2020).

2.2.3 In depth use of the Hot-Warm-Cold zone model by the Dutch National Police

The general outlines of the approach which the police uses for the hot, warm and cold zones have been discussed in the previous paragraph. This approach does not only apply to the Dutch National Police, but it is implemented in other countries too. As the focus of this study is put entirely on the Dutch National Police, a more in-depth analysis is required of their current method of dealing with hot, warm and cold zones. In this paragraph the current way of dealing with the Hot-Warm-Cold zone model by the Dutch National Police will be elaborated on.

General approach to hot, warm and cold zones by the Dutch National Police

Within the Dutch police force it is customary to apply the Hot-Warm-Cold zone model when it is required for certain incidents. This is usually the case with incidents in the field of Counter-Terrorism, Extremism and Radicalisation (CTER; *Contra-Terrorisme, Extremisme en Radicalisering*) or in the field of Extreme Violence. Previously the main roles of the police in the different zones have been discussed. These roles can be more specified for the Dutch National Police. In the hot zone any actions by police officers are only allowed with personal protection, e.g. heavy vests. There are no emergency workers or investigative people allowed in this zone, except for people from the 'basic police care' (BPZ; *Basis Politiezorg*) or people from the Quick Reaction Force (QRF, in Dutch DSI; *Dienst Speciale Interventies*). The warm zone is seen as the potential most important zone for the Dutch police. The dynamics of the incident still cause this place to have a high-risk factor, which for the Dutch police means that they should protect the (medical) emergency service workers. The earlier this warm zone is established, the earlier (and more) lives there can be saved. In the cold zone all 'regular' processes of the emergency services take place. Examples of such processes for the Dutch National Police are setting up the command place incident (COPI; *Commando Plaats Incident*), regulating supply and discharge routes etc.

Initially when an incident is reported it will be received in the Operations Centre (OC; *Operationeel Centrum*). The management of the incident will then be executed by the Calamity Coordinator (CACO; *Calamiteiten Coördinator*). The CACO is in control for the first hour of the incident, thus regarding incidents on 'ad hoc' locations the CACO will originally determine the outlines of the safety zones. When the exact nature of the incident has become clear, an upscaling is required to a control model at the location of the incident. This control will then be executed by the duty officer (OvD; *Officier van Dienst*) of that moment. The command and control of the incident will be divided onto 2 OvD-P's (*Officier van Dienst-Politie*):

- OvD-P 1: direct management of the hot and warm zone. This cooperation is required with OvD's of other teams.
- OvD-P 2: responsible for the management of the cold zone and the corresponding 'regular' police processes. This OvD-P 2 will support OvD-P 1 with people and resources.

It could be the case that further upscaling is required because the incident is increasing in size and/or risk. In that case a higher coordination structure is required. When this is the case the OvD-P 2 is the responsible link between the current management and the Staff Large-scale and Special Performances (SGB0; *Staven Grootchalig en Bijzonder Optreden*).

The Dutch National Police using the Hot-Warm-Cold zone model in practice

The Hot-Warm-Cold zone model is part of the '5 rings model' (*5 ringen model*) within the Dutch National Police. This '5 rings model' was implemented to create more unity and clarity during incidents for all police teams. The 5 rings represent:

1. Area with the incident, the crime scene
2. Surrounding areas
3. Strategic positions and measures
4. Country borders
5. Outside of the country borders

In this model, the Hot-Warm-Cold zone model takes place in ring 1: the area with the incident. The earlier mentioned SGB0 will only be deployed when an incident is of a larger scale than ring 1, so larger than the Hot-Warm-Cold zone model in its own.

When a hot, warm and cold zone is required, the starting point is to decide on the hot zone. Thereafter, the cold zone is decided on and automatically a warm zone comes into existence in between the hot and cold zone. The supervising officer will ultimately decide on the outlines of the zones. It depends on the type of incident who does this, it could be the OvD-P, a ME commander, a team leader from the explosives reconnaissance (TEV; *Team Explosievenverkenning*), an OvD in cooperation with the fire brigade etc. With incidents regarding extreme violence it is not possible to create exact outlines of the hot zone. These will normally need to be created on the intuition of the police officer in charge. Incidents with explosives or chemicals do create the possibility to define the hot zone with specific distances, again depending on the exact incident. In this research the premise is to solely look at static incidents, in which the hot zone stays put in one location, contrary to other incidents (e.g. concerning terrorism or riots) in which the hot zone could need to be moved.

Originally the Hot-Warm-Cold zone model was used for incidents with toxic chemicals and it still is, only the model has been extended to other serious incidents as well. When an incident regarding any toxic chemicals happens the forensic investigation team with the portfolio of Chemical, Biological, Radiological and Nuclear (CBRN; *Chemisch, Biologisch, Radiologisch en Nucleair*) is called into action. They determine the outlines of a hot zone via various steps. First the type of substance needs to be declared, then the level of danger of this substance needs to be clear, next the amount of the substance needs to be known and lastly the possibility of dissemination needs to be clear too. With all that information, the different zones can be demarcated. There are existing standards for the size of the hot zone, depending on the found substance. However, many factors play an important role, e.g. the wind, the amount of the substance, the location of the incident. Therefore, the supervising officer needs to make a decision combining the standards and his intuition.

Hence, for incidents with extreme violence or incidents regarding CBRN there are not solid outlines or distances for the hot, warm and cold zones. These incidents do follow 'natural barriers' with the demarcation of the hot zone. Indicating that outlines of the hot zone will usually follow streets, so that maximal safety can be guaranteed. Sometimes the infrastructure creates difficulties, for instance with a ditch or waterway, then concessions need to be made. The safety zones following natural barriers will then be drawn onto paper or a tablet, thus on 2D data. An example of this is shown in figure 2.3, where the hot and warm zone were created along natural barriers, in this case following the street pattern. It is visible that the shapes appear random, since they are following the ending of streets, instead of being circled. It should be noted that the Hot-Warm-Cold zone model in figure 2.3 is an example of the current method and has not been used in real life.

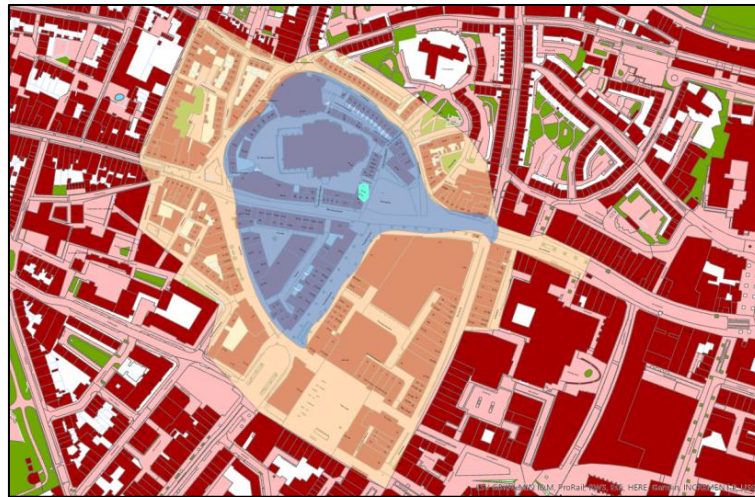


Figure 2.3: The Hot-Warm-Cold zone model represented along natural barriers, with the blue zone depicting the hot zone, the orange zone depicting the warm zone and the 'left over' area depicted as the cold zone

Incidents with explosives are the only incidents where solid distances or sizes can be applied to the hot zone. Depending on the type of explosive, the leader from TEV will know which distance is required for the hot zone, so that the warm and cold zone stay relatively safe. An example of such an incident with explosives is an explosive attack on an ATM (*ram en plofkraak*). When an explosion happens at an ATM, debris can be blown away even more than 30 metres from the crime scene. Next to this, explosives or gas bottles could be left behind at the crime scene, leading to (another) explosion. For this reason it is of importance to create a wide hot zone. Additionally, ATMs are often located in urbanised areas. When this is the case debris can be reflected by the explosion and the debris can ricochet up to many different directions. Therefore, first responders of such an incident should take a careful first glance at this incident, not closer than 25 meters to the ATM. When this observation shows signs of left-over explosives, a crime scene should be created with a radius of approximately 50 metres. This is a rather wide hot zone which should keep people safe until more details are known by the OC in cooperation with for instance the TEV or the Explosive Disposal Services (EODD; *Explosieve Opruimingsdienst Defensie*). With additional details an even more accurate hot, warm and cold zone can be demarcated.

2.3 3D datatypes and 3D models

With the introduction of 3D data for the casus of 'Hot, warm and cold zones' the demarcation of these different zones can be decided on more efficiently and effectively in the end. However, 3D data is still a very broad concept, as multiple 3D datatypes and models exist. In the introduction the outlines and added value of 3D data have already been discussed, hence this chapter will contain more technical and in-depth aspects of 3D

data and representations. Here, different 3D datatypes and 3D models will be discussed to eventually find out what suits best for the Hot-Warm-Cold zone model.

2.3.1 3D datatypes

As for 3D datatypes, 3 different datatypes will be discussed in this paragraph. Starting with voxels, then tetrahedronised irregular networks will be discussed and the last discussed 3D datatype is point clouds.

Voxels

Through voxels a 2D space can be extended into a 3D representation. Voxels are also referred to as 3D volume elements and can be described as the 3D counterpart of pixels, which are 2D elements (Hahn et al., 2020). These small building blocks can be used to build functional 3D architectures, since they are represented as cubes in 3D space. However, the disadvantage of voxels is that it is not possible to record topological information (Heywood et al., 2011). An implicit topology is present towards neighbouring voxels, however information such as their position or coordinates is not explicitly encoded in voxels. Thus, a 3D model can be created with voxels but it will not be able to provide you with a lot of (topological) information. Also, voxels require a large memory consumption which could form problems during the visualisation and processing of high-resolution 3D models (Graciano et al., 2018). Nonetheless, voxels are still appropriate for representing a number of phenomena, for instance soil and geology, since these are continuous phenomena (Stoter & Zlatanova, 2003). An example of a voxel representation is the GeoTOP model from the TNO Geological Survey of the Netherlands, shown in figure 2.4. This voxel representation is an underground model of the Netherlands through which the different soil types can be explored.

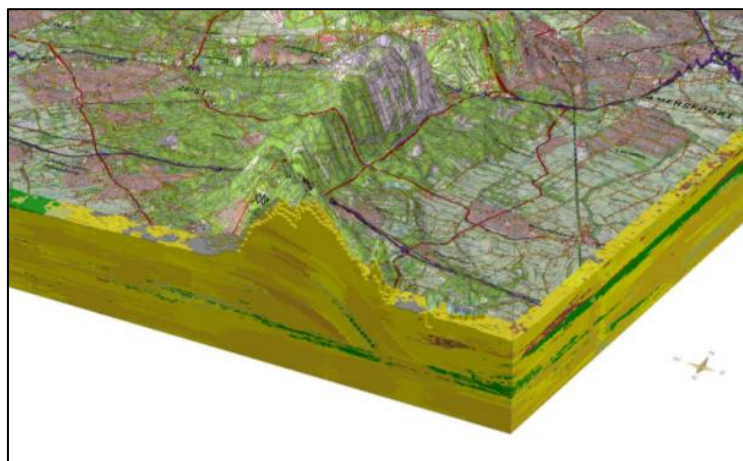


Figure 2.4: Voxel representation of the soil of the Netherlands, example of the Utrechtse Heuvelrug (TNO, 2013)

Tetrahedronised Irregular Networks (TENs)

Another feasible 3D datatype is representation through tetrahedronised irregular networks, also TENs. These TENs can be seen as the 3D version of Triangular Irregular Networks (TINs). A TIN is mainly used for surface representation and is created by arithmetically (or algorithmically) connecting points (Verbree & Si, 2008). It is therefore made up of 2D simplexes, or in other words triangles. A TEN also consists of 3D complexes (e.g. tetrahedrons), besides the triangles, so volumetric shapes can also be represented (Graciano et al., 2018). Such a tetrahedron object is well defined, since the 3 points of each triangle are always located in the same plane. A TEN can therefore be used, as TINs, to reconstruct surfaces, only with a TEN a 3D representation will be created (Peninga & van Oosterom, 2008).

Point clouds

Point clouds are a different type of 3D data compared to the earlier discussed datatypes. Fundamentally, a laser scanner records a mass of 3D points and this mass of points is known as a point cloud (Heywood et al., 2011). These recorded datapoints are defined by a X, Y and Z coordinate linked to a 3D coordinate system (Achlioptas et al., 2018). A point cloud dataset can be derived from aerial images or laser scanning (or a combination of both resources).

For laser scanning, point clouds can be derived in various ways, namely via airborne laser scanning (ALS), terrestrial laser scanning (TLS), mobile laser scanning (MLS) or scanning from an unmanned aerial vehicle (UAV-LS) (Virtanen et al., 2017). An advanced technology for (airborne) laser scanning is LiDAR (*Light Detection and Ranging*). With LiDAR direct 3D point clouds can be obtained and it is therefore widely used in earth surface research (Cheng et al., 2018). Point cloud data obtained through LiDAR scanning has a high density of points (often 1 point per m² and higher), which results in precise and accurate data usage (Zhang et al., 2017). An example of a point cloud created with LiDAR measurements is the height model of the Netherlands (AHN; *Actueel Hoogtebestand Nederland*) dataset, in this case the third version (AHN 3). In figure 2.5 part of this dataset is shown as an example of a LiDAR point cloud.

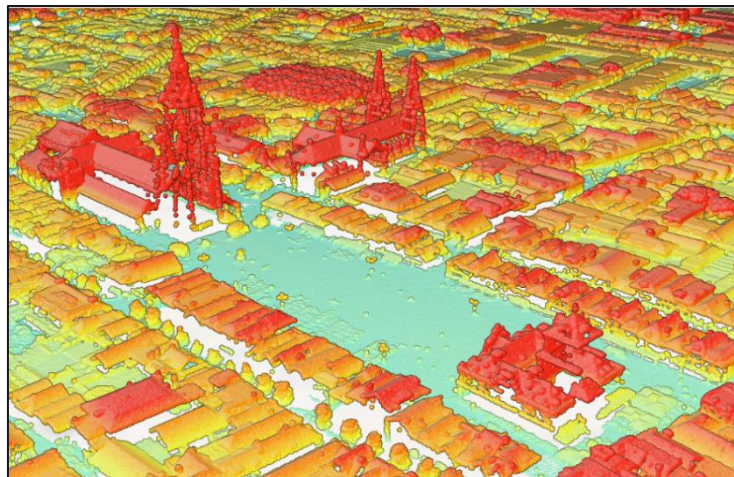


Figure 2.5: The market square of Delft as an example of a 3D LiDAR point cloud (AHN 3)

Besides laser scanning, point clouds can also be created through aerial images. From these aerial images 3D point clouds can be derived from a bird's eye perspective (Richter & Döllner, 2014). Such images can be made by either airplanes or unmanned aerial vehicles (UAV). These images do need to be taken from multiple angles, to ensure that the surface is captured adequately (Cheng et al., 2018). However, aerial images are only able to capture the top visible surface in contrast to the laser scanned point clouds which can capture the full distribution of an observed surface. Still these aerial images can be transformed into detailed point clouds through the method of photogrammetry (Filippelli et al., 2019). The obtained point cloud can then for instance be used as input for a mesh model, to be discussed in the next paragraph.

2.3.2 3D data models

Regarding the 3D data models, 3 different models will be discussed. Firstly the mesh models, then city models, and lastly smart point cloud models.

Mesh models

A mesh model is a 3D representation of surface subdivisions through the use of a set of polygons, making it a geometric data structure. In its essence a mesh model is made up of a few thousand points (different vertices) which are connected by edges, creating facets of polygonal shapes. When all these facets are triangles a triangular mesh model is formed, which is the most prevalent mesh model (Poux, 2020). An example of such a triangular mesh model is a Triangular Irregular Network (TIN). This model is vector based and constructed by unregulated triangulating a set of points. The rendering of the then created triangular facets creates a 3D visualisation. Another desired triangular network can for instance also be created by combining oblique images and point cloud data with a network construction method/3D surface reconstruction. Many algorithms for the construction of a triangular network, and additionally a triangular mesh model, have been proposed, resulting in widely used 3D reconstructions via mesh models (Ma et al., 2018).

These 3D mesh models are widely used due to accurate geometric information extraction and 3D object reconstructing (Wu et al., 2019). Therefore, 3D mesh models are often used in 3D simulation, 3D animation and in the field of smart cities, where large scenes will consist out of several 3D mesh models, all containing their own triangular facets (Liang et al., 2019). In figure 2.6 an example of a 3D mesh model is shown. This 3D mesh model of a city shows that due to the combination of an aerial image with point cloud data all needed information is present, e.g. trees, buildings, elevation data. Although all existing objects are shown a disadvantage of a mesh model is that the data can only be represented to a certain degree (Poux, 2020).



Figure 2.6: An example of a 3D mesh model (Esri, n.d. a)

City models

A different type of 3D models which can also be used as an accurate 3D representation method is the city model. These models are digital representations of urban environments, where the focus is put on buildings (Billen et al., 2014). 3D city models are based on 2D datasets, most often containing building footprints (e.g. the BAG). With remote sensing technologies the height of buildings can now also be measured automatically and remotely which is the required input for a volumetric representation of the buildings (Biljecki et al., 2016a). This volumetric representation is instantaneously also the advantage of 3D city models over 2D maps. Due to the volumetric data, visibility analyses can be carried out easier and more efficiently. This volumetric representation also indicates the earlier discussed LoD for city models, which is LoD2 (or even LoD1). This

level of detail means that buildings will be represented with detailed roof structures and planar facades, which is adequate for small and medium scale visualisations (Haala et al., 2015).

A 3D city model usually consists of different models making it one whole, namely of digital terrain models (DTMs), green space models, street-space models and building models. However, the focus still lies on buildings, so in this case on the building models (Buyukdemircioglu et al., 2018). Also, different techniques can be used to create these models, such as LiDAR point clouds, UAV images, airborne or satellite images. A popular approach is to combine various data sources and techniques, for instance by combining a DTM or DSM with a cadastral map (Buyukdemircioglu et al., 2018; Biljecki et al., 2016a). An example of a 3D city model, which was created by combining a DSM and a cadastral map, is shown in figure 2.7. This illustration shows the LoD, which in this case is LoD1 since all buildings are shown volumetrically, but there is no detail visible in the roof structures or on the facades of the buildings.

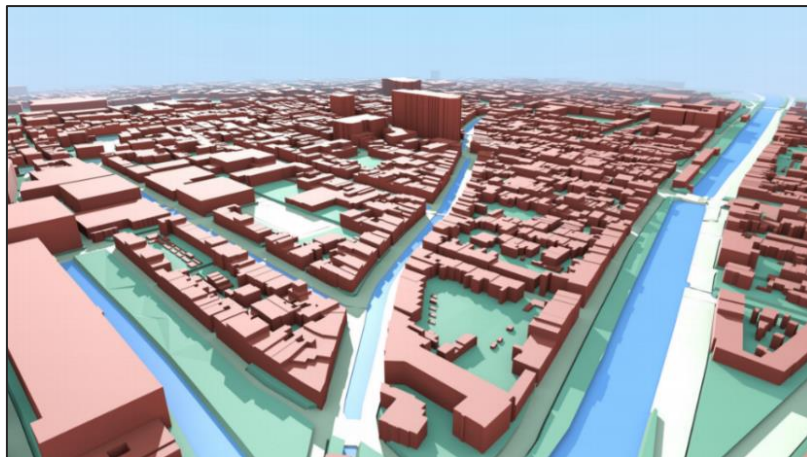


Figure 2.7: A 3D city model of the city of Delft (Biljecki et al., 2016a)

Smart point cloud models

Point clouds have already been discussed in paragraph 2.3.1 as 3D datatypes. Additionally, point clouds can also be seen as 3D models, which will be discussed in this paragraph. Smart point cloud models are based on several millions of points, in other words on a point cloud (or multiple point clouds). Due to these millions of points in a smart point cloud model, there is also a rather high level of detail, especially compared to other 3D models. This high level of detail facilitates a visibility analysis in different fields, e.g. urban design, GIS technology or landscape planning (Zhang et al., 2017). When the point clouds are involved in a decision-making process, this will additionally also be facilitated due to the high level of detail. For example, when comparing figure 2.5 with figure 2.7 it becomes apparent that different roof structures can be identified in the point cloud example of figure 2.5, while in figure 2.7 all roof structures are identical. Precise and accurate data use is achievable for point cloud visualisation and analysis due to a high point density and a dense and close-to-reality representation of the 3D point clouds (Cao et al., 2019).

Hence, smart point cloud models are able to realistically represent phenomena in different fields of study, whereby a visibility analysis can be performed on different LoDs depending on the case. However, the presence of the millions of points in smart point cloud models also comes with its disadvantages, namely in the form of large point cloud datasets. A 3D point cloud model can only be created with a huge amount of data, which subsequently can form issues with rendering, compression etc. (Cao et al., 2019). Also, besides the accuracy of smart point cloud models it is also a characteristic of many 3D point clouds that they display incomplete information. Point clouds are not able to give a filled visual representation, so gaps do occur (de Haan, 2009). From a distance this does not form any problems, but from a closer view these gaps will become

visible, as is also visible in figure 2.5 underneath the New Church in the figure. Such a filled visual representation is only possible when supplementing an aerial point cloud with a point cloud created via TLS or MLS.

2.4 3D representations applied to the Hot-Warm-Cold zone model

In paragraph 2.2 the exact outlines of the Hot-Warm-Cold zone model have been set forth. Also, different 3D models and 3D datatypes have been discussed in paragraph 2.3. These different aspects come together in this chapter, where the advisable 3D datatype and 3D model will be discussed for the Hot-Warm-Cold zone model. In addition, advisable software packages for creating such a 3D representation will also be discussed.

2.4.1 Added value of 3D representations for hot, warm and cold zones

As explained in chapter 1, the 3 zones represent differences in safety. The hot zone contains a credible threat to life, the warm zone contains an identified threat but without present danger and the cold zone can be called a safe zone (Park et al., 2020). An accurate demarcation of these zones is essential, since a different demarcation of the zones could cost lives. The decision on the demarcation is strongly influenced by the visualisation manner. Currently only 2D maps are used to decide on the safety zones and even these maps are not used to their full extent. A 3D representation can be beneficial for the division of hot, warm and cold zones, since a 3D representation reduces the cognition effort and consequently also improves the efficiency of deciding on the different zones, as is illustrated in figure 1.1 (Kemec et al., 2009).

A 3D representation is more illustrative compared to 2D representations. It is more in line with the perception of people, in this case the police emergency workers (Bandrova et al., 2012). When an on-site officer describes the environment using 3D components, e.g. different floors in buildings, elevation levels, windows, it is a lot easier for the control room to match these descriptions in a 3D representation. However, the representation of 3D data does need to be conveyed in an understandable form. Analysing, processing and presenting 3D data to emergency responders and workers is more complicated compared to the transmission of 2D information (Bandrova et al., 2012). It is important to pay attention to this aspect, otherwise the use of 3D representation will seem too complicated for emergency workers and consequently the significant added value of 3D data in this case will be suppressed.

2.4.2 The applicable 3D model for the Hot-Warm-Cold zone model

In paragraph 2.3 the different 3D datatypes and 3D models have been discussed. A first presumption is that almost any 3D data model will be beneficial for the Hot-Warm-Cold zone model. For instance, a city model generally has a lower level of detail compared to a smart point cloud model, e.g. comparing LoD1 with LoD2 or LoD3. However, even when a city model is used in which all buildings are represented as blocks/boxes, there is still an added value. As mentioned earlier, a 3D representation of the location will connect better with the perception of people. Thus, a location will be recognized earlier with a 3D representation compared to using a 2D representation for the same purpose.

For this research 2 different types of locations will be considered, namely the 'high risk' locations and the 'ad hoc' locations. The main difference between these locations is the amount of available preparation time. A

'high risk' location is a well-known location for the police, whereas an 'ad hoc' location is only known at the time of an active incident. Therefore, there is a difference in preparation time to analyse a 3D model which also indicates a difference in the achievable quality of the 3D representation. 'High risk' locations can be estimated and therefore measured upfront, while with 'ad hoc' locations one must be able to make an analysis with the available resources at that moment. Since these 2 locations will be used and analysed differently, they will both consist out of a different 3D datatype and 3D model.

For a 'high risk' location a smart point cloud model will be used and for an 'ad hoc' location a city model will be used. As mentioned before, the 'high risk' location is a location which is already known by the police and therefore an in-depth analysis can be performed on this location. With a prior analysis of the location all required details can be discovered, so that when a serious incident takes place all important knowledge on the environment is already known or can be viewed instantly. In order to carry out such an analysis a detailed 3D model is essential. A smart point cloud model provides an exact representation of the real location, including details on buildings, vegetation and objects on the street. A relatively simple, yet efficient 3D representation can be created through the use of point clouds (Poux, 2020). Therefore, smart point cloud models are a good fit to use as input for the analysis and to be able to make a more detailed and adequate decision on the outlines of the hot, warm and cold zones.

'Ad hoc' locations, on the other hand, require an even simpler 3D representation, which can be provided by the means of a city model. Such a 3D city model provides volumetric data, so the height and/or volume of all buildings can be shown in 3D (Biljecki et al., 2016a). This is advantageous for analysing 'ad hoc' locations since the situation and its surroundings can be understood quicker and easier. With a more complicated 3D model, e.g. mesh model, too many details could stand in the way of a quick and accurate assessment of the environment regarding the hot, warm and cold zones.

2.4.3 The appropriate software packages

As a distinction is made between different locations, different datasets will be used for each location. This indicates that also different software packages need to be used, since not every software package can work with every type of data. The 2 main software packages which have been used in this research are ArcGIS Pro and CloudCompare. An important prerequisite for both software packages is the user-friendliness, since the end-user of this research does not necessarily possess GIS knowledge, therefore more advanced software packages (for instance Potree) might have more options, but they do not serve the purpose of this research. The justness of these software packages will be elaborated on in this paragraph.

ArcGISPro

ArcGIS Pro is a professional desktop Geographical Information Systems (GIS) application developed by Esri. It is possible to display 2D data as well as 3D data. 2D data is displayed in a 'Map view' and 3D data is displayed in a 'Local scene', see figure 2.8. 2D data is extensively supported with many options, tools, display possibilities etc. 3D data is also supported, however only certain files can be opened within ArcGIS Pro, e.g. .las, .zlas, .gdb. Non-supported data formats, like CityGML, first need to be translated or converted in order to use them within the ArcGIS Pro environment (Esri, n.d. d). Besides this, large files, for instance large point clouds, can cause the software to form problems. Relatively small 3D files are properly supported in ArcGIS Pro and many possible actions can be performed on them. A large file however will slow the programme down which can lead to the inability to use certain tools or even a crash of the software. Therefore, ArcGIS Pro is a suitable software package for 3D data when relatively small files or datasets are used. When using larger datasets it is only

moderately capable, however it is a possibility to select a required part of this dataset and work with the smaller part for ArcGIS Pro to work adequately

A positive aspect of ArcGIS Pro is its accessibility, when having paid for the ArcGIS licenses. As can be seen in figure 2.8, it has an easy-to-use interface. Therefore, it has a good usability, so that all kinds of people are able to work with the software (Esri, 2020). Nonetheless, ArcGIS Pro also has sufficient tools for the more experienced GIS user for an in-depth analysis of data. Depending on the wanted outcome, ArcGIS Pro can be used in a different manner. Since the eventual 3D representation needs to be used and understood by police employees without any GIS education, this is an important prerequisite. Another positive aspect of ArcGIS Pro is the ability to visualise the bigger picture. A topographical base map can be used to keep a good overview of the entire scene, which helps the user to understand where exactly he/she is working with the data.

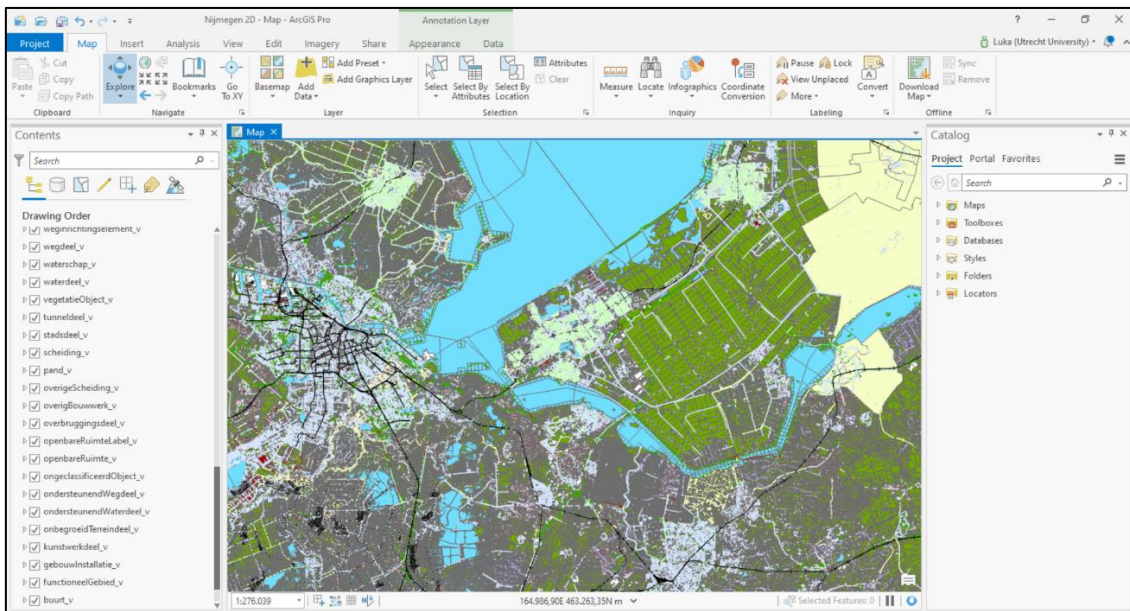


Figure 2.8: The interface of ArcGIS Pro visualising the BGT dataset (2020)

CloudCompare

CloudCompare is a software specifically designed for point clouds, it is a 3D point cloud processing tool. It is a freely available tool and intended to deal with large point clouds, e.g. point clouds with more than 10 million points, on a relatively standard laptop or computer. An example of the interface of CloudCompare is shown in figure 2.9. This interface indicates that a certain amount of knowledge within the GIS/point cloud field is required in order to work with this software package. In this research CloudCompare is mainly used for the in-depth analysis of a point cloud dataset. Such an in-depth analysis will not be carried out by employees of the OC, but by specialists working at the Dutch National Police. Therefore, a good usability is a less important requirement for this software package.

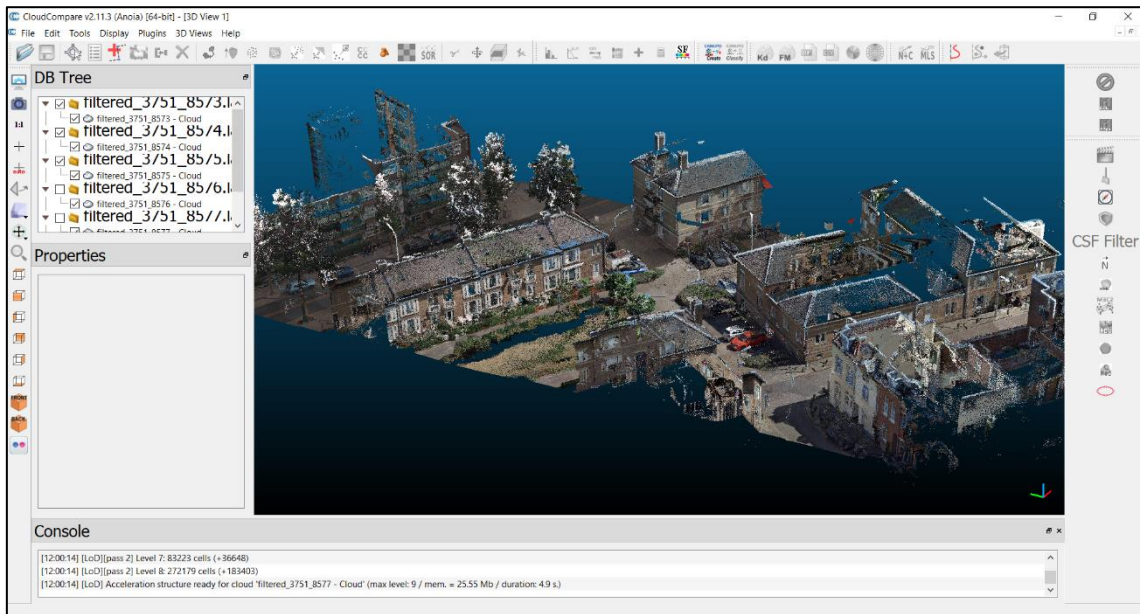


Figure 2.9: The interface of CloudCompare visualising a street in Nijmegen (Cyclomedia, 2020)

Many point cloud processing algorithms are possible within CloudCompare which create the possibility to perform many functions, such as resampling, colour management of points, statistics computation, segmentation, distance computation and registration. Next to such algorithms there are also multiple display tools available to work with, for instance custom colour ramps, shaders, calibrated pictures handling, plugins and OpenGL (CloudCompare, 2015). All these functions allow you to work extensively with a point cloud. The downside is that it does take a while to figure the software package out, since there are so many options.

3. METHODOLOGY

In this chapter the methodology for this research will be discussed. First, the choice for the different study areas is explained in paragraph 3.1. Thereafter, the used software and data are given in paragraph 3.2, whereafter the data preparation and preprocessing is discussed in paragraph 3.3.

3.1 Study area

As has been explained in chapter 1, the study area of this research has been divided into 2 different locations, namely 'high risk' locations and 'ad hoc' locations. These different locations are necessary for different types of incidents. An incident at a 'high risk' location happens at a location already known by the Dutch National Police. This location has been marked as a potential risk for a specific incident, depending on the location. Thus, an in-depth analysis can be performed on such a location prior to an incident. In this way all the ins and outs of a location are already known by the police which gives them a big advantage when an incident does occur. An incident at an 'ad hoc' location on the other hand is not known by the police. With such an incident an analysis about the location needs to be made quick and on the spot. A different location is therefore required for an 'ad hoc' incident since the type of analysis differs for different types of incidents.



Figure 3.1: Complete area of the municipality of Nijmegen with the blue circle indicating the specified study area (TOP10NL, 2016)

For both locations a study area in the city of Nijmegen has been chosen, see figure 3.1. There are already some investigations going on at the Dutch National Police concerning 3D data which take place in Nijmegen. This research connects to these earlier researches which makes it easier to gather certain information, e.g. data, and it is useful for the Dutch National Police too since they can build onto this research again in the future. Both locations are located in Nijmegen to make a straightforward comparison between the different locations. As the location analysis is different the used 3D data model also differs. Using a location in the same city makes it easier to compare both data models with each other. Lastly, the areas chosen are fictional areas. This indicates that the chosen 'high risk' location is not in fact a real 'high risk' location known by the Dutch National Police, the same accounts for the 'ad hoc' location.

The exact study area is shown in figure 3.2 and for both locations this study area entails the city centre of Nijmegen. The hot, warm and cold zones of both locations comprise an area of approximately 400-500 meters. This distance is maintained for the study area and also for the different datasets of both locations. An 'ad hoc' location can entail any type of serious incident. For this research an armed robbery on a store has been chosen as incident. This figure shows the yellow pinpoint as the store which is the centre of the study area for the 'ad hoc' location, also being the centre of the Hot-Warm-Cold zone model in the further analysis. For an incident on a 'high risk' location an explosive attack on an ATM (also known as a 'Ram en plofkraak') has been chosen, visible in figure 3.2 as the blue pinpoint. In this case, the centre of the study area (and the Hot-Warm-Cold zone model) will be the ATM. These study areas will be worked with separately, with different data models for both locations.

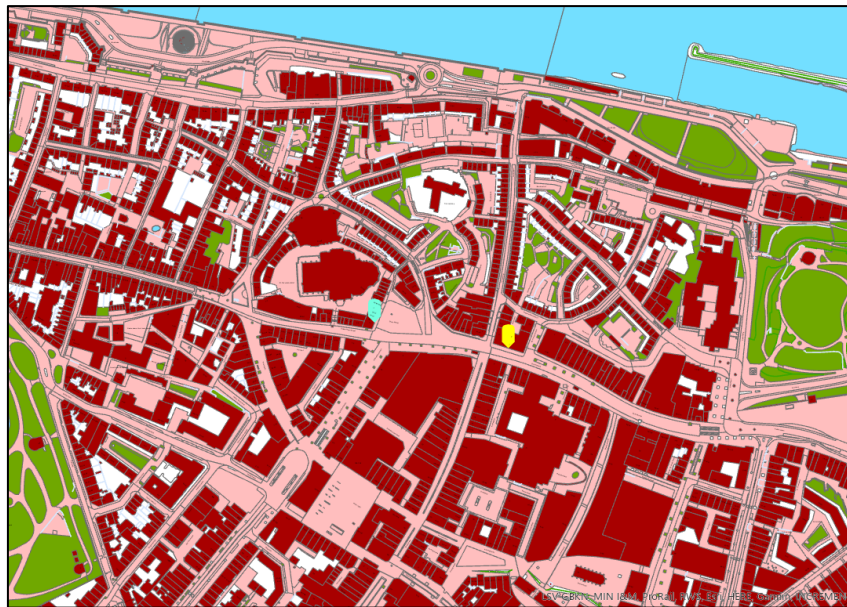


Figure 3.2: The city centre of Nijmegen with the study area for the 'ad hoc' location, yellow pinpoint, and the study area for the 'high risk' location, blue pinpoint (BGT, 2020)

3.2 Data collection

For the data collection of this research different data sources have been used. Firstly, an extensive literature review has been carried out. The bigger part of this literature review can be found in chapter 2. Besides scientific literature, many data for this literature study came from held interviews. Both the literature review and the interviews are discussed in paragraph 3.2.1. The essential software packages are then discussed in paragraph 3.2.2. For the development of the 3D representation, 3D datasets were collected, which are then discussed in paragraph 3.2.3.

3.2.1 Literature review and interviews

To be able to start analysing data and subsequently create a 3D representation for hot, warm and cold zones, first a thorough literature study has been carried out. Most of the literature has been found by means of the snowball method. This means that used articles led to other helpful articles, e.g. by reading the article and/or the reference list. However, there is not much scientific literature to be found on the Hot-Warm-Cold zone model since this model is mostly used operationally instead of scientifically. Some relevant articles were found regarding the general Hot-Warm-Cold zone model, but there is nothing to be found on the use of hot, warm and

cold zones within the Dutch National Police. This information was gathered through informal interviews. Multiple employees of the Dutch National Police from different departments were interviewed to create a complete overview of the current usage of the Hot-Warm-Cold zone model. In table 2 the background of these respondents is shown. No evident interview guide has been designed since different parts of information were required from the respondents and via informal interviews all necessary information was wholly collected.

Respondents	Department/Function/Background
Respondent 1	Operational Specialist, National Staff Large-scale and Special Performances
Respondent 2	Conflict and Crisis Management, National Crisis Management Expert Group
Respondent 3	National Forensic Investigation Team, specifically for Chemical, Biological, Radiological and Nuclear incidents
Respondent 4	Team Explosives Reconnaissance
Respondent 5	Operational Specialist

Table 2: Respondents of the taken interviews, including their background

3.2.2 Required software

As already explained in paragraph 2.4.3, the 2 main software packages which are used are ArcGIS Pro and CloudCompare. These software packages are used simultaneously, depending on the dataset. Besides ArcGIS Pro and CloudCompare, LAStools has also been used. This is a software package meant for LiDAR processing. It is in this case used for the conversion of datasets, from .laz to .las, in order to view point clouds in ArcGIS Pro. CloudCompare can work with either .laz or .las (and many other datatypes).

Another used application, which is not an official software package, is the interactive web viewer Street Smart, created by Cyclomedia. This is a web viewer where all collected data by Cyclomedia is available, provided that you have a (test)license. The collected data encompasses cycloramas, aerial photos, oblique photos and point clouds of several different years. All data can be viewed alongside each other with a slider tool, which is visible in figure 3.3. When certain data is required this slider makes it easy to find this data, since all areas of the Netherlands can be viewed in different formats at the same time. Besides these window configurations it is also possible to use and create overlays and there are multiple measuring tools available in Street Smart.

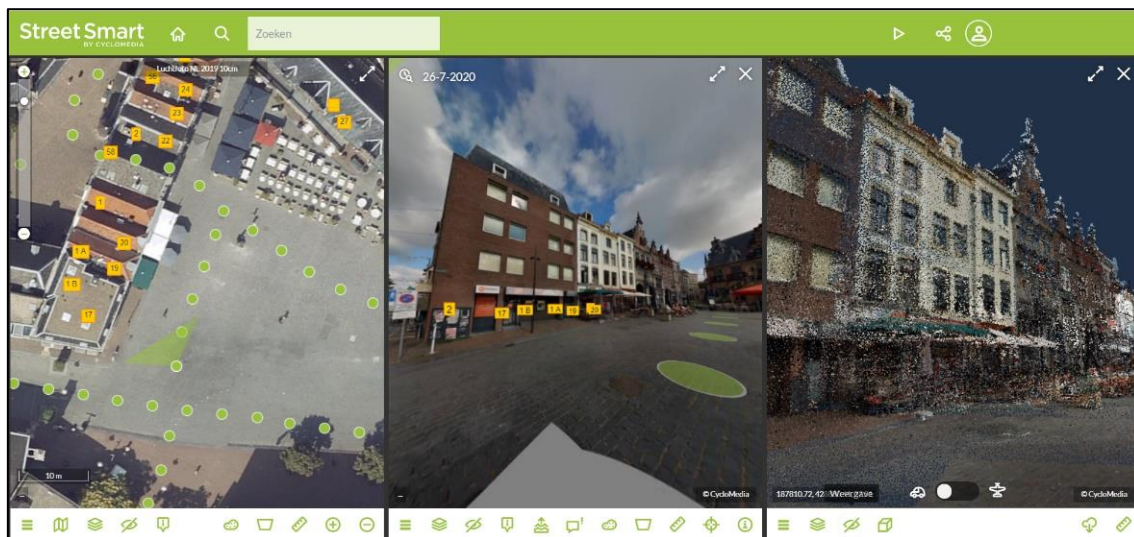


Figure 3.3: The Cyclomedia web viewer showing (from left to right) an aerial photo from above, an aerial photo from street level and a point cloud of the Market in Nijmegen (Cyclomedia, 2020).

3.2.3 Collected datasets

This research will be conducted by using open data in combination with unclassified data gathered by the Dutch National Police. Collaborations with the police could indicate that the research can only be used internally, since a lot of the data obtained and created by the police is classified. Therefore, by using open data and unclassified data it will be possible to conduct this research and publish it as well. However, not all open data sources are useful since 3D data is required, but there are still several options available. Different datasets are used for the earlier mentioned locations, being the ‘ad hoc’ locations and the ‘high risk’ locations since they require different analyses and have different final products.

Another important aspect of the datasets used in this research is their capability of being up to date. As the Hot-Warm-Cold zone model is solely used for serious incidents with a (high) risk factor, the used datasets need to be trusted. It cannot happen that employees of the OC pass on some information about the environment to the officers on location based on the 3D representation and they find out that this information is incorrect. Monthly or bi-monthly updates for the datasets would be best, it is not necessary to have daily updates of the data, as the environment is not changing that quick. Updating the datasets with a bigger timespan is an option, but this will not be conducive for the reliability of the 3D representations. For this research the most up to date datasets have been used within possible limits of the research scope. For further use within the organisation of the National Police in the future, the method of the 3D representation created in this research can also be used with other, even more up to date datasets.

For incidents on ‘ad hoc’ locations the final product needs to be relatively easy to work with and relatively quickly to load and process. For these reasons a smart point cloud model will not suffice, instead a 3D city model has been created for ‘ad hoc’ locations. 3D city models are based on 2D datasets and building prints. For this case the dataset ‘3D Basisbestand’ has been used. This is a dataset based on the ‘Basisregistratie Grootchalige Topografie’ (BGT), ‘Basisregistratie Adressen en Gebouwen’ (BAG) and the ‘Actueel Hoogtebestand Nederland’ (AHN). This indicates that data from a street level point of view as well as data from an aerial point of view is included. This makes this dataset accurate and complete, keeping in mind that all datasets contain flaws and errors. The Kadaster together with the Dutch ministry of foreign affairs and the TU Delft have combined the 3 earlier mentioned datasets into a complete 3D map of the Netherlands, which will be actualised every year (Geonovum, 2020).

The dataset '3D Basisbestand' is available for the whole of the Netherlands, but for this research a selection has been made for the outlines of the city centre of Nijmegen, shown in figure 3.4. The dataset has a LoD1.2 (see figure 1.2 for illustration) which means that the buildings are represented as 'blocks', since there are no roof or façade details visible (Biljecki et al., 2016). However, differences in size of wall structures are represented thus the buildings are not solely squared blocks. In figure 3.4 the unprocessed dataset is presented on the left, as you receive it when downloading '3D Basisbestand'. On the right the same dataset is presented, only all objects are given edges so that it is possible to tell what the dataset entails.

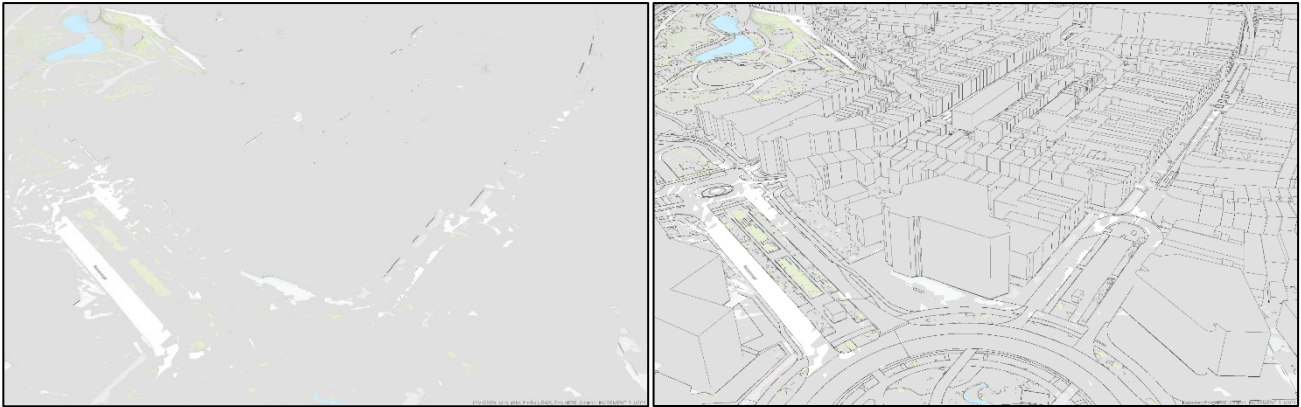


Figure 3.4: The '3D Basisbestand' dataset. The unprocessed dataset is visible on the left and on the right edges are added to all objects

For incidents on 'high risk' locations different data will be used. These locations are known by the police, therefore an in-depth analysis can be performed prior to any incidents. For such an analysis more detailed data is required, so that a complete overview of the environment can be created. The used dataset is a point cloud dataset created and made available by Cyclomedia. This point cloud is also available for the whole of the Netherlands, but only the outlines of the city centre of Nijmegen were downloaded (shown in figure 3.5). It is a LiDAR point cloud which is annually collected through laser scanners from street level and has a high accuracy, < 2 cm (Cyclomedia, 2020). Together with the recorded point clouds, cycloramas are also recorded at the same time from the same MLS car. This indicates that these point clouds are coloured point clouds and these colours are accurate, since a good match can be made due to the simultaneously recorded cycloramas.



Figure 3.5: Top-down view of the city centre of Nijmegen point cloud dataset (Cyclomedia, 2020)

The point cloud can be downloaded in different tiles of 50 by 50 meters. The downloaded dataset contains 89 of such tiles, leading to a study area of 2.950 by 2.950 meters. In figure 3.5 a top-down view of the entire downloaded point cloud is shown. All tiles consist of a different number of points, varying between 1,000,000 and 15,000,000 points per tile. As the entire dataset subsequently consists of a huge number of points the preparing and analysing of the dataset only happens with a selection of the tiles, shown in figure 3.6. The selection in this figure consists out of 9 tiles containing 72,627,524 points altogether



Figure 3.6: Selection of the point cloud dataset showing the Market of Nijmegen (Cyclomedia, 2020)

The discussed point cloud dataset is valuable for the final 3D representation of hot, warm and cold zones. However, it is not suitable data for dividing an area in different zones, e.g. by buffering operations. For this purpose, a 2D dataset will be used to create buffers for the hot, warm and cold zones. Thereafter, the point cloud data can be used again for the real-world visualisation. The dataset used for this purpose is the BGT, which is publicly available to download. The BGT dataset is actualised every month, so the used BGT dataset is the most up to date version of the BGT, being the BGT released in November 2020. The BGT in general is a detailed large-scale basis map of the Netherlands provided by Kadaster. In an unambiguous manner the location of all physical objects is registered and can thereafter be visualised as a complete 2D map. In the BGT a building is defined by the ground level footprint.

3.3 Data preparation and pre-processing

All discussed datasets require some preparation before they can be analysed. In paragraph 3.2.3 it has already been mentioned that all datasets have been selected and cut to the desired study areas. In this paragraph the data will be further prepared and this data preparation will be discussed separately for each dataset. Starting with the '3D Basisbestand', then the BGT dataset and lastly the point cloud of the city centre of Nijmegen.

3.3.1 '3D Basisbestand'

The unprocessed '3D Basisbestand' dataset is not clear and quite complex to understand, as can be seen in figure 3.4. The first step to clarify this dataset is to merge associated layers with each other. This leads to 2 main parts/layers of the dataset, being the terrain layer and the buildings layer. After this merge it is easier to

adjust the symbology for different infrastructural objects, e.g. roads, buildings, waterways. The terrain layer consists of different infrastructural objects, as can be seen in figure 3.7, and therefore consists of different symbology's, opposed to the buildings layer which is one whole. By changing the symbology it is more clear to work with a large dataset.



Figure 3.7: '3D Basisbestand' showing Nijmegen with symbology's

Hereafter, the '3D Basisbestand' dataset has been clarified, but not enough yet. To be able to visualise different areas as different safety zones, it is important to have an apparent distinction between all buildings. All buildings in figure 3.7 can be distinguished by their different sizes, but the differences in height are hard to see with the applied symbology. Therefore, 'Multipatch Textures' have been added to all buildings in the selection of the city centre of Nijmegen. These multipatches add colour and/or textures to multipatch features, in other words 3D features. With these multipatches the different heights and shapes of buildings can be easier distinguished, as can be seen in figure 3.8.

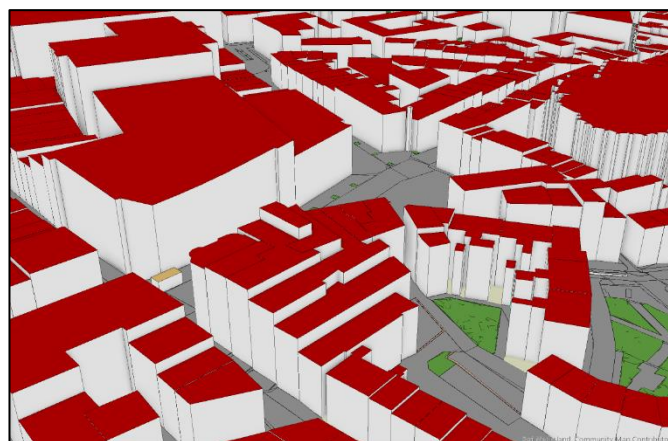


Figure 3.8: The addition of multipatches buildings to accentuate their differences

Lastly, the projected coordinate system has been set to 'Rijksdriehoekstelsel new' (RD new), to ensure that all infrastructural objects are shown in the correct location. This has been done for all datasets, so that in the end everything can be compared appropriately. With all these preparations carried out the data for the 'ad hoc' location was ready to be further analysed.

3.3.2 BGT dataset

The BGT dataset is only necessary for certain buffering operations for the ‘high risk’ location, as this is not feasible with point cloud data. The dataset is quite abstract without any preparation. Therefore, the only preparation aspect required is a change of the symbology for all features. In figure 3.9 the BGT dataset is presented with a new symbology. This symbology complements with the symbology of the ‘3D Basisbestand’ dataset for comparison purposes. Additionally, some features have been left out of the dataset, as they were not of added value for the purpose of creating hot, warm and cold zones.

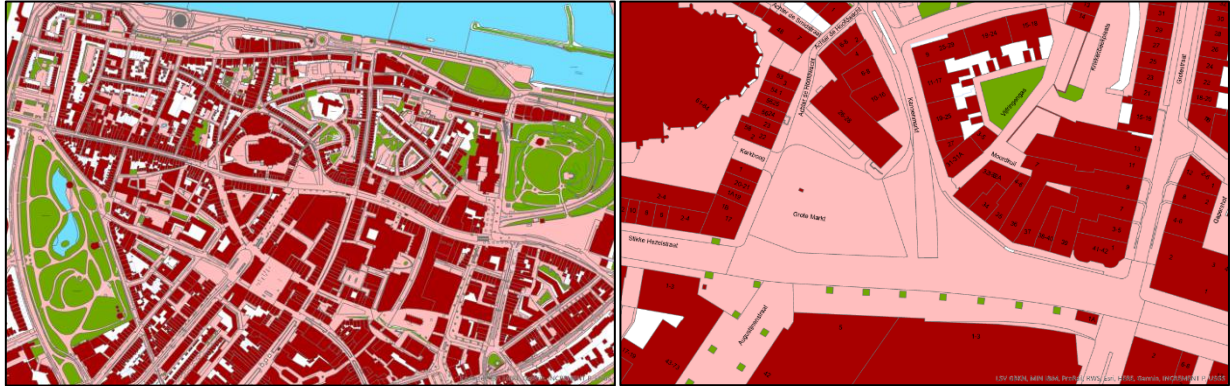


Figure 3.9: BGT dataset with a new symbology, showing the city centre of Nijmegen with a close-up on the right image (BGT, 2020)

3.3.3 Point cloud dataset

As mentioned in paragraph 3.2.3, the downloaded point cloud as a whole is too big to be able to work with. Therefore, the first operation was to make a selection of the entire dataset, which is visible in figure 3.6. Any noise removal will not be done, since this will primarily decrease the quality of the point cloud dataset instead of removing definite noise, e.g. outliers. It is more important for the purpose of this research to maintain all details of the infrastructural objects, e.g. buildings, trees, traffic signs, instead of removing some noise. In figure 3.10 it is visible that through noise removal any unwanted points are indeed removed, however some points which form an essential part of the point cloud are also removed.



Figure 3.10: On the left image there is no noise removal and on the right image there is noise removal. The red circle shows that the façade of the building partly vanishes due to the noise removal (Cyclomedia, 2020)

This algorithm locally fits a plane around each point and when a certain point is located too far away from the fitted plane it will be removed (CloudCompare, 2015). The distance of this fitted plane can be chosen as the maximum error, to decide whether a point is removed or not. The algorithm of noise removal is very powerful on flat surfaces, however on any other surfaces the possibility exists that corners will also be removed, as can be seen in figure 3.10. Points can be removed by either a nearest neighbour search or defining a constant radius (CloudCompare, 2015). However, in both cases required points for the model are removed as well. For the purpose of this research it is of a significant importance to visualise the city centre of Nijmegen as realistic as possible. Therefore, the small amount of outliers and unwanted points are accepted into the model.

4. ANALYSIS

In this chapter the process before creating the final products, being the 3D representations of the Hot-Warm-Cold zone model, is described. This chapter can be divided into 2 sections, first the analysis for 'ad hoc' locations will be described and thereafter the analysis for 'high risk' locations will be described.

4.1 Analysing an incident on an 'ad hoc' location

For the 'ad hoc' location, the '3D Basisbestand' dataset has been used. This dataset has been analysed in ArcGIS Pro to create an adequate 3D representation for incidents on such locations. In order to determine the right analysis method for the creation of hot, warm and cold zones for 'ad hoc' locations several analysis methods have been explored.

4.1.1 View dome

One of the tools which can be used in ArcGIS Pro for exploratory 3D analysis is the View dome tool. In general, a point of location can be chosen via different ways and from this point a view dome is created showing the parts of the environment which can and cannot be visible from that exact point. This 3D dome shows the possibly visible volumetric spaces and specific distances from the chosen location.

The dome is created based on 3 parameters:

1. Vertical offset - This is the distance of the chosen location (centre of the dome) above the ground. When this value is 0, the visible volumetric spaces are shown from ground level. However, when the value is 1.5 m (approximate eyesight distance) then the visible volumetric spaces from this offset are shown, which will differ from the offset at 0 m.
2. Minimum distance - This is the minimum distance which needs to be analysed from the centre of the view dome. When any buildings or infrastructural objects appear closer than the minimum distance, they will not be analysed.
3. Maximum distance - This is the maximum distance which needs to be analysed from the centre of the view dome. Similar to the minimum distance parameter, any objects outside the maximum distance will also not be analysed.

With these parameters a view dome can be interactively created, by clicking on a wanted location in the map. It can also be manually created and in this case specific points need to be created for the vertical offset, minimum and maximum distance, and consequently a view dome will be created based on this point layer. The advantage of such a point layer is that it can be saved and used again for other purposes. A disadvantage of the view dome is that there is a 'display budget' within ArcGIS Pro. 3D exploratory analysis objects consume a large part of display capabilities when rendered in ArcGIS Pro. Thus, when several view domes have been created the limit is exceeded and no more view domes can be created, unless an earlier created view dome is deleted.

In figure 4.1 a view dome is illustrated for the 'ad hoc' location in Nijmegen. Here, it has been calculated for a zone of 100 meters around the centre of the incident. Besides the desired size of the view dome, the visible places from the centre of the view dome are also highlighted. The green part of the view dome signifies visible places from the centre of the view dome and the pink part signifies places which are not visible. These aspects of the view dome are very useful however, the shape of the created dome is not practical for the purpose of the Hot-Warm-Cold zone model. The view dome is represented as a dome and not as a buffer. In figure 4.1 this dome is visible, but the area located behind the dome is hard to see from this perspective. The dome is blocking most of the view for that part. This is not convenient for the purpose of creating hot, warm and cold zones, as all areas around the incident location should be clearly noticeable at all times. Also, the exact outlines of the buildings within the view dome are not very distinct due to the height of the roof of the dome.

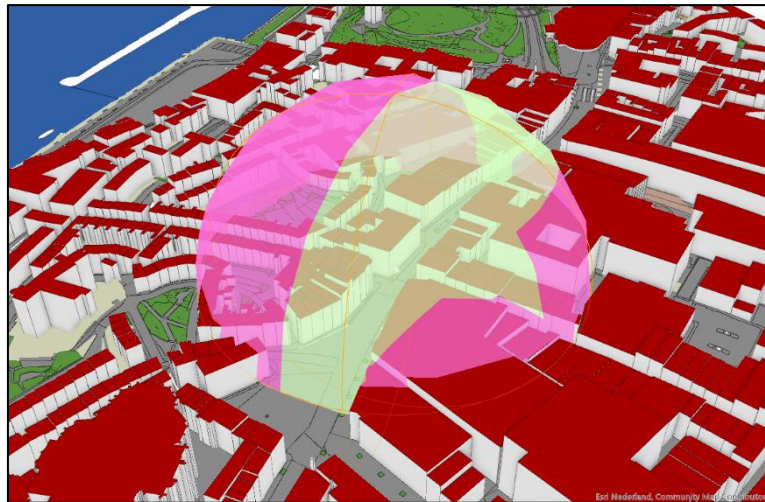


Figure 4.1: A view dome at the 'ad hoc' location

4.1.2 Line of sight

This exploratory 3D analysis tool can be used to see whether a target (or multiple targets) is visible from a specific location, for instance from an observer's viewpoint. The line of sight is calculated against the displayed content, thus all buildings, trees, bridges etc. will be taken along in the calculation providing an accurate line of sight. The line of sight is, similar to the view dome, created based on 3 parameters: the vertical offset, the maximum distance and the minimum distance (these distances are calculated from the observer's point). The only difference being that there is a target and an observer with this tool, hence there is also a target vertical offset and observer vertical offset which needs to be filled in. A line of sight analysis can be carried out with 1 target, but also with several targets seen from the observer's viewpoint.

Likewise the view dome, a line of sight can be created by clicking in the map and via point layers. Additionally, the line of sight can also be created via a camera position from the observer's viewpoint. For this function you need to position the camera in such a way that it is located at the observer's viewpoint; first-person visualisation. From this observer's viewpoint you appoint the target and see the target line directly from the observer's viewpoint. Lines of sight can be adjusted and updated at any time. As becomes clear from the explanation above, with the line of sight tool no specific zones can be created, only lines. Therefore, this tool will not be sufficient in its own for a hot, warm and cold zone analysis. However, it can be an useful enhancement in combination with other analysis tools.

In figure 4.2 an example of a line of sight has been created for the 'ad hoc' location. In the left picture a line of sight is shown which is 100 metres long and does not intersect with any infrastructural object. This distance can be derived from the number 100,00 which is shown above the line and the line is of a green colour, which indicates that this entire line is visible from the starting point. This line could for instance be used to calculate distances from the centre of the incident, which could help in demarcating the hot zone.

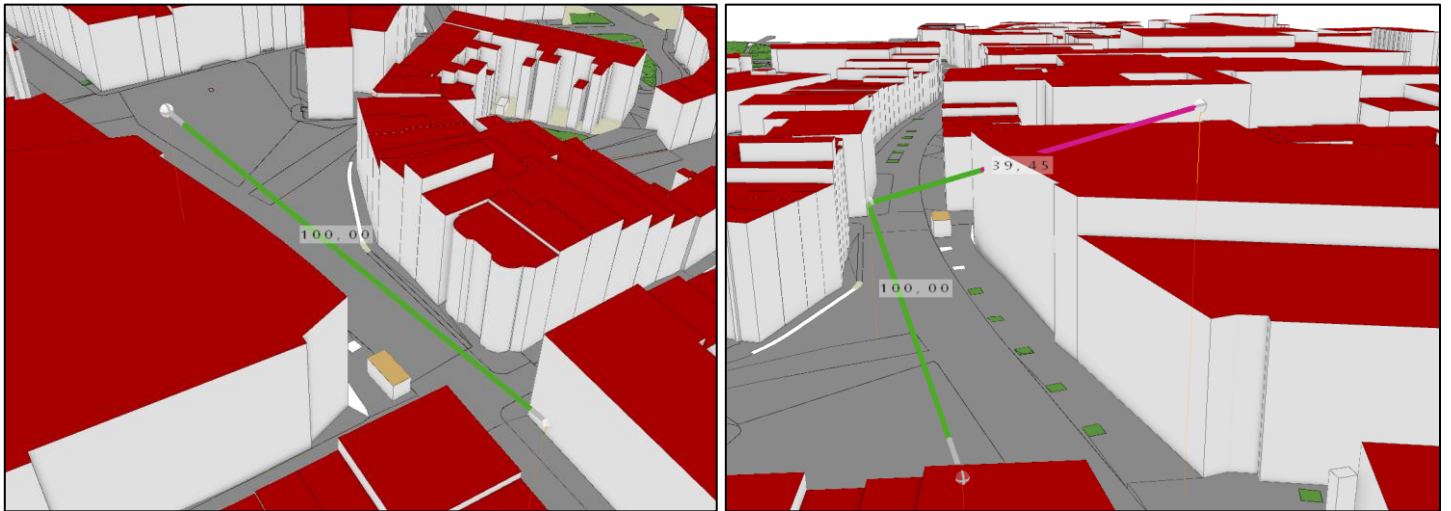


Figure 4.2: 2 lines of sight at the 'ad hoc' location, with a continuous line of sight on the left and an intersecting line of sight on the right

In the right image of figure 4.2 another line of sight has been added. This line intersects a building opposite of the centre of the incident. The location of the intersection is noted by the distance, the number 39,45 in figure 4.2, and by the change in colour, from green to pink. The green colour indicates visibility up to that point and the pink line indicates that it cannot be seen anymore from the observer's viewpoint. Another element which has been added to this line of sight is the change in vertical offset for the target. As visible in figure 4.2 the end of the line, the target point, is situated higher than the observer's viewpoint and the target point of the first line of sight. In this case the vertical offset has been set to 10 metres. With an incident containing explosives there can be a presumed danger of reflecting debris. Such a line of sight could give more insights in the possible directions of the debris and what buildings will be in danger at that moment.

4.1.3 Viewshed

The last 3D analysis tool which has been investigated is the most extensive tool, called the viewshed. A viewshed is defined as an identification method which can identify the cells of the input map which can be seen from an observation point (Esri, n.d. c). An example of a 'simple' 2D viewshed is shown in figure 4.3. It does not matter what the environment is, when the input surface, observer point and certain parameters are given, an output viewshed can always be calculated. In this example the height of the land causes lack of sight and only the green areas are visible from the observer point.

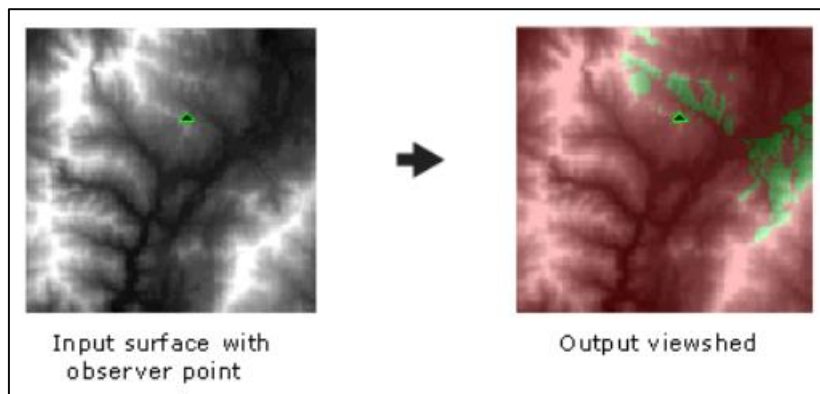


Figure 4.3: An example of the creation of a viewshed from 1 observer point (Esri, n.d.)

A visibility analysis through the viewshed tool can be performed on a 2D as well as a 3D dataset, but the method is the same. In figure 4.4 the method of the viewshed is visualised in a 3D environment. A viewshed is created by 9 parameters in total: SPOT, 2 different vertical offsets, 2 different azimuths, 2 different vertical angles and 2 different radiuses. All these parameters are visible in figure 4.4, where the abbreviations for the parameters can be found in the pink legend. The surface elevation is first shown with the SPOT parameter. This figure also shows that there is 1 observation point (OF1) with the direction looking to the right. The horizontal and vertical angle which can be seen from this point are illustrated through the radiuses and azimuths.

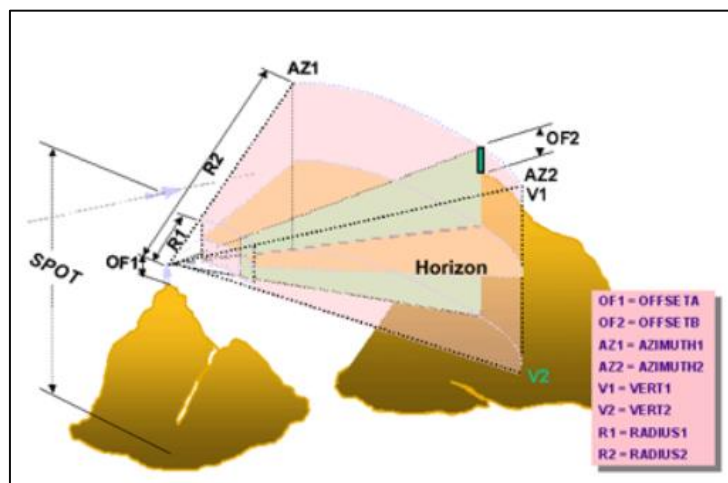


Figure 4.4: The principle of the viewshed tool with its parameters (Esri, n.d. c)

The principle of the viewshed tool as illustrated in figure 4.4, is also used within the 3D environment of ArcGIS Pro, only the denomination is different. The initial viewpoint needs to be selected, including the heading (AZ1), tilt (R1) and offset (V1), thereafter the 2 viewshed angles (V1 and V2) need to be decided on and lastly the viewshed distance (R1 and R2) needs to be filled in, which consist of the minimum and maximum range. When this is all completed the viewshed can be created via different methods:

- Interactive placement – Clicking in the map to create the observation point and thereafter also the viewshed.
- Interactive orientation – Clicking in the map to create the observation point and click again to create the view direction of the viewshed.

- Observer from camera – Use the camera to locate the required position for the observation point (first-person orientation).
- Along a line – A line (or layer with lines) needs to be created along which a viewshed can be created based on the distance or certain percentage of that line.
- From layer – Creating a viewshed based on a point layer.

The accuracy of the viewshed tool is tied to the relative distance and the viewing angles seen from the observer point. Thus, results will be clearer from a higher angle showing short distances compared to a lower angle with large distances. Another aspect affecting the accuracy is the ratio of the maximum and minimum range. This ratio should be as low as possible, otherwise visual inaccuracies might occur.

In figure 4.5 a viewshed has been created in ArcGIS Pro. For the viewshed on the left, the maximum distance has been set to 100 metres with the heading set to ± 280 degrees and the horizontal viewshed angle set to 60 degrees. This resulted in the shown viewshed on the left, with the green zones again standing for visible areas from the viewpoint and pink areas are non-visible areas.



Figure 4.5: Viewsheds at the 'ad hoc' location with on the left a viewshed with an angle of 60 degrees and on the right a viewshed with an angle of 360 degrees

When extending the horizontal viewshed angle to 360 degrees and the vertical viewshed angle to 180 degrees a full zone around the centre of the incident can be created. This is shown in the right image of figure 4.5. The difference between this viewshed and the discussed view dome in paragraph 4.1.1 is that the zone created with the viewshed tool is draped over the buildings, instead of a circle which encompasses the entire zone (as is the case with the view dome). This has to do with the vertical viewshed angle, which creates the possibility to also choose the vertical extent of the zone. Therefore, a viewshed is a more suitable tool for the purpose of the Hot-Warm-Cold zone model as it does not restrict sights anywhere in or around the incident location.

4.2 Analysing an incident on a 'high risk' location

As already mentioned in paragraph 3.3.2, the point cloud dataset is not suitable for dividing an area into different zones, e.g. with buffering operations. For this purpose the BGT dataset will be used. Therefore, the focus will firstly be on analysing the BGT dataset whereafter the focus will be moved onto the point cloud of the city centre of Nijmegen.

4.2.1 Buffering operations on the BGT dataset

There are several methods to create buffers around a specific location. The process of buffering can be described as a method used to identify a specific zone around an entity, e.g. a point, a line or an area. The end result of buffering is the creation of new areas besides the already existing areas. Buffering can be complicated when a buffer needs to be created around a line or an area (Heywood et al., 2011). The centre of the 'high risk' location is an ATM, pictured as a point in ArcGIS Pro. This indicates that a circle of the required radius can be drawn around that point in order to create the buffer. There are several ways to perform buffering operations in ArcGIS Pro.

Buffer

Hence, a buffer can be created for different features, namely a line, point or area. One of the most important aspects of creating a buffer is choosing what method will be used, there are 2 main methods. The first method is Euclidean buffers, which measure the distance in a 2D Cartesian plane. This means that a straight line is calculated between 2 points on a flat surface, being the Cartesian plane. The other method creates geodesic buffers, which take the actual shape of the earth into account. Therefore, distances are calculated on a curved surface, on a geoid, instead of a flat surface (Esri, n.d. e). On a flat map geodesic buffers may seem dispersed, therefore for a correct buffer with this method the input features need to be dispersed and the spatial reference system also needs to account for distorted distances.

Besides the choice of buffer method, the distance also needs to be decided for the buffer. This distance can be chosen in any linear unit, but in this research everything is calculated in metres. Furthermore a side type can be chosen, which implies the side of the features that will be buffered, e.g. full, left or right. However, this is not of relevance for point features. Lastly, when creating multiple buffers they can be maintained as individual buffers/features, but they can also be dissolved into a single feature. In that case any overlap will be removed since 1 feature will be created out of the buffers, however with the Hot-Warm-Cold zone model it is crucial to maintain the different zones and therefore nothing will be dissolved.

In figure 4.6 a buffer has been created for the 'high risk' location. This is a singular buffer as an example of the outlines of the hot zone. The distance of the buffer has been set to 100 metres, which will be calculated from the centre of the buffer, in figure 4.6 visible as the blue pinpoint. This buffer has been created as an Euclidean buffer as the input features and underlying base map are all flat surfaces. Besides this, the transparency of the buffer has been set to 42% leading to a clear buffer and the area within the buffer is also still visible, which is an important aspect. Depending on preferences, all visual aspects of the buffer can be adjusted, e.g. the colour, transparency, edge.



Figure 4.6: A buffer of 100 metres created around the centre of the incident 'high risk' location

It is good to keep in mind that buffers are not 100% accurate. The distance between the buffer and the buffered object should everywhere be equal to the desired distance, in the case of figure 4.6 this is 100 metres. However, a buffer is an enlarged version of the buffered object leading to an error in the corners, thus the distance between a vertex of the buffer and the vertex of the buffering object is greater than the desired distance (de Vries, 2001). This distance will not be significantly different, but it is still good to acknowledge this little malfunction of buffers.

Graphic Buffer

Similar to the 'normal' buffers previously discussed, graphic buffers are also buffer polygons created around input features for the desired distance. However, the distinct aspect of graphic buffers is the different buffer ends and corners of a created buffer. In figure 4.7 these different buffer ends are illustrated by means of different buffered features. The earlier mentioned disadvantage of buffers not being 100% accurate is handled differently with these buffers. The corner of a buffering object is the main cause for inaccuracies, graphic buffers can be created with different caps (buffer ends) and joins (corners) making it possible to keep the desired buffer distance the same everywhere. The upper left feature in figure 4.7 shows a buffer with rounded corners which leads to the same desired buffer distance around the entire buffer.

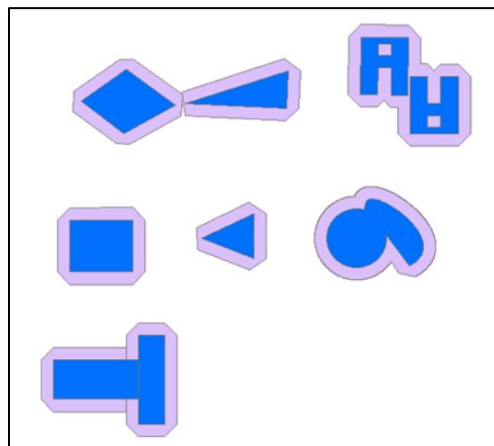


Figure 4.7: Examples of graphic buffers around various features (Esri, n.d. f)

However, for the Hot-Warm-Cold zone model graphic buffers will not be used. The buffers which need to be created are mainly buffers around points, namely the centre of an incident location. A buffer around a point will always be round, as any corners do not exist. When changing the caps for such a buffer a squared buffer is created instead of a round buffer, which is not desired. For buffering different features, for instance buffering an oval shape, graphic buffers are useful. However, the graphic buffers are 2D features which decreases its usability for this research.

Multiple Ring Buffer

With the multiple ring buffer tool in ArcGIS Pro multiple buffers can be created simultaneously. The method of creating such a buffer is the same as described earlier in this paragraph, thus a choice needs to be made between Euclidean and geodesic buffer. The difference here is that multiple buffer distances need to be chosen, as multiple buffers will be created around the buffering object. These multiple buffers can be no n-overlapping, then they are represented as rings, but they can also be shown as overlapping buffers, then called disks.

In figure 4.8 a multiple ring buffer has been created in the city centre of Nijmegen. 3 buffers are shown, representing the hot, warm and cold zone, of which the created buffer distances are: 25 metres, 50 metres and 100 metres (counting from the inside out). This multiple ring buffer contains disks instead of rings, thus the

'dissolve all' option is specified. In the event of a multiple ring buffer containing all separate distances, as is in this case, then a multiple ring buffer with disks will contain separate feature for each distance. However, when buffers have the same distance, than these buffers will be dissolved together. In such a scenario a multiple ring buffer with rings is the more suitable choice.

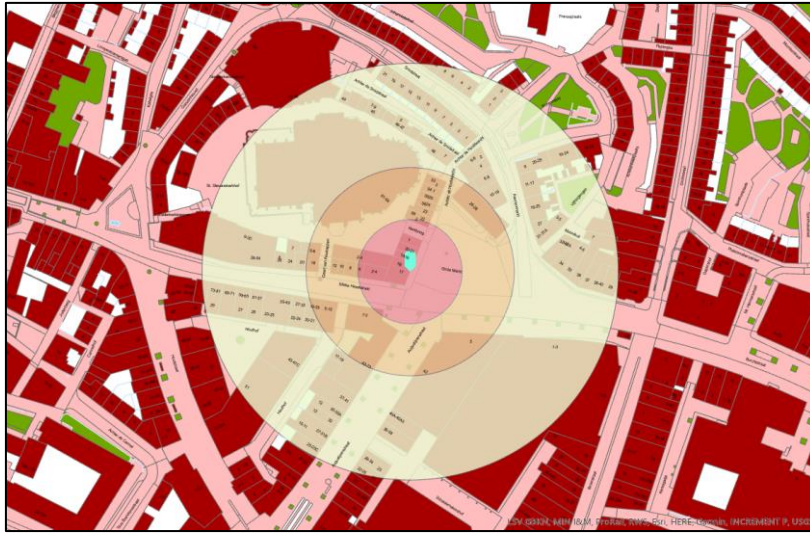


Figure 4.8: A multiple ring buffer created around the 'high risk' incident location

4.2.2 Point cloud visibility analysis

The demarcation of the hot, warm and cold zones cannot be performed in the point cloud dataset. For this purpose the earlier discussed BGT dataset will be utilised. The point cloud dataset is required for the supplementary visualisation and visibility analysis of the environment containing the safety zones. In paragraph 3.3.3 it has been specified that unprocessed point clouds will be used. This prevents any limitations caused by the transformation of point clouds and an accurate and precise analysis can be performed considering the high point density and relatively simple filtering and/or selection of points (Zhang et al., 2017). Besides this benefit of point clouds the main reason why unprocessed point clouds are used in this research is the presence of vegetation and other infrastructural objects which could otherwise be left out. Certain vegetation, for instance trees or bushes, could block lines of sight and can therefore not be neglected.

There are multiple point cloud visibility methods developed. Alsadik et al. (2014) classified these different visibility methods into 3 groups:

- Voxel approaches. In these approaches point clouds are represented as voxels, thus it is not necessary to create a different surface. However, the analysis might be affected by the fact that sparse points are not depicted, as voxels are used.
- Triangulation approaches. These approaches are based on a triangulated mesh surface whereafter a visibility analysis can be performed. In this research unprocessed point clouds are used for earlier mentioned reasons, which is why this method is not applicable in this case.
- Hidden Point Removal (HPR) approaches. In HPR there is also no need to create another surface and additionally sparse points (along with dense point clouds) can also be depicted with this method. In this research HPR will be used as the point cloud visibility method for 'high risk' locations.

The HPR method for point cloud visibility has been developed by Katz et al. (2007) and it implies to discover which points are visible from a certain viewpoint. This operation can be performed by using a HPR operator, in

CloudCompare available as the 'qHPR' tool (CloudCompare, 2015). This operator functions without a need to reconstruct the point cloud indicating an absence of complication and additionally a direct and visible result (Katz et al., 2007). A point does not have volume, therefore line of sight analysis does not work for point clouds since a point is always visible (unless it is positioned in the exact same ray as another point). HPR discards this problem by removing points that should be hidden from the viewpoint through a projection of the points to a spheroid around the same viewpoint.

The HPR operator calculates when a point is considered visible from a certain viewport, since a point can be considered to always be visible. This visibility is calculated via 2 steps: inversion and a convex hull construction. The first step, inversion, is performed via spherical flipping. For this a sphere is created around the viewpoint (viewport) and every point inside this sphere is reflected, along the ray of the viewport. This process of spherical flipping is illustrated in figure 4.9. Thereafter, as step 2, a convex hull is required as a check for visibility. Depending on the size of the radius, points are marked as visible on the convex hull, such a convex hull is visible in figure 4.9. This convex hull is obtained through repeatedly adding the point and its origin. Then all points can be plotted within the convex hull and after excluding their origin and removing all overlapping points the HPR operation has been completed and the visibility of point cloud has been improved.

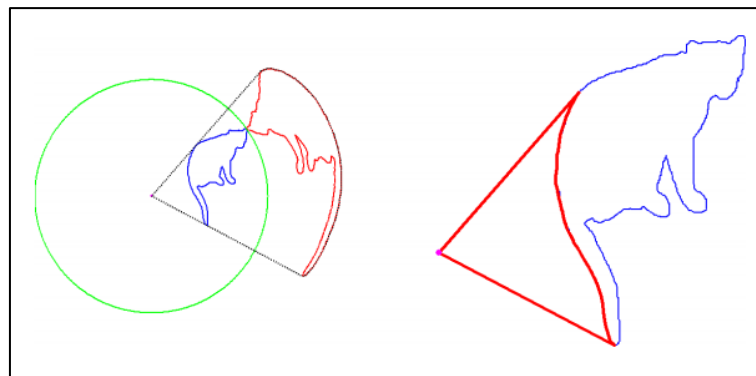


Figure 4.9: Left - The process of spherical flipping with the sphere in green, the 2D curve in blue, the viewport in pink and the end result of spherical flipping in red. Right - the back projection of the convex hull, ultimately leading to the visible points from the viewport (Katz, 2007)

To be able to directly compute the visibility of a point cloud dataset a camera needs to be set up in the point cloud, as the required viewpoint. This camera needs to be set up at the desired position by specifying the viewing direction, view angle and the X, Y and Z coordinates. As an example for this case the camera has been set up at the centre of the incident at the 'high risk' location, being the ATM at the market of Nijmegen, scanning the area to the right of the ATM. These camera settings are shown in table 3, whereafter the set camera in the point cloud is shown in figure 4.10.

Centre	X coordinate (right)	Y coordinate (up)	Z coordinate (inv. view dir.)
-45.984001	0	1	0
-18.527000	0	0	1
47.273487	1	0	0

Table 3: Camera settings for the camera shown in figure 4.10



Figure 4.10: A camera positioned in front of the ATM at the 'high risk' location (Cyclomedia, 2020)

The camera settings for the ATM location shown in table 3 were retrieved via 'point picking' in CloudCompare. When clicking on a point in the point cloud, this tool provides you with the coordinates of this point. The coordinates of that point were thereafter used as coordinates for the camera. In figure 4.11A the view from the camera itself is shown, in other words the viewport is shown. This is the view from street level and most of the view which is indicated by the transparent green box in figure 4.10. The view shown in figure 4.11A gives a good idea of what can be seen from the position of the camera. Experimenting with different cameras, views, positions and zooming levels already creates a good indication of the location of the incident.

After accurately positioning the camera and the viewport, the operation of HPR was applied onto the point cloud. For the 'qHPR' tool to work in CloudCompare the octree level needs to be set. In this case an octree level of 7 has been used. The greater the octree, the finer the result will be with an octree of 1 subdividing the entire dataset into 8 cubes, an octree of 2 subdividing all cubes into 8 cubes etc. (CloudCompare, 2015). However, the disadvantage of a higher detail level is a longer processing time. In figure 4.11B the same viewport is shown as in figure 4.11A, only now HPR has been applied onto the point cloud.

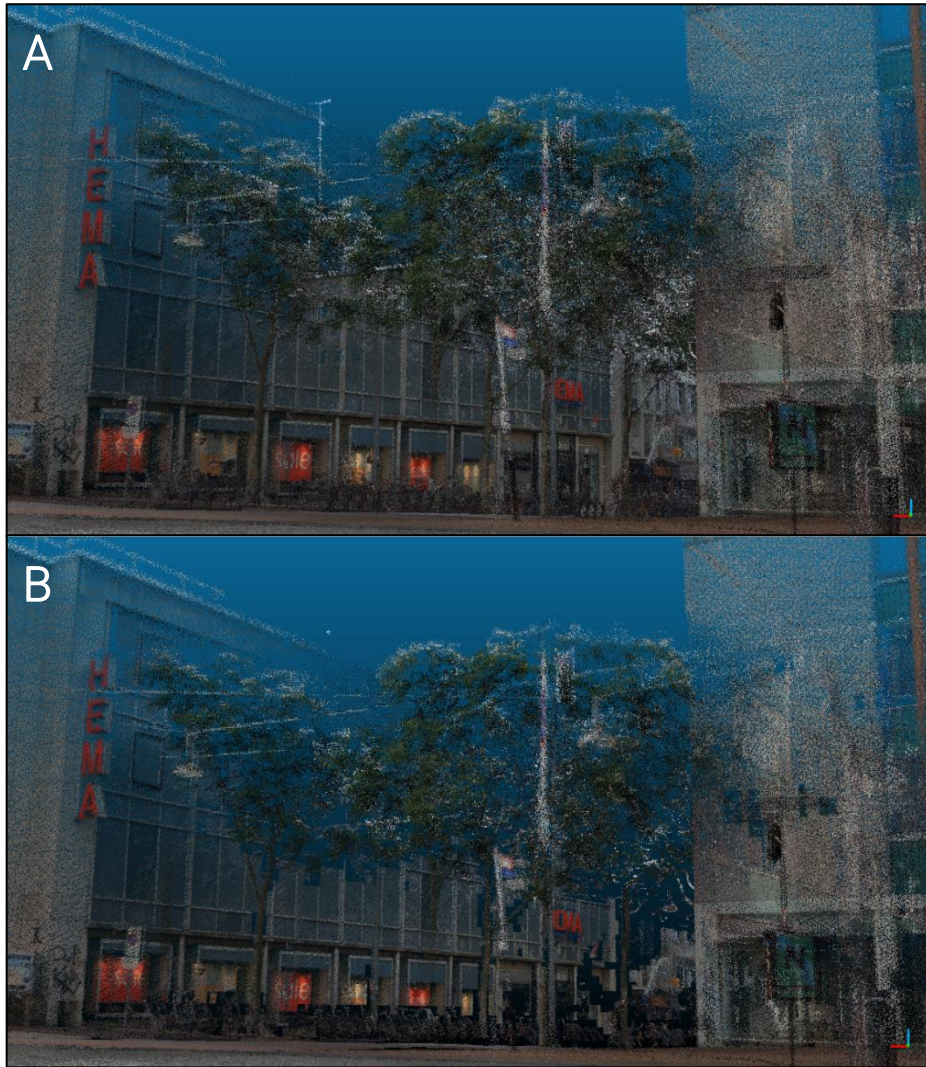


Figure 4.11: Viewport from the set camera depicted in figure 4.10 (A) and the same viewport with HPR applied onto it, octree level 7 (B) (Cyclomedia, 2020)

A visible feature is the difference between A and B in figure 4.11, or in other words the difference HPR makes on a viewport of a point cloud. The algorithm of HPR removes points, thus it is not the case that more points have been added in figure 4.11B. The view from a viewport in CloudCompare focuses on all visible points, which could lead to points in the front not being shown/visible, as is the case in figure 4.11A. After the appliance of HPR this distinction is not made anymore, as any unimportant points have already been filtered out, and therefore the extents of the entire scenery are visible.

Also, points located in the back of this viewport make figure 4.11A a bit noisy and unclear. All these points have been removed in figure 4.11B, creating a clearer image. Another aspect which proves that HPR clarifies a point cloud is that the present trees and the building of the 'Hema' are more refined and filled in in figure 4.11B, compared to figure 4.11A. Especially the trees are better visualised in the scenery with HPR applied onto it. Thus, sceneries from point clouds with HPR applied onto them form a closer resemblance to reality, or in other words such sceneries can be called real-life representations. For point clouds to be used within the National Police regarding the Hot-Warm-Cold zone model this is an important determinant.

5. RESULTS FOR 'AD HOC' INCIDENTS

In this chapter the outcomes of the analysis, chapter 4, will be incorporated into the actual Hot-Warm-Cold zone model for the 'ad hoc' location. An 'ad hoc' location is not known by the police in advance and therefore when an incident happens at such a location a relatively quick analysis of the surroundings is required in order to create an accurate Hot-Warm-Cold zone model. The 3D representation for such incidents is created as a 3D city model. This 3D model is relatively easy to work with and relatively quick to load and process.

Furthermore, it has a level of detail of LoD1.2, thus the size and height of all buildings is correct, however there are no roof or façade details present. This indicates that from this model the correct height and size of all buildings can be deduced and furthermore the layout of any other infrastructure is also depicted. It is attainable to work in the 3D environment of the city model, thus the environment can be seen from any wanted perspective. This indicates that more insights can be gathered based on this 3D model. Additionally, it is also possible to perform visibility analyses in this 3D model, which is not possible with a 2D dataset.

The Hot-Warm-Cold zone model can be used for all different kinds of incidents. For each incident different factors come into play and so, a 3D representation with solely round buffers might not work for every incident. Therefore, a variation has been developed for the 3D representation on the 'ad hoc' location. First, in paragraph 5.1 the 3D representation for an incident at an 'ad hoc' location will be discussed in the form of spheres, thereafter in paragraph 5.2 a 3D representation for an incident at an 'ad hoc' location will be discussed in the form of ellipsoids and lastly in paragraph 5.3 a 3D representation in the form of ovoids will be discussed. In paragraph 5.4 the conclusions from all these paragraphs are lined out.

5.1 The Hot-Warm-Cold zone model represented as spheres

Currently when hot, warm and cold zones are created they are drawn as circles on paper or in 2D data. Creating spheres (round buffers) around an incident location for the 3D representation is the most straightforward and apparent method for the Hot-Warm-Cold zone model, especially because it complements with the current method of drawing safety zones. For every incident first the hot zone is set. In this case, this will be accomplished via the previously discussed viewshed tool, see paragraph 4.1.3. With the viewshed as hot zone, the use of 3D features is optimally utilised and besides the outlines of the hot zone, the actual incident location inside of the outlines can also be identified. In figure 5.1 a viewshed has been created as a hot zone for an armed robbery on a store.

For an accurate viewshed, the vertical offset needs to be set at 1.5 meters, which is the approximate eyesight level. Doing so, the shown visible and non-visible areas are the most accurate. The parts of the hot zone pictured in green are visible from the centre of the hot zone, in this case the front door of the robbed store, and the pink parts represent areas which are not visible from the centre. In figure 5.1 this centre can be recognised by the small white circle in the middle of the hot zone. This centre is located on the right side of the building, the street on this side is coloured green, thus the street on the other side of this centre is not visible and therefore coloured pink, as is visible in figure 5.1. The viewshed can be used as a hot zone by adjusting the

viewshed angles in such a way that a sphere is formed. This completes the viewshed as the hot zone, shown in figure 5.1.

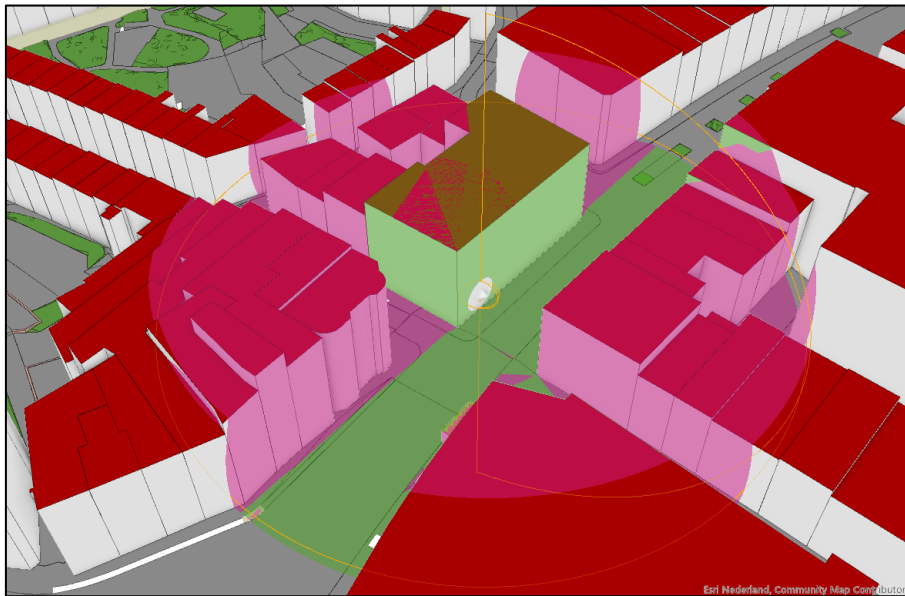


Figure 5.1: The hot zone of an 'ad hoc' location represented through a viewshed

For figure 5.1, and all other figures showing a 3D representation for 'ad hoc' incidents, it is important to keep in mind that these are static images. This may affect what insights can be gathered from the created 3D representation. However, when the concept of this 3D representation is used for a real incident by the Dutch National Police, it will be used within the 3D environment. This indicates that the scenario can be viewed from any wanted perspective and any distance, therefore relevant information can always be obtained by changing the viewing direction.

After the creation of the hot zone, the warm zone can be created by means of a buffer. 2 different buffers are an option for this case, being a normal buffer and a 3D buffer. In figure 5.2 on the left the warm zone is shown as a normal buffer and on the right a 3D buffer is shown. A normal buffer does not work in a 3D environment, as it will not be visible on top of all 3D objects, it is placed underneath. Therefore, for the normal buffer to appear visible the extrusion of the buffer needs to be adjusted. For this, the minimum height needs to be set, then the extrusion is added to the minimum Z-value of the feature which corresponds to the chosen buffer distance. To still be able to see the hot zone within the warm zone after these actions and additionally see all buildings and the terrain of the hot zone, the transparency needs to be adjusted to approximately 80%. The result of this process is shown in the left image of figure 5.2. The clear transparency and high boundaries of the warm zone ensure that all areas within and around the warm zone are clearly visible.

On the right image of figure 5.2 a 3D buffer has been created as the warm zone. This buffer can only be created around a point or line, in this case the centre of the 'ad hoc' incident was used. After enlisting a buffer distance, for both buffers 100 meters in this case, the buffer automatically appears as a sphere. Again, after changing the transparency of the buffer, clarification is created for both inside and outside the warm zone, this is visible in figure 5.2 on the right. This 3D buffer has a shorter rendering time, as less actions are required to create the buffer (e.g. no extrusion options are needed). This is beneficial for 'ad hoc' incidents, as 3D representations need to be created quite quickly. The only disadvantage is that, since it is a sphere, the height of the buffer is different in the middle compared to the sides of the buffer. The normal buffer, on the left image, is a continuous area with no differences in height. This might make a difference when dealing with high-rise buildings or hilly areas.

After the creation of the hot and warm zone, the cold zone automatically comes into being on the outside of the warm zone. It is possible to create yet another buffer for this purpose, however this will only cost more precious time. It is also coherent to consider the outside of the warm zone (the 'left-over' areas) as the cold zone, thus the safe area. In addition, depending on the incident, any desired lines of sight can also be added.

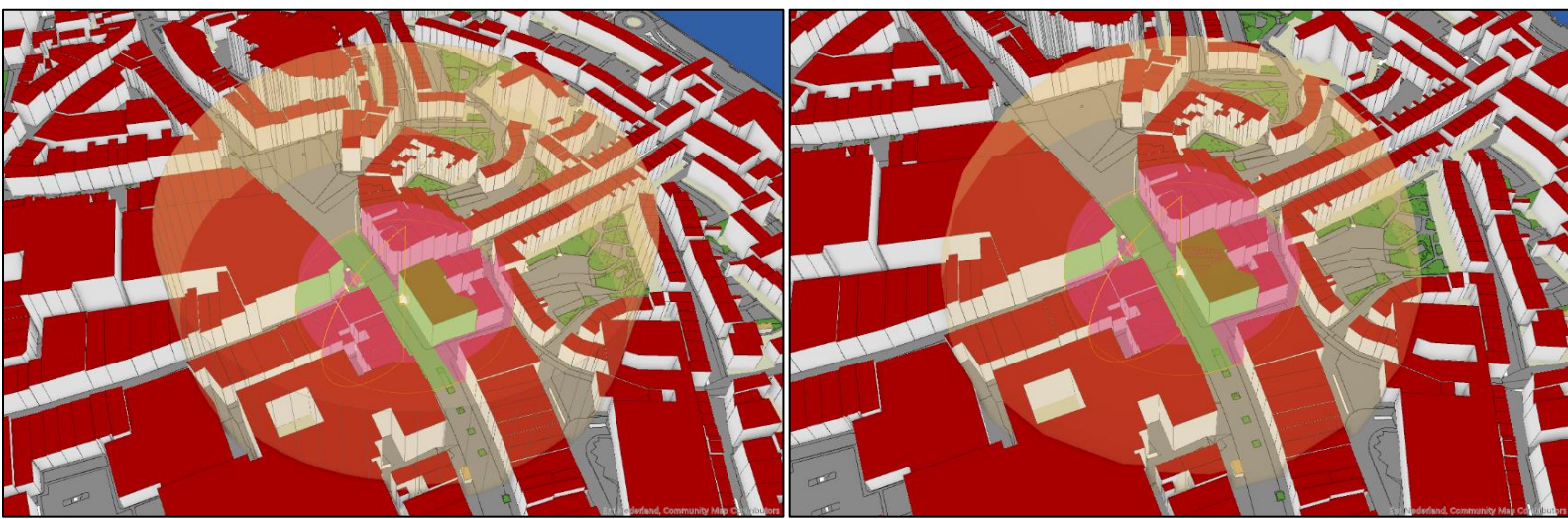


Figure 5.2: A sphered 3D representation for the Hot-Warm-Cold zone model with on the left a normal buffer for the warm zone and on the right a 3D buffer for the warm zone

5.2 The Hot-Warm-Cold zone model represented as ellipsoids

As has been explained in paragraph 2.2.3, the Hot-Warm-Cold zone model is originated from incidents regarding chemical substances. With such incidents it is important to consider the wind direction, as toxics can spread in different directions depending on the force and orientation of the wind. When this is the case, a 3D representation with spheres will not be adequate, as wind direction cannot be pictured via this method. Wind direction can be considered with this method, but not interpreted in the 3D representation. When using ellipsoids instead of spheres for the 3D representation, the wind direction is directly visible. This is the only exception of when a sphered 3D representation is less competent than another shaped 3D representation.

First of all, ellipses as depicted in figure 2.2 cannot be created as a 3D feature in ArcGIS Pro, therefore the only possibility is to create an ellipsoid as a 2D feature and adjust the Z-value, so that it will become visible on top of the 3D environment. Such a shaped ellipsoid as the hot zone is visible in figure 5.3. It becomes apparent that the hot zone is ellipse-shaped and that it is not draped over the buildings, as it is a 2D feature. Similar to the sphered 3D representation it is possible to create a buffer around the hot zone, also visible in figure 5.3. Again, similar to the buffer in paragraph 5.1.1 the extrusion of the buffer needs to be adjusted in order to make the buffer visible in the 3D environment. For visibility purposes the hot zone is blue of colour in this figure, with a red hot zone it is more difficult to distinguish the different zones, but also the buildings located in the hot zone.

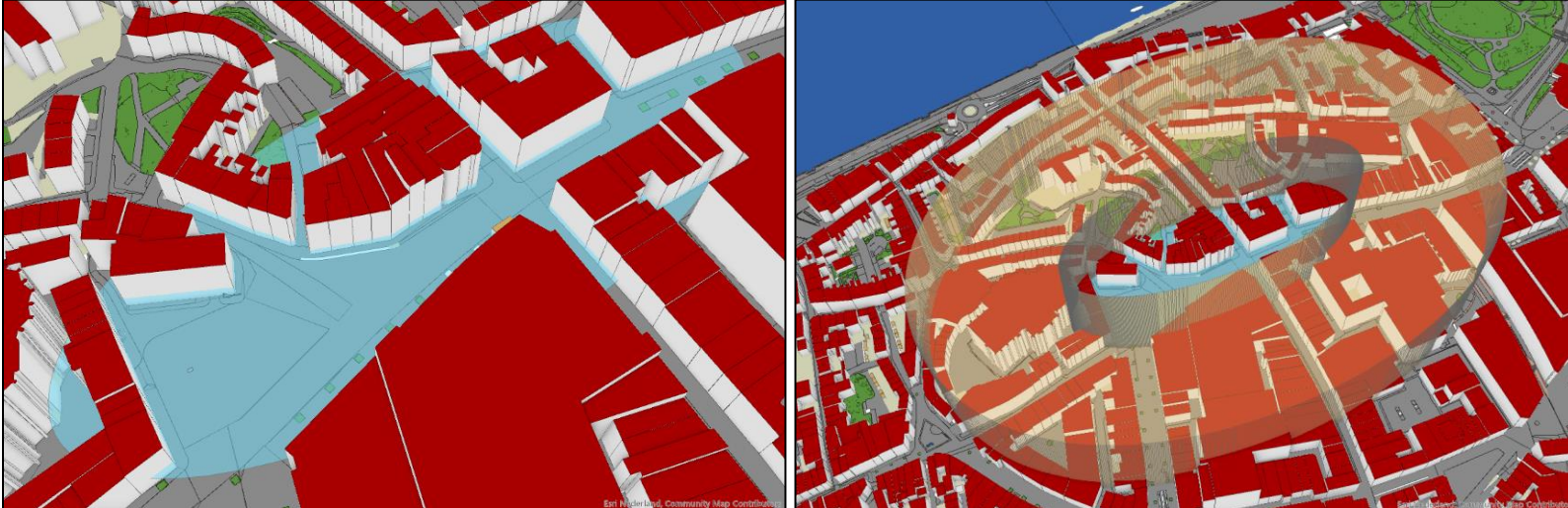


Figure 5.3: Left- An ellipsoid shape representing the hot zone. Right – The Hot-Warm-Cold zone model represented as ellipsoids, with an ellipsoid shaped hot zone and a buffer as a warm zone

Although the pictured Hot-Warm-Cold zone model in figure 5.3 is a clear model, it is not adequate for the purposes of this research. As discussed in the beginning of this paragraph, the 3D environment is not optimally used. One of the purposes of this research is to see whether 3D usage is beneficial for the Hot-Warm-Cold zone model and the use of 2D features does not support this theory. Therefore, another method has been developed in which the 3D environment is coming into its own. This model will complement less with the ellipses of figure 2.2, where all zones are represented as ellipses following the original shape of the hot zone, but it is still accurate to depict wind directions.

5.3 The Hot-Warm-Cold zone model represented as ovoids

As the ellipsoid shaped 3D representation does not optimally use the 3D environment, a different 3D representation is required for chemical related incidents. For this purpose the ovoid shaped 3D representation has been developed. The most important factor to depict for these incidents is the wind direction. With an ellipse shaped safety zone this is possible as the 'extended' shape can correspond with the direction and strength of the wind. The ovoid shape resembles less with ellipses, but it still suits the purpose of depicting the wind direction. Additionally this model does correspond to the 3D environment as 3D features can be used in this case. The 3D features used are created via a buffered line, which ensures accurate and precalculated safety zones, contrary to the ellipsoids which cannot be created in such manner.

For the Hot-Warm-Cold zone model represented as ovoids, first a line needs to be created for the centre of the hot zone, this is visible in figure 5.4, whereafter an ovoid can be created by means of this line. In this figure the centre, in this case the front door of the store which is robbed, is depicted with a green dot. This line was constructed by setting the starting point, the distance and the angle of the line. The decision on these settings automatically generates coordinates for the starting and ending point of the line, which is convenient when the line needs to be re-used or saved. In this case the distance of the line is 100 metres and its angle is 287 degrees, this is also visible on the line in figure 5.4. For this example the wind direction is coming from the east. Therefore, the line is longer on the western side of the centre of the hot zone since a toxic will spread more in this direction when it is coming from an eastern direction. With this line the ovoid shape for the hot zone can be formed accurately.

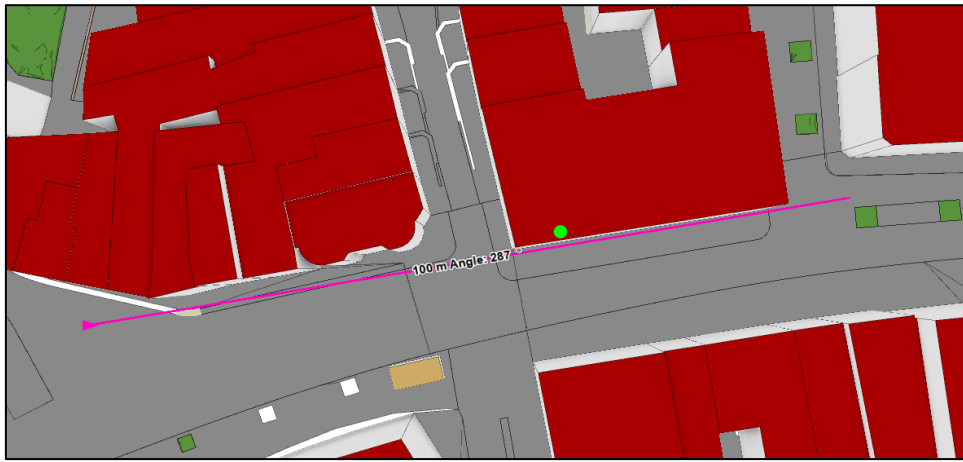


Figure 5.4: Line created as input for the ovoid shaped hot zone with the green dot representing the centre of this hot zone

It is possible to create a 3D buffer around the designed line. This 3D buffer is formed by choosing the distance, in this case 50 meters, and the joint type. The joint type stands for the shape of the buffer between the vertices of the line segments. The joint type can be either straight or round and for this buffer round has been chosen since the hot zone needs to resemble an ellipse shape. In figure 5.5 this is visible, around the earlier constructed line a hot zone has been formed. The colours of pink and blue have been chosen for visibility purposes. On the right image of figure 5.5 the hot zone is visible from the side showing that the buffer is at its highest in the middle and slowly decreases in height when coming to the sides of this buffer. Therefore, the buildings at the side of the buffer do not fall into the buffer with their full height, however they do belong to the hot zone. This is important to keep in mind.

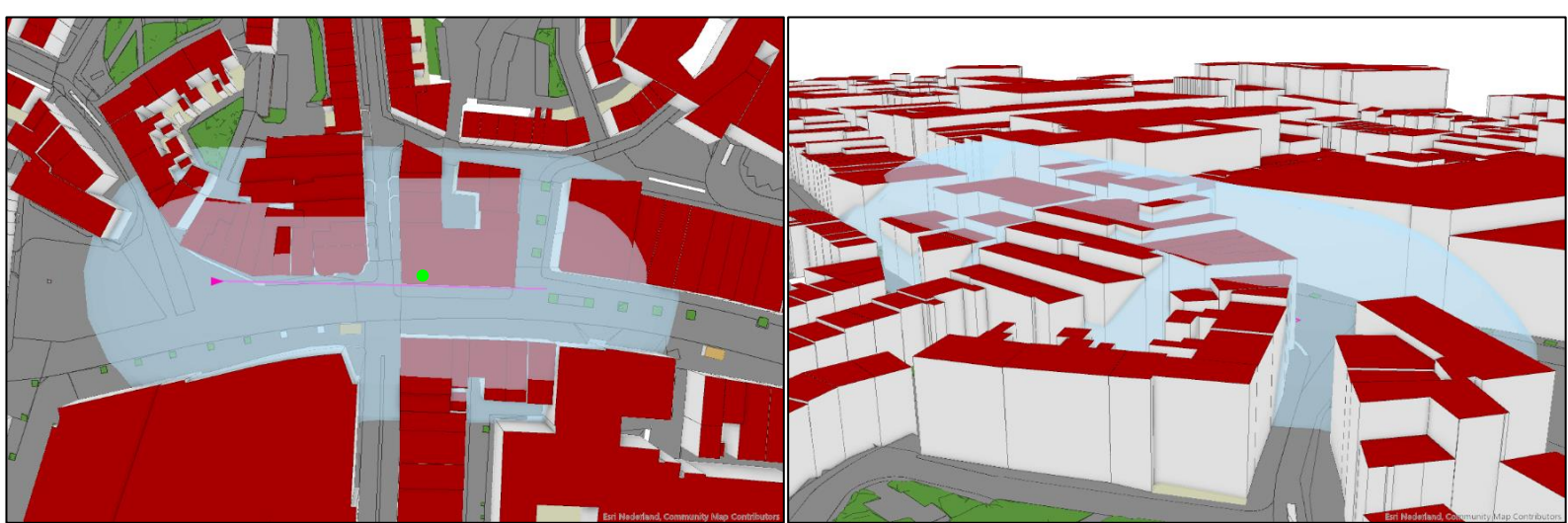


Figure 5.5: The hot zone created by a 3D buffer. Left – top view, right – side view

The warm zone can again be created via a 'regular' buffer or a 3D buffer. First of all, a 'regular' buffer is created around the hot zone, which is visible in figure 5.6 on the left. As visible in this figure, the outcome of the shape for the warm zone does not resemble an ellipsoid shape in any way. As it is buffering the 3D hot zone and the set distance, 100 meters, needs to be maintained along all sides, the warm zone gets a different shape (visible in figure 5.6 – left). For this reason, a 'regular' buffer will not be used and instead of buffering the hot zone, the line of the hot zone will be buffered. Thus, similar to the hot zone a 3D buffer will be used for this, but the 3D buffer for the warm zone differs in colour, distance and transparency. This is visible in figure 5.6 on the right, where the warm zone corresponds better with the hot zone.

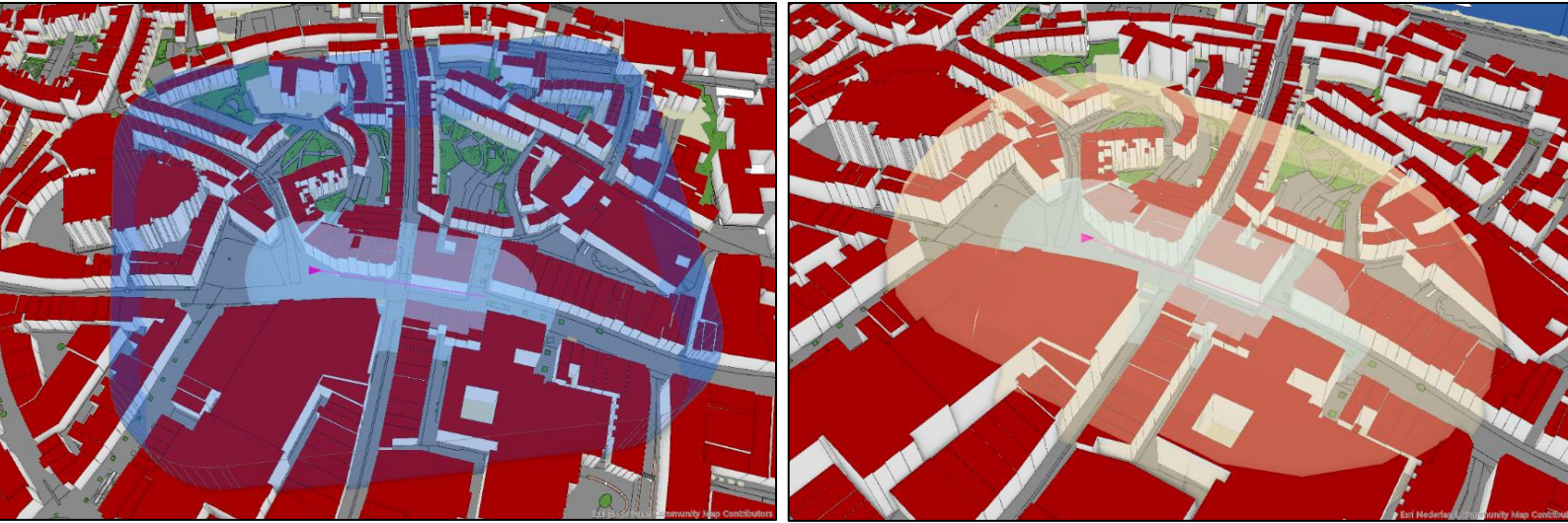


Figure 5.6: Left – Hot-Warm-Cold zone model created through buffering the hot zone, using a 'regular' buffer. Right – Hot-Warm-Cold zone model created through buffering the line inside of the hot zone, using a 3D buffer

A buffer is created by implementing the set distance, 100 metres, along the entire outlines of the desired feature. This means that the created buffer is not shaped along the directions of the wind. In figure 2.2 an illustration is shown of the Hot-Warm-Cold zone model, where all zones are represented as ellipses following the original shape of the hot zone. In order to create such a Hot-Warm-Cold zone model, all safety zones need to be created manually and without buffers. This leads to non-accurate safety zones, as the zones are not created through set distances and angles. Therefore, the use of buffers has its disadvantages but it is still the preferred method compared to other methods. Another aspect to keep in mind with the model shown in figure 5.6 on the right is that the warm zone is created through buffering the line of the hot zone. When setting a distance for the warm zone, the hot zone needs to be covered first and therefore a bigger distance needs to be filled in than the desired distance.

The only aspect missing, compared to the sphered Hot-Warm-Cold zone model, is the possibility of a visibility analysis. In paragraph 4.1.1 this is present through the means of a viewshed. As the hot zone is ovoid shaped in this scenario, this is not a possibility. However, it is possible to create a line of sight in this model, which also accounts for visibility from the centre of the hot zone. In figure 5.7 a line of sight has been created for the ovoid shaped Hot-Warm-Cold zone model. In this image it is visible that the line of sight has been placed inside the hot zone, where the observer point starts at the centre of the hot zone. The line changes in colour from green to pink when intersecting with a little building, indicating that for 23.27 meters (see figure 5.7) there is perfect visibility and after that there is no visibility anymore from the centre of the hot zone. This addition makes the ovoid shaped Hot-Warm-Cold zone model just as complete as the sphere shaped Hot-Warm-Cold zone model.

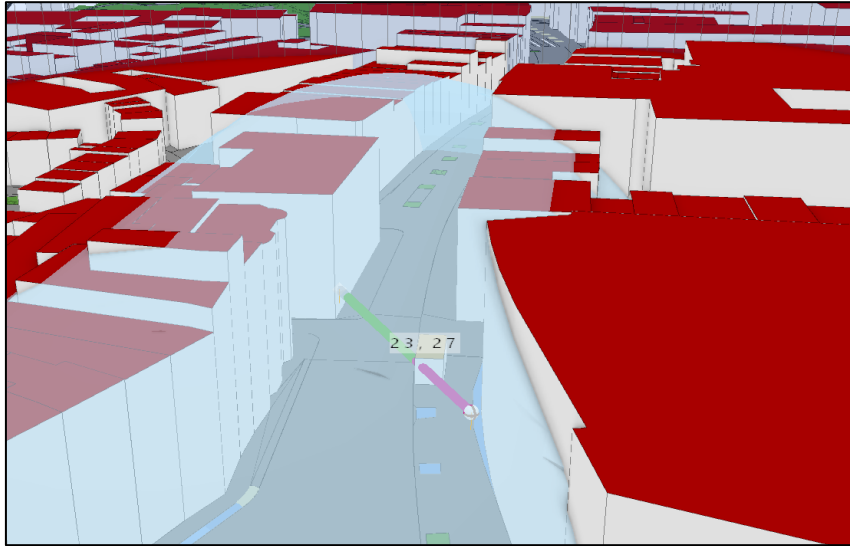


Figure 5.7: A line of sight added to the ovoid shaped Hot-Warm-Cold zone model, where a green line stands for perfect visibility and a pink line stands for no visibility from the observer point

For this ovoid 3D representation, as for the sphered 3D representation, a step-by-step guide has been created which is visible in appendix III. These 3D representations will ultimately need to be created by police employees, who will not necessarily possess GIS knowledge. Therefore, this could form challenges. The implementation process of this method into the organisation of the police needs to be as small as possible and an elaborate step-by-step guide will help in this process. This is mainly required for 'ad hoc' incidents, as people without a lot of GIS knowledge will be in charge of that. Although for 'high risk' incidents people with GIS knowledge are involved, there is also a step-by-step guide for these incidents involved, for convenience.

5.4 Addition of street view images for 'ad hoc' incidents

With the sphere and ovoid shaped 3D representation the basis for the 3D Hot-Warm-Cold zone model for 'ad hoc' incidents has been made. The different safety zones can be designed adequately and precisely in a 3D environment. Furthermore, it is also possible to perform a visibility analysis, either via a line of sight or via a viewshed. With these aspects combined, the employees at the operational centre can make a more straightforward decision on the outlines of the safety zones and immediately have a better general overview of the environment. However, as a 3D city model is used for this purpose, any details on the environment are missing. Hence, when more detail is required (street view) images can be used additionally.

As the main reason for including images is the lack of detail, in the 3D city model solely street view images are of added value. Aerial images will not be as detailed and/or give that much extra information, compared to the current use and availability of 2D data. When the 3D representation is created for an 'ad hoc' incident or during the creation process, it could be the case that more detailed information is needed prior to an important decision. In such a situation, a street view image of that location could be decisive. In figure 5.8 an example of such a street view image is shown and the depicted situation resembles the location shown in figure 5.7.



Figure 5.8: A street view image of the surroundings around the 'ad hoc' incident location, comparable with the view shown in figure 5.7 (Cyclomedia, 2020)

The desired addition of more detail is visible in figure 5.8, especially compared to the 3D city model in figure 5.7. An example of this is the present terraces on the left side of the image and the present trees on the right side of the image. The same street is shown in figure 5.7, but in this image only the buildings are shown and these details are lacking. Street view images, as shown in figure 5.8, are created with a special camera system mounted on cars. Therefore, these images can only show the surroundings as seen from a street level. However, in the images of the 3D city model sometimes a view from above or a sideways view can also be convenient or necessary. In that case, oblique images can also be used. Oblique images are aerial images, however they are created from a certain angle, usually 45 degrees, so that the terrain is obliquely viewed and the front and/or sides of a building are seen in addition to the top of the building.

In figure 5.9 an oblique image is shown of the same location as shown in figure 5.8, only from a different angle. As visible in this image, the front door (indicated with a green dot) of the 'ad hoc' location is visible as the angle is tilted. Thus, more information is provided compared to a normal aerial image. Details from the front or sides of the building can be seen and additionally information about the top/roofs of building can be extracted from such images. The only disadvantage of oblique images is that the angle of the image is fixed, thus the view cannot be altered contrary to the street view images and 3D city model. Combining these images with the street view images, provides the operational centre employees with a detailed overview of the incident location. Therefore, when using the proposed method for the basis and outlines of the Hot-Warm-Cold zone model in combination with street view and oblique images, a complete overview of the location is generated.

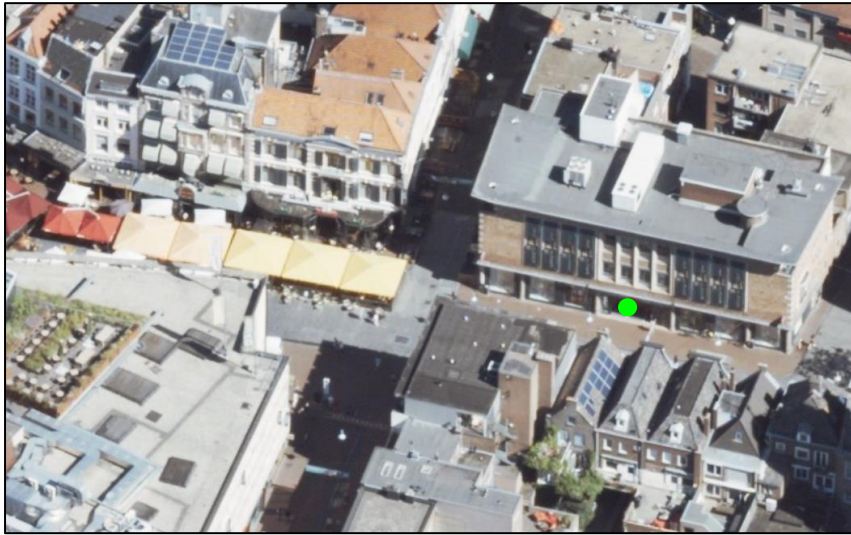


Figure 5.9: An oblique image of the 'ad hoc' incident location, with the green dot indicating the front door of the robbed store (Cyclomedia, 2020)

5.5 Sub-conclusion for 'ad hoc' incidents

As an example for an 'ad hoc' incident the location of the city centre of Nijmegen has been chosen and the corresponding incident was an armed robbery on a store. Ultimately 2 different 3D representations have been designed for scenarios regarding 'ad hoc' incidents, being: a sphered 3D representation and an ovoid 3D representation. An aspect which accounts for both 3D representations is the additional use of street view images and oblique images. The created 3D representations as a 3D city model is suitable for the basis and the creation of the outlines of the safety zones. However, when more details on the environment are wanted, especially regarding infrastructural objects, additional sources are required. For this purpose, street view images and oblique images can be used of the same location.

The sphere shaped 3D representation consists out of a viewshed as hot zone and this viewshed can also be used for a visibility analysis from the centre of the hot zone. Furthermore, the warm zone is represented by a 3D buffer and the cold zone is considered to be the further areas outside the warm zone. In figure 5.10 this final sphered 3D representation is shown as of how it will ultimately look like when created in the operational centre for an actual 'ad hoc' incident. In this figure the hot zone has a radius of 50 meters and the green parts represent visible areas from the centre of the hot zone (the front door of the robbed store) and the pink parts represent nonvisible areas.

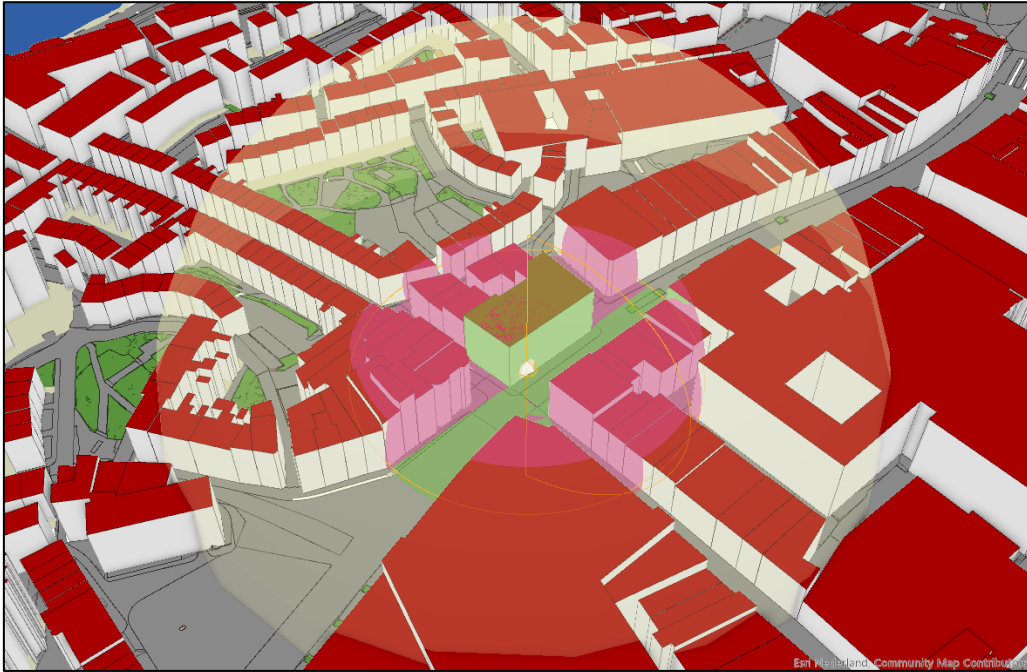


Figure 5.10: The final sphere shaped 3D representation for the Hot-Warm-Cold zone model concerning 'ad hoc' incidents

Besides the sphered 3D representation there is also another version which has been developed, namely the ovoid 3D representation. When using the Hot-Warm-Cold zone model for chemical incidents a sphered 3D representation will not be adequate, as it is important to also take the wind direction into account, which is not possible to depict in sphere shapes. Thus, depending on the type of 'ad hoc' incident a sphere or ovoid 3D representation suits best. Depending on the force and orientation of the wind, the safety zones will be shaped bigger in the opposite direction of the wind. This final ovoid 3D representation is shown in figure 5.11, for the same location of the robbed store.

Due to the ovoid shapes it is not possible to represent the hot zone as a viewshed, therefore the hot zone is depicted as a 3D buffer. Similar to the hot zone, the warm zone is also depicted as a 3D buffer, only the distance, colour and transparency differs. To still also be able to perform a visibility analysis with this representation a line of sight has been added with the observer point as the centre of the hot zone. The line of sight intersects on the border of the hot and warm zone at 92.97 metres, where green indicates that it is situated in the hot zone and pink indicates that it is situated outside of this hot zone. This line of sight can be changed to any desired position and the colours can also be changed to indicate visibility.



Figure 5.11: The final ovoid 3D representation for the Hot-Warm-Cold zone model concerning chemical 'ad hoc' incidents

6. RESULTS FOR ‘HIGH RISK’ INCIDENTS

In this chapter the outcomes of the analysis, chapter 4, will be incorporated into the actual Hot-Warm-Cold zone model for the ‘high risk’ location. A ‘high risk’ location is already known by the Dutch National Police. It has been marked as a potential risk for a specific incident, depending on the location. Therefore, an in-depth analysis can be created prior to an incident which leads to a more detailed and extensive Hot-Warm-Cold zone model.

For ‘high risk’ incidents the outlines of the hot, warm and cold zones first need to be created in the BAG dataset, which will be explained in paragraph 6.1. Thereafter, the point cloud data can be used to look into the environment in more detail and to create an in depth analysis, this will be discussed in paragraph 6.2. In the last paragraph all results of this chapter are given in a sub-conclusion.

6.1 Creating the outlines of safety zones for ‘high risk’ incidents

For the outlines of the safety zones the BAG dataset is required. Initially, the outlines of the safety zones, especially the hot zone, will be decided on in this dataset after which an in-depth analysis can be performed by using the point cloud dataset. Similar to incidents at ‘ad hoc’ locations, the hot, warm and cold zones can be created in different shapes, being circles and ovals. The circled safety zones can be created either by singular buffers or via the multiple ring buffer tool, as explained in paragraph 4.2.1. After setting the desired distance for the buffers and changing the transparency level, so that underlying areas are visible, the outlines of the Hot-Warm-Cold zone model as circles are established.

For the further process of visibility analysis through point clouds only the hot zone is required, as the centre of the hot zone is taken as viewpoint for a more in-depth view of the surroundings and the additional visibility analysis. However, when required it is also possible to perform a more in-depth analysis on the warm or cold zone. In figure 6.1 a created hot zone in the BAG dataset is visualised. This hot zone was created as a singular buffer instead of the multiple ring buffer tool, as buffers cannot be depicted individually with this tool. The blue pinpoint inside the hot zone indicates the location of the ATM, which will be the viewpoint in the pursued analysis.



Figure 6.1: A circled hot zone for a 'high risk' incident, blue of colour for visibility purposes, 50 meters radius

For the oval shaped hot, warm and cold zones, the same method will be used as explained in paragraph 4.1.2 for 'ad hoc' incidents, only in this case 2D data will be used. First, a line will be created by deciding on its starting point, ending point, distance and angle. Thereafter a buffer is created around this line, which represents the 'ellipse' shape. Lastly, around this buffer which represents the hot zone, yet a nother buffer is created for the warm zone. In figure 6.2 all these aspects are visible, forming an oval shaped Hot-Warm-Cold zone model. Although it is not as ellipse shaped as the model in figure 2.2, it still suits its purpose of depicting the wind direction. The centre of the hot zone is represented by a blue pinpoint and it is visible in figure 6.2 that this pinpoint is not located in the middle of the hot zone. The hot zone is far more extended in a south-western direction, indicating that the wind in this case is coming from a north-eastern direction. The warm zone looks even less like an ellipse, but since the hot zone is more extended in a certain direction, the warm zone automatically is also located further away from the centre in some areas (in t his case areas in the south-western direction).



Figure 6.2: An oval shaped Hot-Warm-Cold zone model, most suitable for depicting wind directions

6.2 A comprehensive representation of the safety zones through point clouds

When the outlines of the safety zones are coherent in the BAG dataset, point clouds can be used for an in-depth view of the surroundings of the accident. In this case this scenery is the city centre of Nijmegen, more specifically the market square of Nijmegen, where an explosive attack on an ATM represents the 'high risk' incident.

6.2.1 The camera setup for the point cloud visibility analysis

The point cloud visibility method which will be used to achieve a complete picture of the scenery is Hidden Points Removal (HPR), which has been explained in paragraph 4.2.2. HPR ensures to discover points which are visible from a certain viewpoint, in this case all points visible from the ATM. This certain viewpoint is decided on through setting up a camera in the point cloud. In figure 4.10, in paragraph 4.2.2, the first set up camera is shown together with its camera settings in table 3. This camera is directed towards the market square on the right side of the ATM. Such a camera is set up by deciding on the desired position and orientation of the camera, which encompasses the view angle and the X, Y and Z coordinates. A complete visibility analysis can only be performed when the entire market square as seen from the ATM is included in the camera viewpoint, thus a 180 degrees view is required. For this, several other cameras have been set up. In figure 6.3 all set up cameras are shown, which are 4 in total, from a bird eye's perspective.

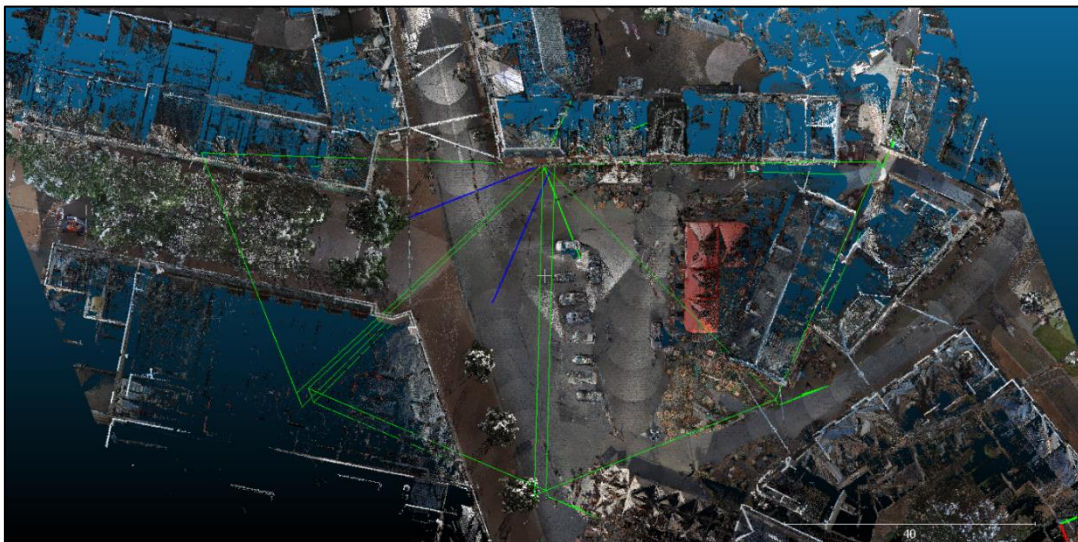


Figure 6.3: 4 cameras showing the entire area which will be captured from the centre of the hot zone, thus from the ATM

It is a 180 degrees view from the set up viewpoint, being the ATM. In this figure the cameras show the entire area visible from the centre of the hot zone. However, the viewport from these cameras show a distorted view of the market place, as these cameras provide a widescreen view instead of a normal view of the market place. Thus, the cameras in figure 6.3 are there to illustrate the areas which are captured from the centre of the hot zone. The actual cameras which are used for the further HPR analysis are shown in figure 6.4 and provide an undistorted, 'normal' view of the market of Nijmegen. For these cameras the vectors are normalised, indicating that they have a norm equal to 1 which ensures an undistorted view.



Figure 6.4: The 4 definite cameras used in the HPR analysis, providing an undistorted view of 180 degrees around the ATM

Several cameras with the same position and orientation coordinates as pictured in table 3 have been created. This matrix with coordinates has been changed to different coordinates, via a so-called transformation matrix. The size of the camera, the vertical field of view, and the coordinates of the viewpoint had no need to change, the only aspect which is different for all 4 cameras is the rotation angle. For each camera the rotation angle was increased with 45 degrees. After performing this rotation the initial viewpoint also changed, therefore this viewpoint needed to be set to the original viewpoint again whereafter the 'new' camera was set in the right position. In table 4 the differences between all 4 matrixes of the cameras are shown, with camera 1 standing for the original camera thus the camera on the left in figure 6.4. The essence of the settings of table 4 is the same compared to table 3, however it is pictured differently as a transformation matrix had to be applied onto the settings and these changes are shown more clearly in the arrangement of table 4.

Camera 1	Camera 2
0.000000 1.000000 0.000000 -45.984001	0.000000 0.707107 -0.707107 -45.984001
0.000000 0.000000 1.000000 -18.527000	0.000000 0.707107 0.707107 -18.527000
1.000000 0.000000 0.000000 47.273487	1.000000 0.000000 0.000000 47.273487
0.000000 0.000000 0.000000 1.000000	0.000000 0.000000 0.000000 1.000000
Camera 3	Camera 4
0.000000 -0.000000 -1.000000 -45.984001	0.000000 -0.707107 -0.707107 -45.984001
0.000000 1.000000 -0.000000 -18.527000	0.000000 0.707107 -0.707107 -18.527000
1.000000 0.000000 0.000000 47.273487	1.000000 0.000000 0.000000 47.273487
0.000000 0.000000 0.000000 1.000000	0.000000 0.000000 0.000000 1.000000

Table 4: Matrix input for all 4 cameras

6.2.2 Setting the right octree level for HPR

With the cameras set up correctly, the operation of HPR can be performed for each camera individually. For the HPR operation to work properly, the octree level needs to be set. The greater the octree level, the finer the result will be. However, the disadvantage of a higher detail level is a longer processing time. Additionally, with a higher octree level details of the environment which should be preserved in the model, can be left out, as a higher octree level automatically results in a lower number of total points. To find out which octree level suits best for the point clouds of the city centre of Nijmegen, several octree levels have been set. From the viewpoint of camera 4 HPR has been performed with an octree level of 7 and 9. After testing HPR with octree level 9 it already became clear that an even higher octree level will only leave more gaps and therefore decrease the accuracy of the image. Furthermore, when trying to apply a higher octree level, for instance an octree level of 12, the entire software package of CloudCompare crashed, indicating that it was too much to handle for the computer.

In figure 6.5 the results of HPR with the 2 different octree levels is shown. In figure 6.5A the original point cloud is shown, as seen from the viewport of camera 3, in B HPR with an octree level of 7 has been applied and in C HPR with an octree level of 9 has been applied. A striking aspect is the image where HPR with an octree level of 9 has been applied. This image appears with gaps at many places throughout the entire image. A higher octree level causes a finer result, however the result can also be too fine. As the number of points decreases with an increase of an octree level, the octree level of 9 proves to be too high as the image in figure 6.5C does not appear complete anymore. This leaves the octree level of 7 to be appropriate for this point cloud, figure 6.5B. This image is clearer than 6.5A, where no adjustments were made.

The image shown contains several different cars in the middle of the image, different buildings with some parasols on the left and on the right of the image a part of the building of the HEMA is shown with some trees in front of it. This causes a rather full image with many different details. However, in figure 6.5B the different buildings in the back have become more detailed and clearer and the cars in the middle of the image stand out more, as they are located in front of the buildings. An example of this is the most-left car, which is now clearly located in front of the building in 6.5B, while in 6.5A this car is blended together with the points of the building and parasols located behind the car. The cars in the middle of the image still might seem a bit unclear, but figure 6.5C proves that the octree level of 7 is the right level, as the cars in 6.5C are even more unclear, with some parasols appearing through the cars. In this case too many points are taken out with HPR and the visible features from this perspective do not match the real-life situation anymore, contrary to 6.5B which does resemble the real-life situation.

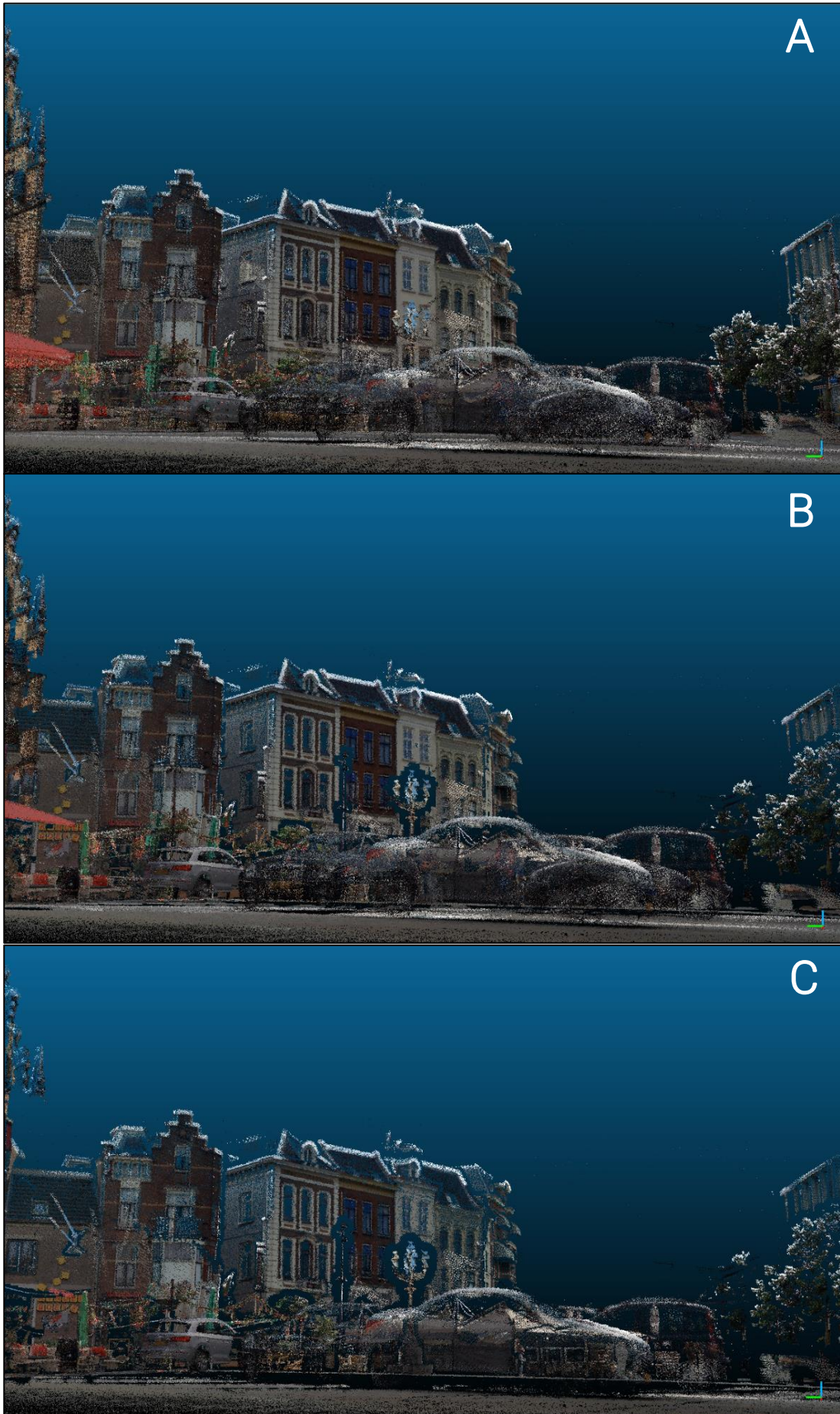


Figure 6.5: The view from the viewport of camera 3 with A - original point cloud, B - HPR with octree level 7, C - HPR with octree level 9

6.2.3 Points visibility

The entire point cloud of the city centre of Nijmegen is divided into squared tiles. Camera sensor 3 is located on 4 different square tiles. Combining these 4 square tiles the original point cloud has a total of $10,681,084 + 13,364,117 + 6,876,268 + 11,756,814 = 42,678,283$ points. After performing the HPR operation for camera 3 with an octree level of 7 this total number of points has changed to $5,527,572 + 3,179,310 + 1,958,022 + 2,459,192 = 13,124,096$ points, which is a significant number of change in points. In figure 6.6 the points visibility is illustrated for camera 3 where the red points represent visible points and the blue points represent non visible points from the viewport. The 13,124,096 points comprise the red and blue points, thus the number of points visible from the viewport of camera 3 (solely the red points) is significantly smaller. The original point cloud, containing all points, is still visible in the background. This image shows that even though it might not be obvious in figure 6.5, there is still a big difference between the original point cloud and the point cloud with HPR applied onto it; only the required and essential points are restored. This loss of points makes further analysis easier regarding processing and rendering times.

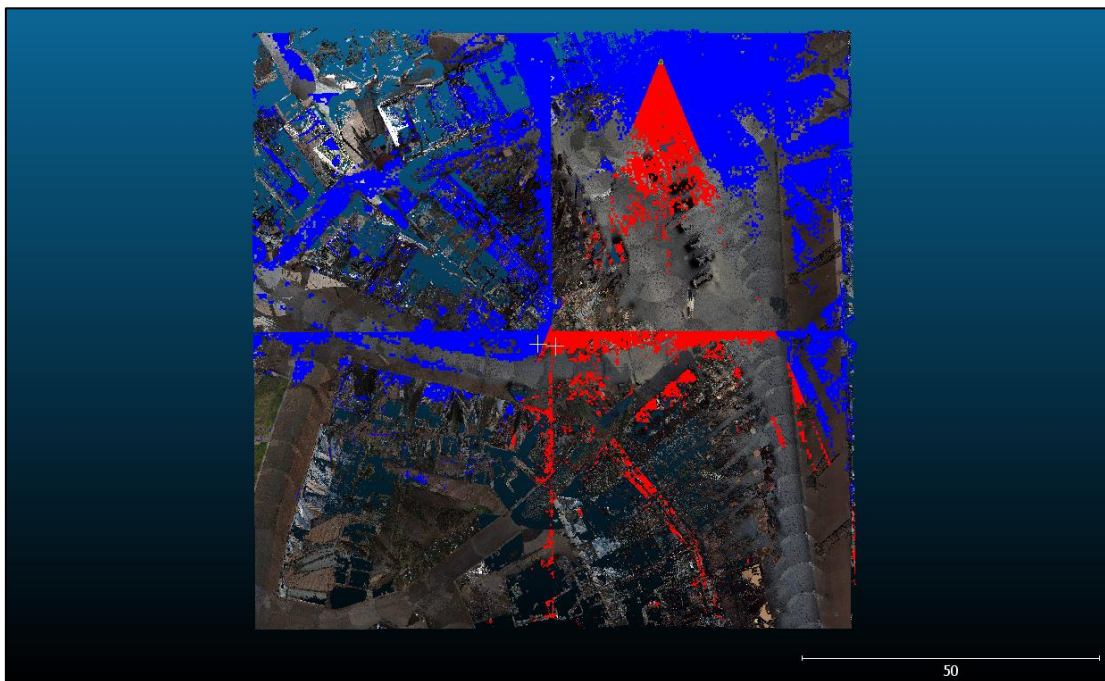


Figure 6.6: The points visibility for camera 3 with HPR applied onto it with an octree level of 7, where red stands for visible points and blue for non-visible points

Thereafter, based on figure 6.5 it has been decided that the octree level of 7 is the appropriate octree level for this case, as a higher octree level comes with too many gaps in the point cloud which makes the image of the scenery not complete anymore. Therefore, HPR with an octree level of 7 has been performed for all 4 cameras. The outcomes of these operations are visible in appendix I. Additionally, in this appendix an image of the original point cloud has been added for all camera sensors, so that the influence of HPR can be notified by comparing the 2 images. The HPR images for all 4 cameras shown in appendix I indicate that a 180 degrees view from the centre of the hot zone is now at hand.

Another aspect which has been added in appendix I for all 4 cameras is an image with HPR applied onto it (octree level 7), however the size of the points has been adjusted here. For some cases, increasing the size of the points in a point cloud, visibility can be improved. In figure 6.7 an image is shown of a point cloud with HPR applied onto it, with an increased point size for camera 3. This is the same perspective and image as shown in

figure 6.6B, however it seems a lot clearer and different objects are easier to distinguish. Therefore, depending on the perspective and point cloud, it is always optional to adjust the size of the points.



Figure 6.7: The perspective from camera 3 with HPR, octree level 7, applied onto it and an increased size in points, which improves the visibility

6.2.4 Comparing the point cloud images to street view images

To be able to say that the created point cloud images are detailed and suitable enough for usage of the Hot-Warm-Cold zone model they have been compared with street view images. These street view images have also been obtained via Cyclomedia and they were made by the same car on which the lidar scanner was also positioned, hence the images were created on the same day. In appendix II a panoramic view has been created for all point cloud images, whereafter a comparison can be performed with the street view images, which are also shown in appendix II.

This panoramic view makes it possible to have a complete overview of the entire market square and instantly compare every image with each other. In figure 6.8 one of these images from appendix II is highlighted, together with its corresponding street view image. The visible perspective is viewed from camera 2. It should be noted however, that the viewpoint from the street view camera is not the same as the view point from the point cloud image. The point cloud image is seen from the ATM, at eyesight, while the street view image is seen approximately 10 metres in front of the ATM and higher positioned than eyesight level. Therefore, these images cannot be identical and some distortions may exist.



Figure 6.8: A comparison of the view from camera 2, with at the top the point cloud image after HPR and at the bottom a street view image (Cyclomedia, 2020)

6.2.5 The advantages of using point clouds

A visible aspect is the similarity between both images. All distinguishing objects are clearly visible in the point cloud, notice the building of the Hema with all details in the windows, the trees, the graffiti on the building etc. The main prerequisite for the point cloud is its usability and recognisability, so that the surroundings of the incident are evident for the police prior or at the moment of an incident. This also indicates that the point cloud needs to represent the real-life environment, as it cannot be afforded to display false or incorrect information at the time of an incident. Comparing the images of figure 6.8 it can be said that this is the case and that the environment shown through point clouds is similar to the real-life situation. Furthermore, the advantage of point clouds is that any environment can be shown from any point of view, contrary to the street view image of figure 6.8. This ensures more applicable and detailed 3D representations.

With point clouds the main benefit is the visibility aspect: 'you see, what you see'. This means that there is perfect visibility, when the point cloud is up to date the view of the point cloud is almost the same as the real-life view. This creates the possibility to perform visibility analyses without any geometries, e.g. the line of sight analysis or viewshed analysis discussed in paragraph 4.1. Due to this perfect visibility, limitations are also overcome regarding transformations of point clouds. Since the raw data is fully usable, it is possible to avoid a lot of processing and the need for extended surface models. This does not only increase the usability of point clouds, but it does also cause shorter analysis periods, while the detailed information of point clouds still stays available.

6.3 Sub-conclusion for 'high risk' incidents

For a 'high risk' incident the same location of the city centre of Nijmegen has been chosen, with the corresponding incident being an explosive attack on an ATM. The creation of a 3D representation for this incident exists out of 2 steps: first the creation of the Hot-Warm-Cold zone model in a 2D dataset, which will either be a circled or an oval Hot-Warm-Cold zone model, and secondly the in-depth visualisation of the hot zone by means of point cloud data. The creation of the outlines of the safety zones in 2D are created through buffering operations, either for a circled or oval shaped model. Thereafter, the hot zone is visualised more detailed through Hidden Point Removal (HPR) operations in a point cloud.

The 2D hot zone is taken as the starting point for the in-depth analysis. Thereafter, the cameras placed in the point cloud comprise a 180 degrees view, seen from the centre of the hot zone, and these cameras cover an area up to the outlines of the hot zone. In this way all areas visible from the centre of the hot zone are included, whereafter HPR operations are performed on each camera for the point cloud visibility analysis. In figure 6.9 as an example of the final view, one camera perspective from the hot zone is shown after HPR was performed for this image. This image establishes the high level of detail and accuracy which is present in point clouds, especially compared to the 3D city model of the 'ad hoc' incidents. The building, the vegetation in front of the building, the cars on the left: everything is clearly visible, which is required for the analysis of the incident location by the Dutch National Police. After the HPR operations, a detailed view is created of the entire surroundings and combining the outlines of the safety zones in 2D together with the point cloud images, a detailed 3D representation is constructed for 'high risk' incidents. In appendix II this entire view is shown as a panoramic view created out of all 4 camera perspectives.

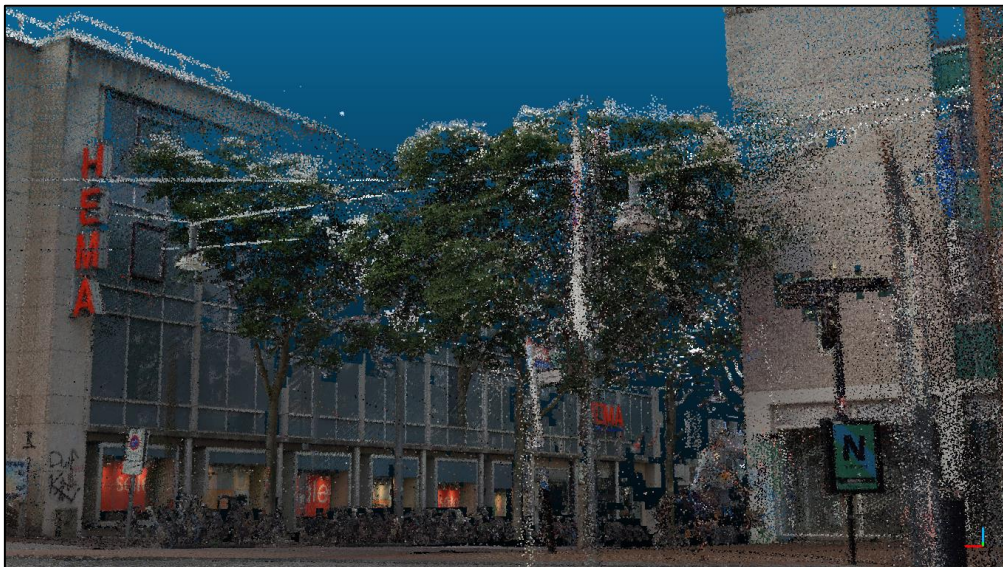


Figure 6.9: One perspective of the final 3D representation for 'high risk' incidents (Cyclomedia, 2020)

Hidden Points Removal has been chosen as a method opposed to using 'raw' point clouds or even simpler, street view images. Essentially, the entire surroundings of an incident can be viewed in detail, without any objects or points blocking the view. The created HPR point cloud images will be used as static images by operational centre employees at the moment of an active incident. This means that points will show through the foreground when 'raw' point clouds are used, diverting the attention from the environment which needs to be seen and shown. Furthermore, with a point cloud it is possible to take any desired position and view the environment 360 degrees. With a normal or street view image this is not possible, the positions are fixed to the places where the images were taken. Therefore, when combining these aspects the most detailed and complete overview of the environment is visualised through a HPR operated point cloud.

7. CONCLUSION

In this chapter the earlier stated research questions will be answered. In paragraph 7.1 the research sub questions will be answered, whereafter in paragraph 7.2 an overview of the most important results is given, immediately answering the main research question, which is:

To what extent will the use of a 3D representation in the case of 'Hot, warm and cold zones' be conducive for the Dutch National Police?

7.1 Answering the research sub questions

The research sub questions will all be discussed individually and in numerical order over the next paragraphs. The research sub questions are:

1. How are the hot, warm and cold zones defined?
2. How does the Dutch National Police currently establish the hot, warm and cold zones?
3. What are the different existing 3D datatypes and models?
4. What are the differences in analysing a 'high risk' location compared to an 'ad hoc' location?
5. Which 3D models and corresponding software packages are most suitable for the case of 'Hot, warm and cold zones' and why?
6. How can the hot, warm and cold zones be established and visualised in 3D?
7. What is the added value of 3D in the case of 'Hot, warm and cold zones' for the Dutch National Police and how can this be measured?

7.1.1 The Hot-Warm-Cold zone model defined

The Hot-Warm-Cold zone model is a safety model used for certain calamities where a safety risk for the surrounding environment exists. This model is familiar and used by all emergency services in multiple different countries. The Hot-Warm-Cold zone model fundamentally consists of 3 parts. The first part is the hot zone, this is a zone with a credible and ongoing threat to life. The second part is situated around the hot zone, being the warm zone which is a zone with a still identified threat, but the danger is not present here. The last part consists of the cold zone and this zone is situated around the warm zone. In this zone only a little risk factor exists, so this zone can be called relatively safe for emergency workers and civilians.

These 3 different safety zones create the possibility to clearly identify the risk and its location during an incident in the public living environment. Such an incident can happen suddenly and in that case choices need to be made quickly, accurately and in efficient collaboration with all emergency services. The Hot-Warm-Cold zone model is a great help during this decision process and it is therefore used for a range of different serious incidents, e.g. chemical incidents, extreme violence incidents or incidents with explosives.

7.1.2 The Hot-Warm-Cold zone model specified for the Dutch National Police

Although the Hot-Warm-Cold zone model is used by all emergency services, the police are the only emergency service which lead the analysis of the threat and the subsequent declaration of the 3 safety zones. The model itself is only used for certain incidents, being in the field of explosive incidents, extreme violence or chemical related incidents. The Dutch National Police possess their own procedures to ensure an accurate declaration of the hot, warm and cold zone. In the hot zone, only police officers with personal protection are allowed. The warm zone is considered to be the most important zone for the Dutch police, as the dynamics of the incident still causes this zone to have a high-risk factor, which causes the police employees to protect any emergency service workers here. Lastly, in the cold zone all 'regular' processes take place, e.g. setting up the command place incident and regulating supply and discharge routes.

A timeline from the registration of an incident to the decision of the safety zones is as follows: Initially when an incident is reported it will be received in the operational centre and the initial management of the incident will be executed by the calamity coordinator. This person is in control for the first hour of the incident and when the exact nature of the incident has become clear, an upscaling is required. This upscaling to a control model at the location of the incident will then be managed by the duty officer (OvD = *Officier van Dienst*) of that moment. The outlines of the safety zones are ultimately decided on by the duty officer, possibly in combination with other officers. The management of the safety zones is then divided over 2 OvD-P's: OvD-P 1 is directly responsible for the hot and warm zone and the OvD-P 2 is responsible for the management of the cold zone.

7.1.3 The different 3D datatypes and 3D models

Different 3D datatypes and 3D models have been discussed, to decide on the most suitable 3D model for the 3D representations depicting the Hot-Warm-Cold zone model. 3 different 3D datatypes were described, namely voxels, tetrahedronised irregular networks (TENS) and point clouds:

- Voxels are 3D volume elements, they are the so-called counterpart of pixels. Functional 3D architecture can be built with voxels, as they are represented as cubes in 3D space.
- TENS can be seen as the 3D version of triangular irregular networks (TINs), which are a form of vector-based representations of geographical data and constructed by triangulating a set of points. These TINs reappear when discussing the mesh models. TENS are made up of 3D complexes, thus tetrahedrons, so that volumetric shapes can be represented and 3D surfaces can be reconstructed.
- A point cloud consists of recorded datapoints defined by a X, Y and Z coordinate which is linked to a 3D coordinate system. These points can be obtained via either aerial images or laser scanning and they can also be used to reconstruct an environment in much detail.

For the 3D data models also 3 different types were discussed: mesh models, city models and smart point cloud models:

- Mesh models are 3D representations of surface subdivisions through using sets of polygons. These sets of polygons are nearly always triangles which subsequently indicates that the most prevalent mesh model is a triangular mesh model. An example of such a form of mesh model is the TIN which can represent 3D surfaces through irregularly distributed lines and nodes containing 3D coordinates. A

mesh model can be created through combining an aerial image with point cloud data, whereby every triangle is built up of 3 points of the point cloud.

- A city model is a digital representation of an urban environment where the focus lays on buildings. They are based on 2D datasets and with remote sensing technologies, such as aerial and lidar photogrammetry, the height of buildings can be measured automatically, which is the input for a volumetric representation of buildings. Compared to 2D maps, this volumetric data makes it easier to carry out visibility analyses, e.g. deciding on the visibility of a surrounding region from a certain observation point.
- Smart point cloud models are based on several millions of points. This high level of points ensures a high level of detail, compared to other 3D models, for instance vegetation is included in smart point cloud models, whereas this is neglected in TINs or city models. This facilitates a visibility analysis, as all aspects of the environment are depicted, and also a (subsequent) decision making process. Point cloud visualisation guarantees a dense and close-to-reality representation of the environment.

7.1.4 The differences between ‘ad hoc’ incidents and ‘high risk’ incidents

The main difference between both incidents is the amount of available preparation time. The location of an ‘ad hoc’ incident is only known at the time of an active incident, whereas the location of a ‘high risk’ location is already well-known to the Dutch National Police. For a ‘high risk’ incident it is known that something can very well happen here, the only question is when. Therefore, there is a lot of preparation time to create and analyse a 3D representation for this location, while a 3D representation for an ‘ad hoc’ incident needs to be analysed quickly, as there is little time.

This directly also affects the achievable quality of the 3D representation for both incidents. ‘High risk’ locations are known upfront and can therefore also be measured and analysed upfront, while ‘ad hoc’ locations need to be analysed with the available resources at that moment. Hence, different 3D models and methods for the creation of the 3D representations have been chosen to use for both incidents. For ‘high risk’ locations all important details can be discovered upfront as the analysis has taken place prior to the incident. This leads to a more detailed 3D representation for the ‘high risk’ location compared to the ‘ad hoc’ location. This does not indicate that the 3D representation for the ‘ad hoc’ location is less accurate, it is less detailed, but nonetheless still very accurate and more detailed than the current 2D representation of the Hot-Warm-Cold zone model.

7.1.5 The most suitable 3D model and software package for the Hot-Warm-Cold zone model

In the end 2 different 3D models seem to be the most suitable for the Hot-Warm-Cold zone model, when making a distinction between the ‘ad hoc’ incidents and the ‘high risk’ incidents. As a ‘high risk’ incident happens at a location already known by the police, a detailed 3D representation can be created for these incidents. Therefore, a smart point cloud model is the best option, since this model provides an exact representation of the real location. Time is not an issue for ‘high risk’ incidents, hence it is not a problem to work with smart point cloud models which come with big masses of data, possibly creating difficulties during the analysis.

‘Ad hoc’ incidents require a ‘simpler’ 3D representation, as time is limited. Therefore, a 3D city model has been chosen since this model provides volumetric data without a time-consuming analysis. The 3D representations for ‘ad hoc’ incidents have been designed in such a manner that they can be created in under ± 10 minutes,

provided that the police employees are familiar with the method. As the calamity officer of the operational centre is in charge for the first hour of the incident, there should be enough time to collect all required data and subsequently create the 3D Hot-Warm-Cold zone model. The 3D city model which has been used is provided by the '3D Basisbestand' dataset. This dataset consists out of 3D buildings, which are created as closed and sealed surfaces, together with infrastructural objects, mainly represented in 2D. With this model the surroundings of the entire location can be understood relatively quick and easy.

For each different 3D model, a different software package has been chosen to use. Both software packages have been considered for 'high risk' as well as 'ad hoc' incidents and the final decision on software packages was made due to the competency of each software package with the datasets used. For the 'high risk' incidents, smart point cloud models are used and therefore CloudCompare is the most suitable software package. This software is specifically designed for point clouds and intended to deal with large point clouds on a relatively standard computer. Besides this, many point cloud processing algorithms are available within CloudCompare which create the possibility to work extensively with the point cloud. For the 'ad hoc' incidents the software package of ArcGIS Pro has been chosen to use. This is a GIS application with the possibility to display and work with 2D data as well as 3D data. ArcGIS Pro is an accessible software and relatively easy to use with many tools and display possibilities. This good usability is an important aspect, as this software will need to be used to create 3D representations with a time limit and by people without a lot of GIS experience.

7.1.6 The establishment and visualisation of the hot, warm and cold zones in 3D

As is explained in paragraph 7.1.4, a divide has been made between 2 different incidents, also leading to 2 different 3D representations. For both incidents the hot, warm and cold zones are established in ArcGIS Pro through the use of buffering operations. For 'ad hoc' incidents concerning chemicals the hot zone is created via a 3D buffered line, which leads to an ovoid hot zone. Thereafter, the warm zone is created via a 3D buffer, whereafter the cold zone immediately comes into being as the remaining area. For other types of 'ad hoc' incidents the hot zone is created with a viewshed and the warm and cold zone are created similarly as the chemical 'ad hoc' incidents. For the 'high risk' incidents the hot, warm and cold zones are established in the 2D BGT dataset through the creation of 3 separate buffers. For both incidents, the decision on the establishment of the safety zones will be made by employees at the operational centre in cooperation with on-site police officers.

The 'ad hoc' 3D representations are visualised in ArcGIS Pro. The big advantage of using 3D data is that the created safety zones can be viewed and visualised from any desired perspective. Additionally, a visibility analysis is performed either through a viewshed or a line of sight, depending on the type of incident. These 2 tools affirm the added value of 3D, as the hot, warm and cold zones can be visualised from a different point of view. For the 'high risk' incidents the outlines are created in 2D, however additionally point clouds are used for a more in-depth view of the environment. With these point clouds a visibility analysis is performed through the use of Hidden Points Removal. By means of this algorithm the direct environment of an incident can be visualised from any wanted perspective, for instance a complete 180 or 360 degrees (street) view can be created.

7.1.7 The added value of 3D for the Dutch National Police

In the end, for the Dutch National Police the 3D representations need to be worked with in an appropriate and suitable way. Therefore, the use of 3D for the Hot-Warm-Cold zone model needs to be efficient, effective and satisfactory up to a certain level. Although the 3D representations have not been used for real incidents yet, it can be said to be effective. Compared to the current usage of 2D data, the use of 3D provides more insight concerning the environment of the incident. Furthermore, decisions on the outlines of the safety zones by employees of the operational centre are facilitated with the use of 3D, as more information is available and as this information is presented in 3D a rather straightforward visualisation process can be performed. This subsequently ensures a safer environment for the on-site officers and civilians present at the location of the incident.

At this moment, the efficiency of the 3D representations is the critical factor for the Dutch National Police. The 3D representations in itself can be said to be efficient since one clear format has been created and this format can be applied onto all different kinds of incidents. However, implementing these representations in the 3D environment forms an organisational and/or operational challenge. The creation of these 3D representations is a step in the right direction, but for a high level of efficiency internal changes in the organisational and ICT field at the Dutch National Police are required. Lastly, it is difficult to state the level of satisfaction, as the 3D representations have not been used for existent incidents yet. However, from the input given by various police employees the designed 3D representations appear to connect well with the current procedures of the Dutch National Police. Considering minor changes in the proposed methodology and bigger changes in the organisation of the police, it can be said that 3D is of added value for the Dutch National Police.

7.2 Answering the main research question

In this paragraph the main research question, as stated in the introduction of this chapter, will be answered. This main research question regards:

To what extent will the use of a 3D representation in the case of 'Hot, warm and cold zones' be conducive for the Dutch National Police?

Currently the Dutch National Police uses 2D data for the Hot-Warm-Cold zone model. In this research a 3D representation has been created for the Hot-Warm-Cold zone model, making a divide between 'high risk' incidents and 'ad hoc' incidents. Using these 3D representations instead of the 2D data, more information is now available about the location of an incident. Employees of the operational centre have the ability to create or obtain a complete 3D view of the surroundings around an incident, opposed to relying on 2D data and information gained from officers at location. As a calamity coordinator of the operational centre is in charge for the first hour of an incident, the outlines of the safety zones can be decided on with more complete and detailed background knowledge. This especially accounts for 'high risk' incidents, as these locations have had a prior in-depth analysis which can easily be obtained and used at the operational centre, when required.

In figure 7.1 comparisons of the 3D representations of 'ad hoc' incidents as well as 'high risk' incidents with 2D representations are given. This figure implicitly shows the added value of 3D. In figure 7.1A and 7.1B, the difference between 2D and 3D for 'ad hoc' incidents is visible. More information on the environment is present in 7.1B (e.g. height and size of buildings, differences in elevation) and furthermore besides the outlines of the safety zones, this 3D representation also includes a viewshed for a visibility analysis. This final 'ad hoc' 3D

representation can be viewed from any desired angle, opposed to 7.1A, which is beneficial for establishing a complete overview of the incident location.

Furthermore, in figure 7.1C and 7.1D, the difference between 2D and 3D for 'high risk' incidents is visible. The angle of these images does not correspond, as 2D data can only be viewed from above, but the same location is shown. From figure 7.1C the only information which can be gathered is the location, size and amount of buildings, whether vegetation is present and the pattern of the streets. Comparing this to 7.1D, a completely different view is given with details on every aspect of the environment. It is evident that a decision on the outlines of the Hot-Warm-Cold zone model will have a different outcome, depending on the choice of data; whether this is 2D data (7.1C) or 3D data (7.1D). Besides the inclusion of more detail in figure 7.1D, with 3D data it is also possible to view the incident location from any desired angle, which again creates the possibility for the police to acquire a more complete view of the environment.



Figure 7.1: A comparison between 2D data and 3D data. A – Example of the Hot-Warm-Cold zone model with 2D data. B – Example of the Hot-Warm-Cold zone model with 3D data for 'ad hoc' incidents. C – Part of the market of Nijmegen from the BGT dataset. D – Part of the market of Nijmegen from a point cloud dataset.

However, it should be kept in mind that for now the 3D representations will only be used at the operational centre, as it is solely possible to install the required equipment and software at the operational centre. For officers at location this does not apply, since they will view the outlines of the Hot -Warm-Cold zone model on a phone or tablet and the software used for the 3D application cannot be viewed on these devices. This indicates that it is of significant importance that the 3D representation can also be translated to a 2D representation, so

that all partakers are able to view the created Hot-Warm-Cold zone model. Besides, the officers on location are already viewing the real-life environment in 3D, thus a 2D version of the model is adequate for them.

All in all, a 3D representation for the case of hot, warm and cold zones ensures a safer environment, as more all-round information is available for the operational centre and officers at location. Furthermore, the information which is available is more understandable, thus it takes less effort to compare and relate the 3D representation to the real-life location. Besides this, more specific outlines of the safety zones can be created due to more information on infrastructural objects and the actual height and size of buildings. Additionally, the Hot-Warm-Cold zone model does not necessarily need to be divided into spheres or circles anymore. When certain incidents require different shapes this is possible, for instance using the ovoid or oval 3D representation for toxic chemicals related incidents.

8. DISCUSSION AND FURTHER RESEARCH

In this chapter the outcomes of this research will be evaluated. First the methods and results are discussed in paragraph 8.1, whereafter suggestions for future research based on this research are discussed in paragraph 8.2.

8.1 Discussion

Based on the literature research a method has been developed for the Dutch National Police to use 3D data with incidents involving the Hot-Warm-Cold zone model. The interviews and police force background research resulted in a coherent overview of their methodology and clarified the needs for the methodology of this research. Although the 3D representations were developed in close cooperation with multiple people from the Dutch National Police, they have not been tested with a real incident yet. Due to the current corona regulations it was not possible to test the developed method within the environment of the operational centre. Police employees familiar with the Hot-Warm-Cold zone model have regularly delivered input on the development of the 3D representations but working with the 3D representations in the operational centre could provide additional insights or changes. An example of this is the set eyesight for visibility analyses for 'ad hoc' incidents. This is now set on 1.5 metres but use in practice might point out that another height is more suitable. The set eyesight of 1.5 metres is taken as an average number, however when this eyesight is changed into another height (e.g. 0.5 metres higher or lower) the result of the visibility analysis could be entirely different. Thus, the Dutch National Police will need to experiment with such factors.

The main analysis for 'ad hoc' incidents as well as 'high risk' incidents is quite demanding regarding the hardware, the police employees who need to perform the analysis, the software packages and data storage:

- Powerful computers are required, especially for the point cloud analysis where large amounts of data are involved. Within the systems of the police force this should be applicable, as powerful computers are already available for other (geo)data related cases. However, these powerful servers are located in the data centre. Using 3D data also requires vigour from the computers of the employees, which are generally 'thin clients' without a lot of computing power and/or graphic possibilities.
- This analysis of incidents leading to a 3D representation will need to be performed by police employees. In the case of 'high risk' incidents this regards (semi) geo-experts for the prior analysis via point clouds, but for 'ad hoc' incidents this regards employees at the operational centre. These employees only have little to no experience with GIS and limited computer capabilities. For this reason the step-by-step guide in appendix III has been made. However, this alone will not be enough for these employees to implement this method in their current way of working. Ample time also needs to be provided to get used to the method, together with guidance from people with more GIS knowledge. When this proves to be too hard of a task for the employees at the Dutch National Police another option is a construction with a 'geo competence centre' does the preliminary work whereby the police employees can work with a pre-processed 3D map.
- An important aspect which the employees at the operational centre will need to be able to work with is the software programme of ArcGIS Pro. Although this software is quite easily accessible, it will need some time to get used to, especially since it is currently not used within the environment of the operational centre. ArcGIS Pro is currently limited available at the Dutch National Police, hence when

implementing this research method for the entire organisation, this ArcGIS Pro license needs to be changed. This will increase costs for the police force. Therefore, it might be beneficial for the Dutch National Police to perform a cost and benefit analysis regarding the implementation of ArcGIS Pro throughout the entire organisation. A web-based solution is also an option, for example using ArcGIS Online. This has limitations concerning the mapping and analysis tools, but it is more accessible and in many cases also faster.

- Additionally, there are some other aspects of ArcGIS Pro which are not necessarily constructive for the police organisation. For instance, ArcGIS Pro stores its data in a cloud, while the Dutch National Police would want internal storage due to sensitive and confidential data. This could be a reason for the police to work with another software programme. Although the technique for this method is accurately worked out, the end user and organisation are just as important for a successful implementation process.

The 3D representation for 'high risk' incidents has been developed with the use of Hidden Point Removal. This is a powerful algorithm for a distinct analysis of the environment from a certain viewpoint. However, it does take quite some computing power, time and point cloud knowledge and/or experience to perform this Hidden Points Removal analysis. The Dutch National Police could argue that the outcomes do not weigh up to the costs, especially from an organisational perspective. In that case using point cloud data without Hidden Points Removal could also be an outcome. .

This would cost less time and effort for the police force, while providing (near) full coverage of the desired viewpoints with the raw point cloud data. There would be less clarity in this scenario, as points can cover the perspective from certain viewpoints without Hidden Points Removal, but it would still be a useful step forward from the current 2D data use. An option for using the 'raw' point cloud data is via the desktop version of Potree. This is a free open-source WebGL based point cloud programme and has quite recently developed a desktop version. With the Potree desktop version no large software packages need to be downloaded, the point cloud can be dragged into this programme and the point cloud can be viewed from any desired perspective. This desktop version was developed during the timespan of this research, which is the reason why it has not been included in the analysis of this research. An example of the viewing capabilities of the Potree Viewer is shown in figure 8.1, where the point cloud of the market in Nijmegen is depicted. This would not be suitable for any point cloud analysis, as it is solely a viewing application, but for getting acquainted with locations via point clouds it is a very accessible application. Especially considering that the data can be stored locally, since it does not need to be hosted to use the Potree desktop application.



Figure 8.1: The interface of the Potree Viewer, with the point cloud showing part of the view from the ATM of the 'high risk' incident example of this research

For the 'ad hoc' incidents a 3D city model has been used as the foundation of the created 3D representation. The used city model has a Level of Detail of LoD1.2, thus buildings are represented as blocks, but there are no roof or façade details present. Different models, for instance a mesh model, can offer more details on the environment, especially regarding infrastructural objects. A 3D city model solely presents buildings in 3D and roads, vegetation etc. are represented in 2D. However, from interviews with police employees it can be deduced that a city model is sufficient for perception of reality, especially considering that the 3D representation is merely used as support at the operational centre (the real-life situation is viewed by officers on location). A mesh model might be convenient for previews at locations but since such a model is, among other things, created through (aerial) images it cannot be guaranteed that there is a 100% accuracy. This accuracy could form problems when used with ongoing incidents, while a city model does lack more detail but it can be trusted that all present buildings in the model are accurate and without error.

8.2 Future research

To prove the validity of the results of this research, more research needs to be performed. 2 different 3D representations have now been developed for the Hot-Warm-Cold zone model, which can be seen as the foundation for further research. The 3D representations have been developed based on an urban environment and they could also very well be translated to a rural environment. However, 'unique' infrastructural or natural phenomena have not been taken account. For instance, when an incident occurs nearby a tunnel or a waterway the current methodology is not applicable. Especially 3D tunnels are challenging, they might have to be depicted through Building Information Models (BIM) and thereafter incorporated in the 3D city model environment.

For the 'high risk' incidents point clouds have been used, mainly due to their high level of detail. However, this high level of detail comes with an accompanying disadvantage, which is the considerable size of point clouds. For point clouds it is normal to consist out of several gigabytes or even terabytes of data, which does not always make them simple to use. A solution for this could be point clouds with LoD; for each point this represents the importance of this point (Liu et al., 2020). For visualisation purposes, data is rendered at a certain LoD and when more details are necessary points with higher LoD values will be rendered. Due to the

rendering of all these points, large memory is consumed. Further research can therefore be done on possible other frameworks for the management and querying of point clouds. This will be beneficial for the Dutch National Police, as the large amounts of data from point clouds could form an obstruction for usage of point clouds within the police organisation. Point clouds with LoD could solve this problem leading to an improved storage, analysis and visualisation of the point clouds within the Dutch National Police.

Furthermore, the 3D representation for 'ad hoc' incidents is now depicted through a 3D city model with a Level of Detail of LoD1.2. This Level of Detail can be extended, for instance up to LoD4, which also includes the interior of buildings. With certain incidents the interior of buildings is also of importance in addition to the presentation of the outside of buildings. With an explosion for example, it is also valuable for the police force to be familiar with the inside of the buildings, as this can make a difference in the level of safety for civilians and officers on site. This depiction of the interior of buildings will also be beneficial for other emergency services, especially for the fire brigade. An improved and extended presentation of 3D data will only benefit the cooperation of different emergency services during an incident with the Hot-Warm-Cold zone model.

Another possible addition to the foundation of the 3D representation is more clarification on the function of buildings. This is especially beneficial for the Dutch National Police, as they are the emergency service in charge of the declaration of the safety zones and knowledge on the function of buildings could alter this decision process. With the occurrence of a chemical incident, a safety zone will be marked different when a childcare centre is located next to the hotspot compared to a dumping ground located next to the hotspot. Projecting the function on buildings will affect the analysis, but this might be challenging as symbolisation as used in 2D data is not applicable for 3D data.

The most important next step following this research, is the implementation of the 3D representations in the organisation of the Dutch National Police. There is a form called 'OPAFIT', which can show in what direction an organisation is moving and what their progress is. The abbreviation stands for **O**rganisation, **P**ersonnel, **A**dministrative procedures, **F**inancing, **I**nformation and implementation and lastly **T**echnology. This research has had its focus on technology, but with this aspect only the created 3D representations will not be implemented in the police organisation. As it is a national organisation, there are quite a few difficulties which need to be overcome before the 3D representations are applicable within the police systems. For instance regarding financial resources, GIS knowledge, available employees, administrative issues, persuading executives etc. Therefore, from an organisational point of view a lot of aspects can be added to this research.

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LIST OF FIGURES

<i>Figure 1.1:</i> An example of a 2D visualisation (left) and 3D visualisation (right) located in the city centre of Nijmegen (BGT 2020; 3D Basisbestand 2020)	8
<i>Figure 1.2:</i> The different LoDs (Biljecki et al., 2016b)	9
<i>Table 1:</i> Work Breakdown Structure	12
<i>Figure 1.3:</i> Research flowchart	13
<i>Figure 2.1:</i> Conceptual model	14
<i>Figure 2.2:</i> The Hot-Warm-Cold zone model.....	15
<i>Figure 2.3:</i> The Hot-Warm-Cold zone model represented along natural barriers, with the blue zone depicting the hot zone, the orange zone depicting the warm zone and the 'left over' area depicted as the cold zone.....	19
<i>Figure 2.4:</i> Voxel representation of the soil of the Netherlands, example of the Utrechtse Heuvelrug (TNO, 2013)	20
<i>Figure 2.5:</i> The market square of Delft as an example of a 3D LiDAR point cloud (AHN 3).....	21
<i>Figure 2.6:</i> An example of a 3D mesh model (Esri, n.d. a)	22
<i>Figure 2.7:</i> A 3D city model of the city of Delft (Biljecki et al., 2016a).....	23
<i>Figure 2.8:</i> The interface of ArcGIS Pro visualising the BGT dataset (2020).....	26
<i>Figure 2.9:</i> The interface of CloudCompare visualising a street in Nijmegen (Cyclomedia, 2020).....	27
<i>Figure 3.1:</i> Complete area of the municipality of Nijmegen with the blue circle indicating the specified study area (TOP10NL, 2016).....	28
<i>Figure 3.2:</i> The city centre of Nijmegen with the study area for the 'ad hoc' location, yellow pinpoint, and the study area for the 'high risk' location, blue pinpoint (BGT, 2020)	29
<i>Table 2:</i> Respondents of the taken interviews, including their background.....	30
<i>Figure 3.3:</i> The Cyclomedia web viewer showing (from left to right) an aerial photo from above, an aerial photo from street level and a point cloud of the Market in Nijmegen (Cyclomedia, 2020).	31
<i>Figure 3.4:</i> The '3D Basisbestand' dataset. The unprocessed dataset is visible on the left and on the right edges are added to all objects.....	32
<i>Figure 3.5:</i> Top-down view of the city centre of Nijmegen point cloud dataset (Cyclomedia, 2020)	32
<i>Figure 3.6:</i> Selection of the point cloud dataset showing the Market of Nijmegen (Cyclomedia, 2020)	33
<i>Figure 3.7:</i> '3D Basisbestand' showing Nijmegen with symbology's.....	34
<i>Figure 3.8:</i> The addition of multipatches buildings to accentuate their differences	34
<i>Figure 3.9:</i> BGT dataset with a new symbology, showing the city centre of Nijmegen with a close-up on the right image (BGT, 2020).....	35
<i>Figure 3.10:</i> On the left image there is no noise removal and on the right image there is noise removal. The red circle shows that the façade of the building partly vanishes due to the noise removal (Cyclomedia, 2020).....	35

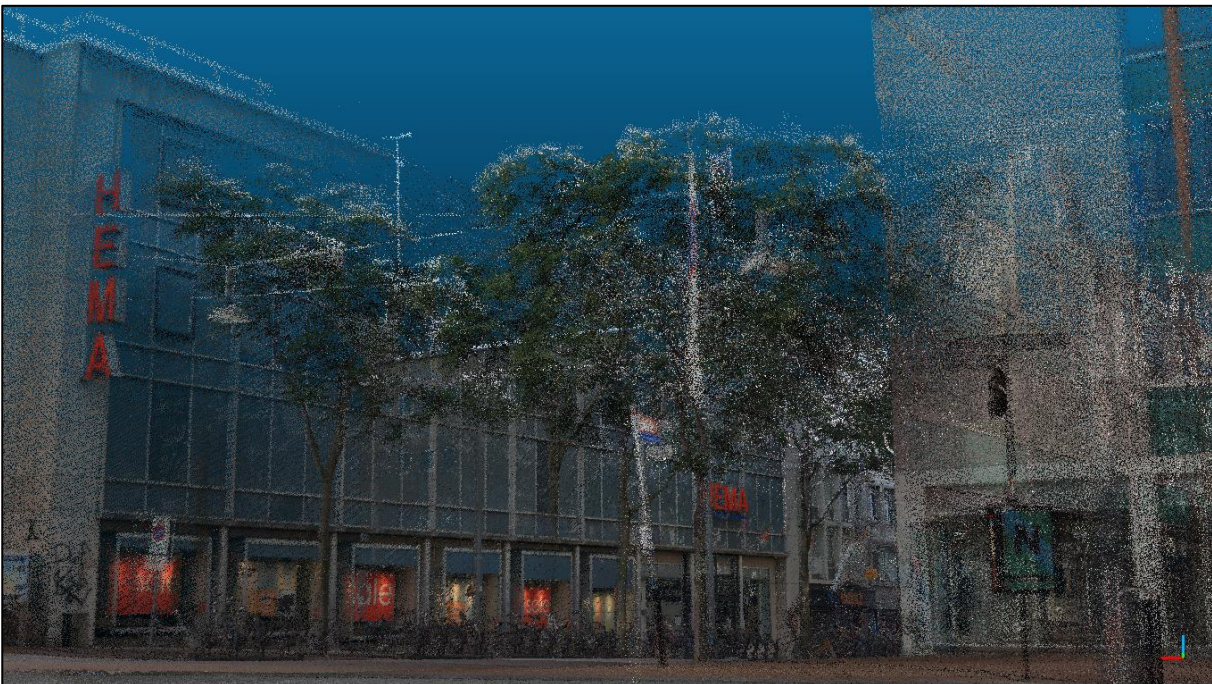
Figure 4.1: A view dome at the 'ad hoc' location	38
Figure 4.2: 2 lines of sight at the 'ad hoc' location, with a continuous line of sight on the left and an intersecting line of sight on the right	39
Figure 4.3: An example of the creation of a viewshed from 1 observer point (Esri, n.d. c)	40
Figure 4.4: The principle of the viewshed tool with its parameters (Esri, n.d. c)	40
Figure 4.5: Viewsheds at the 'ad hoc' location with on the left a viewshed with an angle of 60 degrees and on the right a viewshed with an angle of 360 degrees	41
Figure 4.6: A buffer of 100 metres created around the centre of the incident 'high risk' location	42
Figure 4.7: Examples of graphic buffers around various features (Esri, n.d. f)	43
Figure 4.8: A multiple ring buffer created around the 'high risk' incident location	44
Figure 4.9: Left - The process of spherical flipping with the sphere in green, the 2D curve in blue, the viewport in pink and the end result of spherical flipping in red. Right – the back projection of the convex hull, ultimately leading to the visible points from the viewport (Katz, 2007)	45
Table 3: Camera settings for the camera shown in figure 4.10	45
Figure 4.10: A camera positioned in front of the ATM at the 'high risk' location (Cyclomedia, 2020)	46
Figure 4.11: Viewport from the set camera depicted in figure 4.10 (A) and the same viewport with HPR applied onto it, octree level 7 (B) (Cyclomedia, 2020)	47
Figure 5.1: The hot zone of an 'ad hoc' location represented through a viewshed.....	49
Figure 5.2: A sphered 3D representation for the Hot-Warm-Cold zone model with on the left a normal buffer for the warm zone and on the right a 3D buffer for the warm zone	50
Figure 5.3: Left- An ellipsoid shape representing the hot zone. Right – The Hot-Warm-Cold zone model represented as ellipsoids, with an ellipsoid shaped hot zone and a buffer as a warm zone.....	51
Figure 5.4: Line created as input for the ovoid shaped hot zone with the green dot representing the centre of this hot zone.....	52
Figure 5.5: The hot zone created by a 3D buffer. Left – top view, right – side view.....	52
Figure 5.6: Left – Hot-Warm-Cold zone model created through buffering the hot zone. Right – Hot-Warm-Cold zone model created through buffering the line inside of the hot zone	53
Figure 5.7: A line of sight added to the ovoid shaped Hot-Warm-Cold zone model, where a green line stands for perfect visibility and a pink line stands for no visibility from the observer point.....	54
Figure 5.8: A street view image of the surroundings around the 'ad hoc' incident location, comparable with the view shown in figure 5.7 (Cyclomedia, 2020)	55
Figure 5.9: An oblique image of the 'ad hoc' incident location, with the green dot indicating the front door of the robbed store (Cyclomedia, 2020)	56
Figure 5.10: The final sphere shaped 3D representation for the Hot-Warm-Cold zone model concerning 'ad hoc' incidents.....	57
Figure 5.11: The final ovoid 3D representation for the Hot-Warm-Cold zone model concerning chemical 'ad hoc' incidents.....	58

<i>Figure 6.1:</i> A circled hot zone for a 'high risk' incident, blue of colour for visibility purposes, 50 meters radius..	60
<i>Figure 6.2:</i> An oval shaped Hot-Warm-Cold zone model, most suitable for depicting wind directions.....	60
<i>Figure 6.3:</i> 4 cameras showing the entire area which will be captured from the centre of the hot zone, thus from the ATM.....	61
<i>Figure 6.4:</i> The 4 definite cameras used in the HPR analysis, providing an undistorted view of 180 degrees around the ATM.....	62
<i>Table 4:</i> Matrix input for all 4 cameras.....	62
<i>Figure 6.5:</i> The view from the viewport of camera 3 with A - original point cloud, B - HPR with octree level 7, C - HPR with octree level 9	64
<i>Figure 6.6:</i> The points visibility for camera 3 with HPR applied onto it with an octree level of 7, where red stands for visible points and blue for non-visible points.....	65
<i>Figure 6.7:</i> The perspective from camera 3 with HPR, octree level 7, applied onto it and an increased size in points, which improves the visibility	66
<i>Figure 6.8:</i> A comparison of the view from camera 2, with at the top the point cloud image after HPR and at the bottom a street view image (Cyclomedia, 2020)	67
<i>Figure 6.9:</i> One perspective of the final 3D representation for 'high risk' incidents (Cyclomedia, 2020)	68
<i>Figure 7.1:</i> A comparison between 2D data and 3D data. A – Example of the Hot-Warm-Cold zone model with 2D data. B – Example of the Hot-Warm-Cold zone model with 3D data for 'ad hoc' incidents. C – Part of the market of Nijmegen from the BGT dataset. D – Part of the market of Nijmegen from a point cloud dataset. ...	74
<i>Figure 8.1:</i> The interface of the Potree Viewer, with the point cloud showing part of the view from the ATM of the 'high risk' incident example of this research	78

APPENDIX I

In this appendix the perspective from the viewport of all 4 cameras, shown in figure 6.5, is represented. The original point cloud as well as the point cloud after an operation of HPR with an octree level of 7 is shown for comparison purposes. For visibility purposes, the perspectives of all 4 cameras after HPR are also shown with an increased size in points. These images are also used in appendix II, where a panorama has been created of the 180 degrees view from the ATM. For all 4 cameras it applies that the first shown image is the original point cloud, the second image is the point cloud after HPR and the third image is the point cloud after HPR with an increased point size.

Camera 1 – Point cloud



HPR, octree level 7



HPR, octree level 7, increased size of points



Camera 2 – Point cloud



HPR, octree level 7



HPR, octree level 7, increased size of points



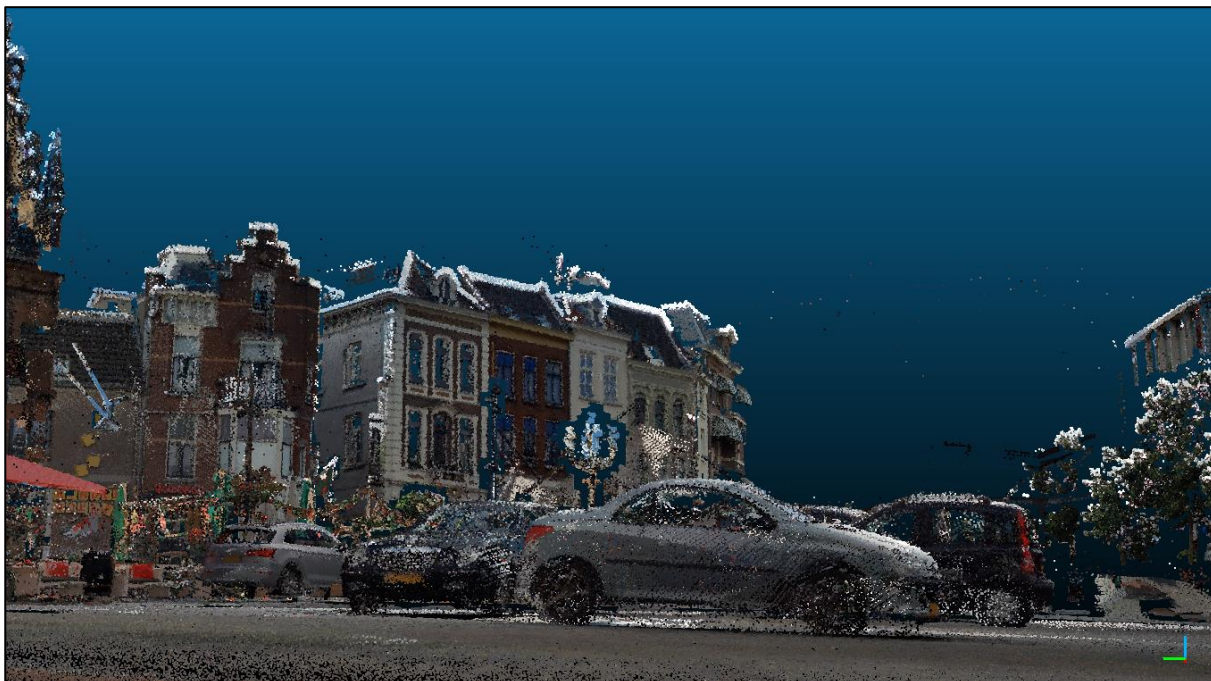
Camera 3 – Point cloud



HPR, octree level 7



HPR, octree level 7, increased size of points



Camera 4 – Point cloud



HPR, octree level 7



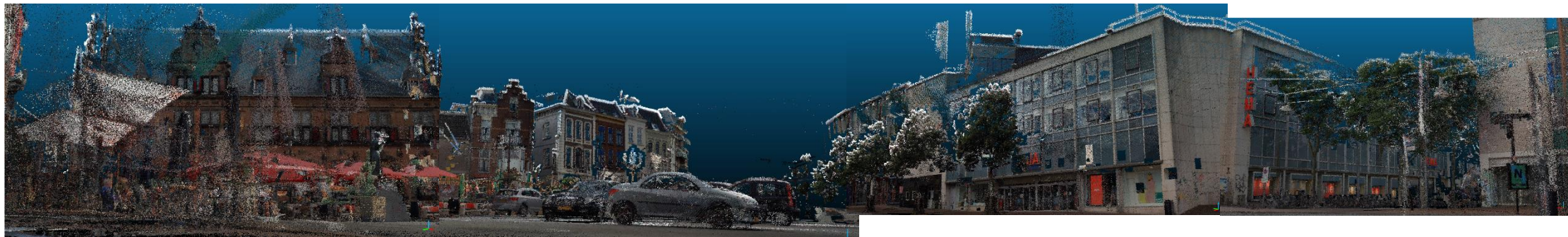
HPR, octree level 7, increased size points



APPENDIX II

In this appendix the 180 degree view of the point cloud is shown in a continuous order for comparison purposes with street view images of the same location, shown underneath the point cloud images. The point cloud as well as the street view images are created by Cyclomedia (2020). As said in appendix I, the point cloud images are HPR images with an increased size of points.

An important remark regarding the street view images is that they were not made from the same point of view. The point cloud images are seen from the perspective of the ATM, while the street view images are seen ± 10 metres in front of this ATM, as this is on the way of the car making the images. Also, the point cloud images are seen from eyesight level, while the camera for the street views is positioned higher. Therefore, the point clouds and street views cannot be identical and could seem distorted when comparing them.



APPENDIX III

This appendix encloses a step-by-step guide for the Dutch National Police on how to create the 3D representations for 'ad hoc' incidents as well as 'high risk' incidents. As the Dutch National Police is a Dutch organisation, the step-by-step guide has been written in Dutch. This constitutes the least barriers for police employees to actually implement the 3D representations in their current methods of working with the Hot-Warm-Cold zone model. Furthermore, the point of view for this step-by-step plan is that little to no GIS experience is present for police employees who will be using the 3D representations.

Stappenplan voor 'ad hoc' incidenten

Voor 'ad hoc' incidenten zijn er 2 mogelijke 3D representaties afhankelijk van het soort incident, namelijk de 3D representatie met cirkels en de 3D representatie met ovaal. Stap 1 t/m 6 is hetzelfde voor allebei deze 3D representaties en daarna verschillen de stappen. Deze zijn apart uitgewerkt. Aan het eind zijn de stappen voor een 'line of sight' toegevoegd, deze kunnen bij allebei de 3D representaties relevant zijn

1. Open in ArcGIS Pro de benodigde dataset, in dit geval het 3D Basisbestand. Als deze dataset al bewerkt is kun je door naar stap 7, zo niet volg dan stap 2 t/m 6.
2. Open de tool 'Merge' en selecteer uit de dataset de datalagen betreffende het terrein, alleen datalagen van gebouwen hieruit weglaten. Geef in deze tool bij 'Output Dataset' de nieuwe dataset de naam *Terrein* (of *Terrein_Nijmegen* bv). Run de tool.
3. Als er meerdere datalagen zijn met gebouwen, voer dan stap 2 nogmaals uit maar nu voor *Gebouwen*. Zo niet, open dan de tool 'Feature Class to Feature Class' en selecteer de gebouwen data laag. Geef in deze tool bij 'Output Name' de nieuwe dataset de naam *Gebouwen* (of *Gebouwen_Nijmegen* bv). Run de tool.
4. Verander vervolgens de symbologie van de datasets, dit kan naar eigen smaak. Rechterklik op een data laag en ga via het drop down menu naar 'Symbology'. Voor *Gebouwen* kan bijvoorbeeld gekozen worden uit *White with Edges*, uit de ArcGIS 3D symbology bibliotheek.
5. Voor de terreinlaag kan gebruik gemaakt worden van een Symbology Layer bestand, dit bestand kan alle verschillende onderdelen van de terrein dataset een andere, passende kleur geven. Open de 'Symbology' voor de *Terrein* data laag, klik rechtsbovenin op het hamburgericoon en selecteer 'import symbology'. Selecteer dan de Symbology Layer, genaamd *Terrein.lyrx* en klik op run.
6. Om de gebouwen te verduidelijken, kunnen 'Multipatch Textures' nog worden toegevoegd. Ga hiervoor naar 'Edit' → 'Features' → 'Modify'. Klik in de 'Modify' tab op 'Multipatch Texture'. Klik nu op de gewenste zijde van een gebouw, bijvoorbeeld het dak in dit geval, selecteer een kleur in de 'Multipatch Texture' tab, bijvoorbeeld bordeaux rood, en herhaal dit voor elk ander gewenst gebouw.

Verdere stappen voor de omcirkelde 3D representatie

7. Ga naar 'Analysis' → 'Exploratory 3D Analysis' en selecteer de 'Viewshed' vanuit het drop down menu, voor het creëren van de hot zone.

8. Onder het 'Initial Viewpoint' verander je de 'Offset' naar 1.5 meter, de gemiddelde ooghoogte, hiermee bepaal je de hoogte van het middelpunt voor wat je ziet.
9. Onder de 'Viewshed Angles' zet je de 'Horizontal' op 360 graden en de 'Vertical' op 180 graden.
10. Onder 'Viewshed Distance' kun je de gewenste minimum en maximum afstand instellen voor de 'Viewshed'
11. Klik in de kaart op het middelpunt van de hot zone om de 'Viewshed' te creëren
12. Vervolgens wordt de warm zone gecreëerd, ga hiervoor naar 'Tools' en zoek op 'Buffer 3D', selecteer deze tool.
13. Bij 'Input Features' klik je op het potlood icoon, selecteer vervolgens 'Points'. Klik op het middelpunt van de hot zone om een punt neer te zetten.
14. Ga terug naar het 'Buffer 3D' tab en geef een passende naam bij 'Output Feature Class'
15. Bij 'Distance' selecteer je meters als 'Linear Unit' en voer je de gewenste afstand in. Houd er hier rekening mee dat de buffer om het middelpunt berekend wordt en niet om de hot zone, de afstand van de hot zone moet dus ook meegenomen worden.
16. Run de 'Buffer 3D' tool.
17. Om de warm en hot zone duidelijk te zien moet de transparantie van de buffer nog veranderd worden. Als er een andere kleur gewenst is voor de warm zone kun je in de 'Contents' tab bij de net gecreëerde warm zone met de rechtermuisknop klikken op de kleur van de 3D buffer, zo kun je een andere kleur kiezen.
18. Klik vervolgens op de warm zone data laag, de nieuwe tab 'Feature Layer' verschijnt dan bovenin je scherm. Klik hieronder op 'Appearance'.
19. Bij het kopje 'Effects' is er een slider voor de 'Layer Transparency'. Zet deze slider op ± 80%.

Verdere stappen voor de ovaal 3D representatie

7. Eerst moet er een lijn gemaakt worden voor de hot zone. Ga hiervoor naar 'Insert' → 'Measurements' → 'Distance and Direction' en selecteer 'Line'.
8. Bij 'From' kan gekozen worden uit 'Points' en 'Distance and Bearing', beide methoden kunnen worden gebruikt. Bij 'Points' creëer je een lijn door deze in de kaart te tekenen en bij 'Distance and Bearing' wordt een lijn gemaakt door een startpunt, eindpunt, afstand en hoek van de lijn te kiezen en in te vullen. Kies een van deze methoden en maak de gewenste lijn in de kaart.
9. Om de lijn zichtbaar te krijgen in de 3D omgeving ga je naar 'Tools' en zoek je op 'Adjust 3D Z'. Selecteer deze tool.
10. In 'Input Features' selecteer je de data laag *Distance and Direction\Lines*. Bij 'Convert to Units' vul je meters in en vervolgens vul je bij 'Adjust Z Value' de gewenste hoogte in van de lijn. Als je bijvoorbeeld 2 invult, gaat de lijn 2 meters omhoog, terwijl als je -2 invult gaat de lijn 2 meters omlaag. Run de tool en verander de Z value nog een keer als de lijn nog niet goed ligt, run de tool opnieuw totdat de lijn op de gewenste hoogte is.
11. Ga voor de hot zone verder naar 'Tools' en zoek op 'Buffer 3D'. Selecteer deze tool.
12. Bij 'Input Features' selecteer je de net gemaakte lijn, *Distance and Direction\Lines*, en bij 'Output Feature Class' geef je een passende naam voor de hot zone.
13. Vul bij 'Distance' de gewenste afstand in en zet de 'Linear Unit' op meters.
14. Selecteer bij 'Joint Type' round. Run de tool.
15. Om de hot zone duidelijk te zien moet de transparantie van de buffer nog veranderd worden. Als er een andere kleur gewenst is voor de hot zone kun je in de 'Contents' tab bij de net gecreëerde

hot zone met de rechtermuisknop klikken op de kleur van de 3D buffer, zo kun je een andere kleur kiezen.

16. Klik vervolgens op de hot zone data laag, de nieuwe tab 'Feature Layer' verschijnt dan bovenin je scherm. Klik hieronder op 'Appearance'.
17. Bij het kopje 'Effects' is er een slider voor de 'Layer Transparency'. Zet deze slider op $\pm 80\%$.
18. Voor de warm zone gebruik je opnieuw de '3D Buffer tool' op dezelfde manier als voor de hot zone (stap 11 t/m 17). Let alleen op bij de in te vullen afstand dat je de lijn weer buffert in plaats van de hot zone, dus de afstand van de hot zone moet er bij gerekend worden.

Stappen voor het creëren van een 'line of sight'

1. Ga naar 'Analysis' → 'Exploratory 3D Analysis' en selecteer 'Line of Sight' uit het drop down menu.
2. Onder 'Observer' zet je de 'Vertical Offset' op 1.5 meter, dit is de gemiddelde ooghoogte.
3. Bepaal vervolgens de gewenste 'Minimum Distance' en 'Maximum Distance' voor de lijn.
4. Onder 'Target' kun je de 'Vertical Offset' bepalen voor het eindpunt. Dit is de hoogte van het eindpunt. Als deze lijn recht moet lopen vul je hier 1.5 meters in.
5. Selecteer onder 'Creation Method', 'Interactive Placement' en klik op het middelpunt van de hot zone als startpunt van de lijn.
6. Klik in de kaart op het eindpunt van de lijn.

Stappenplan voor 'high risk' incidenten

Voor 'high risk' incidenten worden eerst de hot, warm en cold zone bepaald in de 2D BGT dataset, waarna de hot zone in meer detail wordt geanalyseerd in de point cloud. Net zoals bij de 'ad hoc' incidenten kunnen de veiligheidszones in de BGT dataset worden gemaakt aan de hand van cirkels of ovalen. Beide representaties worden individueel uitgelegd.

1. Open ArcGIS Pro en open in ArcGIS Pro de BGT dataset. Als deze dataset al bewerkt is, kun je verder naar stap 5, zo niet volg dan stap 2 t/m 4.
2. Verwijder niet belangrijke datalagen door met de rechtermuisknop te klikken op de desbetreffende data laag en in het drop down menu 'Remove' te selecteren. Verwijder hierbij datalagen die het straatbeeld verstoren. Als je in de kaart op een feature klikt (dus op een punt, of huis, of naam) krijg je een pop-up te zien met informatie, hieruit kun je de naam van de data laag herleiden
3. Verander de symbologie voor de overgebleven datalagen. Voor de datalagen waar dit nodig is kun je met de rechtermuisknop op de naam van de data laag en selecteer je 'Symbology'
4. In de 'Symbology' tab kun je op een kleur klikken van een feature om de kleur te veranderen. Het is ook mogelijk om in de 'Contents' tab met de rechtermuisknop meteen op de kleur van de data laag te klikken, dan kan de kleur meteen veranderd worden.

Het bepalen van de veiligheidszones in de BGT dataset voor een omcirkelde 3D representatie

5. Ga naar 'Analysis' → 'Tools' en zoek op 'Buffer'. Selecteer deze tool.
6. Bij 'Input Features' klik je op het potlood icoon, selecteer vervolgens 'Points'. Klik op het middelpunt van de hot zone om een punt neer te zetten.

7. Vul bij 'Output Feature Class' een passende naam in.
8. Geef bij 'Distance' de afstand van de hot zone aan en vul bij 'Linear Unit' meters in. De andere opties staan al goed.
9. Run de tool.
10. Om de hot zone duidelijk te zien moet de transparantie van de buffer nog veranderd worden. Als er een andere kleur gewenst is voor de hot zone kun je in de 'Contents' tab bij de net gecreëerde hot zone met de rechtermuisknop klikken op de kleur van de 3D buffer, zo kun je een andere kleur kiezen.
11. Klik vervolgens op de hot zone data laag, de nieuwe tab 'Feature Layer' verschijnt dan bovenin je scherm. Klik hieronder op 'Appearance'.
12. Bij het kopje 'Effects' is er een slider voor de 'Layer Transparency'. Zet deze slider op $\pm 80\%$.
13. Ga voor het creëren van de warm zone opnieuw naar de 'Buffer' tool.
14. Gebruik als 'Input Feature' de zojuist gecreëerde hot zone en geef bij 'Output Feature Class' opnieuw een passende naam.
15. Vul de gewenste afstand in en selecteer bij 'Side Type' de optie 'Exclude the input polygon from buffer'.
16. Run de tool en voer voor de zichtbaarheid opnieuw stap 10 t/m 12 uit voor de warm zone.
17. Indien gewenst kan de cold zone ook op deze manier gemaakt worden.

Het bepalen van de veiligheidszones in de BGT dataset voor een ovale 3D representatie

5. Eerst moet er een lijn gemaakt worden voor de hot zone. Ga hiervoor naar 'Insert' → 'Measurements' → 'Distance and Direction' en selecteer 'Line'.
6. Bij 'From' kan gekozen worden uit 'Points' en 'Distance and Bearing', beide methoden kunnen worden gebruikt. Bij 'Points' creëer je een lijn door deze in de kaart te tekenen en bij 'Distance and Bearing' wordt een lijn gemaakt door een startpunt, eindpunt, afstand en hoek van de lijn te kiezen en in te vullen. Kies een van deze methoden en maak de gewenste lijn in de kaart.
7. Ga voor de hot zone verder naar 'Tools' en zoek op 'Buffer'. Selecteer deze tool.
8. Bij 'Input Features' selecteer je de net gemaakte lijn, *Distance and Direction* \ *Lines*, en bij 'Output Feature Class' geef je een passende naam voor de hot zone.
9. Vul bij 'Distance' de gewenste afstand in en zet de 'Linear Unit' op meters.
10. Selecteer bij 'Joint Type' round. Run de tool.
11. Om de hot zone duidelijk te zien moet de transparantie van de buffer nog veranderd worden. Als er een andere kleur gewenst is voor de hot zone kun je in de 'Contents' tab bij de net gecreëerde hot zone met de rechtermuisknop klikken op de kleur van de 3D buffer, zo kun je een andere kleur kiezen.
12. Klik vervolgens op de hot zone data laag, de nieuwe tab 'Feature Layer' verschijnt dan bovenin je scherm. Klik hieronder op 'Appearance'.
13. Bij het kopje 'Effects' is er een slider voor de 'Layer Transparency'. Zet deze slider op $\pm 80\%$.
14. Ga voor het creëren van de warm zone opnieuw naar de 'Buffer' tool.
15. Gebruik als 'Input Feature' de zojuist gecreëerde hot zone en geef bij 'Output Feature Class' opnieuw een passende naam.
16. Vul de gewenste afstand in en selecteer bij 'Side Type' de optie 'Exclude the input polygon from buffer'.
17. Run de tool en voer voor de zichtbaarheid opnieuw stap 11 t/m 13 uit voor de warm zone.

18. Indien gewenst kan de cold zone ook op deze manier gemaakt worden.

Gedetailleerde analyse voor 'high risk' incidenten door middel van point clouds

1. Open CloudCompare en open bij 'File' de gewenste point cloud(s) in dit programma.
2. Ga naar 'Tools' en kies uit het drop down menu 'Point picking'.
3. Klik op een punt in de point cloud, dit is het middelpunt van de hot zone. Als er een notificatie komt betreffende de 'Picking acceleration' klik je op 'Yes'.
4. Er komt een pop-up box tevoorschijn, schrijf de X, Y en Z coördinaten op.
5. Klik rechtsboven in je scherm op het kruisje van 'Point picking' om deze tool weer te verlaten.
6. Ga vervolgens naar 'Edit' → 'Sensors' → 'Camera' → 'Create'.
7. Er verschijnt een scherm met 'Sensor parameters'.
8. Vul bij het tabblad 'Position + Orientation' bij 'Center' de coördinaten in die je net via point picking hebt vergaard.
9. Vul de rest van de gegevens onder het tabje 'Position + Orientation' als volgt in:

X coordinate (right)	Y coordinate (up)	Z coordinate (inv. view dir.)
0	1	0
0	0	1
1	0	0

10. De bovenste gegevens uit de tabel bepalen de grootte van het camera frame, wanneer gewenst kun je deze ook aanpassen naar een andere grootte.
11. Als de richting van de camera niet goed is, ga je naar 'Edit' → 'Apply Transformation'
12. In deze tool ga je vervolgens naar het tabblad 'Axis, Angle' en verander je de 'Rotation angle' naar de gewenste positie van de camera.
13. Wanneer de camera op deze manier niet de goede kant op draait kun je bij hetzelfde tabje 'Axis, Angle' bij 'Rotation Axis' de X, Y en Z as individueel veranderen.
14. Als de camera dan goed staat, creer je nog een camera volgens dezelfde weg als bij de stappen 6 t/m 10, met precies dezelfde gegevens en coördinaten als voor de eerste camera.
15. Klik vervolgens in het tabje van 'DB Tree' op de tweede camera.
16. Ga naar 'Edit' → 'Apply transformation' → 'Axis, Angle' → 'Rotation angle'.
17. Zet deze 'Rotation angle' op 45 graden.
18. De tweede camera is nu 45 graden gedraaid vanaf de eerste camera.
19. Het kan zijn dat de tweede camera zich niet meer in het middelpunt van de hot zone bevindt. Om dit terug te zetten ga je naar 'Edit' → 'Sensors' → 'Edit'.
20. Bij het 'Position + Orientation' tabblad vul je bij 'Center' opnieuw de coördinaten in van het middelpunt, verkregen door point picking.
21. Klik op OK. De tweede camera staat nu gericht op een andere hoek, naast de eerste camera.
22. Herhaal stap 14 t/m 21 voor de andere benodigde camera's om een volledig beeld te krijgen. Verander hiervoor alleen het aantal graden bij 'Rotation angle' per camera.
23. Voor de HPR klik je vervolgens op de camera waar je het perspectief van wilt zien.
24. Klik dan onderaan het tabblad 'DB Tree' op 'Properties' en klik binnen deze 'Properties' op 'Apply Viewport'.

25. Je ziet nu het perspectief vanuit de camera. Sleep met je muis door het beeld om het perspectief horizontaal te zien in plaats van verticaal. Zorg dat de groene verticale/hoogte lijnen van de camera op de rand van je beeld zitten, voor een volledig beeld vanuit de camera.
26. Selecteer vervolgens de point cloud die je wilt gebruiken voor HPR in de 'DB Tree' tab en ga naar 'Plugins' → 'Hidden Point Removal'.
27. Selecteer een Octree Level van 7 en klik vervolgens op OK.
28. Herhaal dit proces van HPR voor andere point clouds als die ook binnen het beeld van de camera vallen.
29. Het beeld vanuit deze camera is nu klaar, hier kun je een screenshot van maken voor verder gebruik.
30. Ga vervolgens naar 'Display' → 'Toggle Viewer Based Perspective', om terug te keren naar de gehele point cloud.
31. Herhaal stap 23 t/m 29 voor de andere camera's.
32. Nu heb je een beeld van 180 of 360 graden (afhankelijk van de hoeveelheid gemaakte camera's) vanuit het middelpunt van de hot zone.