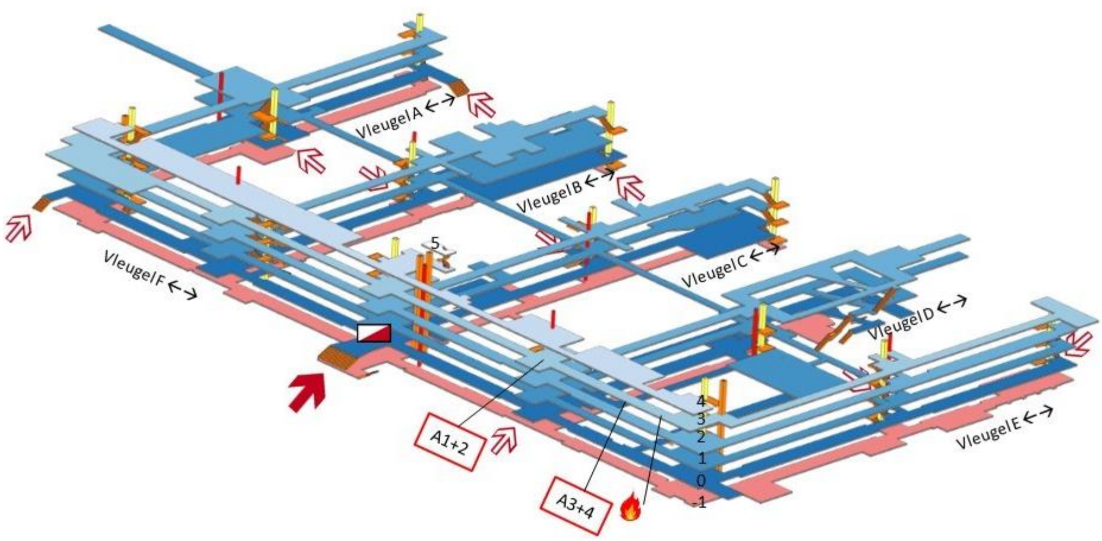
GIMA
Geographical Information Management and Applications

# Geovisualization for the Dutch fire brigade

a research about effective cartographic methods for assisting tactics choice and indoor deployments during building fires.


**Tom van der Meer**


Universiteit Utrecht
TU Delft
UNIVERSITY OF TWENTE.
WAGENINGEN UR

**MSc GIMA Thesis**


**Supervisor:** ir. E. Verbree (TU Delft)
**Professor:** prof. dr. ir. P.J.M. van Oosterom (TU Delft)
**Fire deptartment supervisors:** H.J. Fransen & V. Oskam
(Veiligheidsregio Rotterdam-Rijnmond)

# Contents

# 1. Problem and its context

On 9 May 2008 there was a fire in a shipyard in De Punt, a village in the Dutch province Drenthe. Upon arrival the firefighters saw thick smoke with an unusual yellow colour. During an indoor exploration of the building these yellow fumes ignited resulting in a large explosion and the death of three firefighters. This tragic accident led to the realisation of the Dutch fire brigade that they did not know enough about fires in buildings with modern building materials, and that the former guidelines for indoor deployments were not safe enough for large complex buildings. This realisation led to the development of the 'Brandweerdoctrine' (Fire brigade doctrine), a combination of previous findings and new strategies and methodologies for firefighting. The first product of the Brandweerdoctrine is the report on the quadrant model for fighting building fires (Hagen, Hendriks & Molenaar, 2014). This report is a framework for tactics choice, and it explains which incident factors affect the choice of tactics. For each tactic a different subset of techniques exists. This makes the total number of incident factors very large, how can this be presented in a way that helpful during a deployment?

Information is key for a safe deployment of the fire brigade. Incorrect judgement could lead to decreased effectivity or even casualties. Because of the risks that are posed by building complexity and modern building materials, the Dutch fire brigade is increasingly hesitant to enter the building during a building fire (Hagen et al., 2014). While no two building fires are the same and personal judgement of the fire brigade will remain necessary, good information supply could aid the commanders in making the right choices. There are a lot of factors that come into play when choosing strategy, tactics and techniques. Verbree (2013) also stated that firefighters are dependent on building data for effective deployments. An effective information system should present the right information at the right moment, and it should do so in an intuitive and effective manner. Most cartography research has been done for outdoor applications; indoor cartography is in its infancy (Lorenz et al., 2013). This research aims to develop cartographic methods for presenting indoor building information to help the Dutch fire brigade in tactics choice and choice of indoor methods and navigation.

## 2. Research Objectives

The aim of this research is to develop cartographic methods for presenting building information that aid in effective and safe indoor deployments during building fires. The focus is on the Dutch fire brigade, scientific literature is used to develop methods that are compatible with their methods and techniques. The fire brigade has a wide range of tasks, from preventing incidents to aftercare when an incident has happened. This research focusses on the preparatory tasks by developing methods to effectively respond to these incidents. The main research question is as follows:

*What are effective cartographic methods for presenting building information for assisting the Dutch fire brigade in tactics choice and choice of indoor firefighting methods and navigation?*

First of all the demands of the Dutch fire brigade need to be identified. How does this organization operate during building fires, and what properties should an information system have in order to be a good addition to their deployments? This topic is addressed in the following subquestion:

- What are the demands of the Dutch fire brigade for operational indoor information to be an effective addition to their deployments?

With this subquestion the general demands of the Dutch fire brigade are addressed. However there are different functions within this organization, with possibly different information needs. User groups are identified with the following subquestion:

- Which user groups can be identified that could benefit from an indoor spatial information system?

After the user groups are identified, we can further focus on their specific information needs. Many building factors play a role during fire brigade deployments. A balanced supply of information provides each user group the relevant building factors while preventing information overload. The following subquestion is aimed at identifying these building factors:

- What static and dynamic indoor building factors are suitable for displaying in an operational information system in order to assist the specific user groups and prevent information overload?

The previous subquestion identified the information that should be presented in the system. Next step is to find cartographic methods for doing so:

- What are effective cartographic methods for presenting the static and dynamic building factors in indoor environments to the user groups?
-

Finally this information is combined to create a prototype version of an information system for one public building. This prototype consists of static visualizations for a fictitious fire incident.

## 2.1. Scope

This research is focused on indoor cartography methods. It does not discuss technological aspects such as data collection, the development of indoor models, formal storage of models (UML, indoorGML), indoor localization and indoor routing. Within this project it is assumed that all spatial data is available in functioning building models, and that there are methods for indoor localization and routing even during building fires. A good write-up on indoor positioning with Wi-Fi is written by Braggaar (2018) and information about indoor modeling can be found at the SIMs3D Project (2018). It is important to note that in reality data availability of buildings is limited. Moreover the focus is on large complex buildings where many people are present such as hospitals, large apartment buildings, airports or train stations. The aim is to develop effective indoor cartographic visualization techniques for the fire brigade. These visualizations are static images that represent the desired functionalities.

Crisis management in the Netherlands is divided in 5 phases in the so-called Safety Chain (CCV, 2018):

- Proaction: taking measures to structurally remove causes of unsafety. Example: closing an unsafe factory or not granting a permit for a large event.
- Prevention: taking measures to prevent incidents and to keep incidents manageable. Example: creating fire hazard awareness and increasing surveillance.
- Preparation: enabling an effective response to incidents. Example: creating emergency action plans or giving first-aid training.
- Repression: combatting incidents. Example: fighting building fires or arresting a terrorism suspect.
- Aftercare: recovering to the status quo. Examples: organizing commemoration events or giving psychological support to victims and emergency workers.

This research aims to develop methods to aid in an effective response to incidents, so the research process itself belongs in the preparation phase. The products of this research are meant for use during the repression phase; they can be used during indoor deployments. The other three phases are out of scope.

The fire brigade has a broad set of tasks such as finding gas leaks, giving aid after traffic accidents and fighting building fires. During this research the focus is on information supply for indoor deployments during building fires. It should aid in all possible tasks during these indoor deployments (Hagen, Hendriks & Molenaar, 2014):

- Rescue
- Evacuation of a building
- Creating survival conditions
- Enabling safe entry of a building segment
- Prevention of fire expansion to other segments
- Fire extinguishing
- Limiting environmental and societal effects

# 3. Methodology

The thesis research starts with an assessment of the organization of the Dutch fire brigade during repressive scenarios. Literature will be consulted for this. After that the timeline of an indoor building fire deployment will be described. Methods, techniques and information needs of each deployment phase will be discussed based on literature and interviews. During previous research (van der Meer, 2016) it became clear that fire brigade methods and techniques are highly case dependent. When asking a firefighter what he would do in a certain situation the answer would often be that it depends on a large number of circumstances. Procedures exist, but in many cases firefighters will rely on their own judgement. This leads to challenges during interviews. A structured interview would require experience with firefighting in order to ask the right questions. The choice was made for semi-structured interviews to have some control over the topics to discuss while still leaving the possibility for firefighters to explain additional details.

After an assessment is made of firefighting methods and techniques during each deployment phase, the demands for an indoor information system are discussed. What information is and isn't useful to them, and what practical limitations apply during a deployment? For example their eyesight is limited by smoke and their SCBA (Self-Contained Breathing Apparatus) and they also have limited use of their hands because of the gear they are carrying (van der Meer, 2016). Firefighters operate in indoor environments with even more difficulties; sight could be zero because of the smoke, the power could be out or the navigable space could have been changed due to fire or collapse. During the interviews the firefighters are asked what information they need during their deployment. End users will be identified based on the interviews and the literature review. Their specific needs are also listed.

Next a background research about indoor cartography will be performed. During the cartographic research a start will be made with the basic rules of cartography, assessing map design, data types and their visualization techniques. The book 'Cartography – visualization of spatial data' by M.J. Kraak and F.J. Ormeling (2010) will serve as a starting point for this, and it will be expanded with other scientific literature. Research about semiotics and semiology will give insights into the design of signs. After this, research will be done about the possibilities and rules of modern geovisualization techniques. Methods for creating interactive and geovisualizations and visualizing dynamic data will be researched, as well as different methods for visualizing dynamic and 3D data in digital environments. Moreover techniques and hardware for data display and interaction will be discussed.

The cartographic rules need to be translated into indoor applications: which general rules can be applied indoors, and which can't? Also methods for indoor navigation are needed, as well as methods for prevention of information overload. The technical possibilities to solve these questions will be described with scientific literature. Topics like matching maps to the user environment and practical limitations will be addressed here, as well as the prevention of information overload. Scientific literature will not fully cover the topic because indoor cartography is still in its infancy. Information gaps will be filled with system requirements derived from interviews with the fire brigade.

Findings from the cartographic background research will be applied to the needs of the end user to create effective visualization techniques. Prototypes will be made of the Delft University of Technology Faculty of Applied Sciences (TU Delft, 2018). These prototypes should showcase functionalities that the firefighters demanded during the interviews. Wherever possible they should adhere to (indoor) cartographic principles from the cartographic background research. Should these principles contradict the needs of the end user, concessions will be made that meet the end user requirements as best as possible.

The static visualization prototypes will be tested in a single iteration. A fictional fire incident will be explained to firefighters on-site at the Faculty of Applied Science. These test subjects are asked to compose a deployment strategy based on the static visualizations. They are asked to think aloud so their choices can be written down. After that the test subjects are asked to navigate towards the incident with the visualizations. Finally open interviews are held to discuss the visualizations. Firefighters can then express their opinion about the effectivity of the visualization techniques, and the completeness of the information models. Their feedback is processed to create final designs of an indoor information system. The research process is displayed in Figure 1.

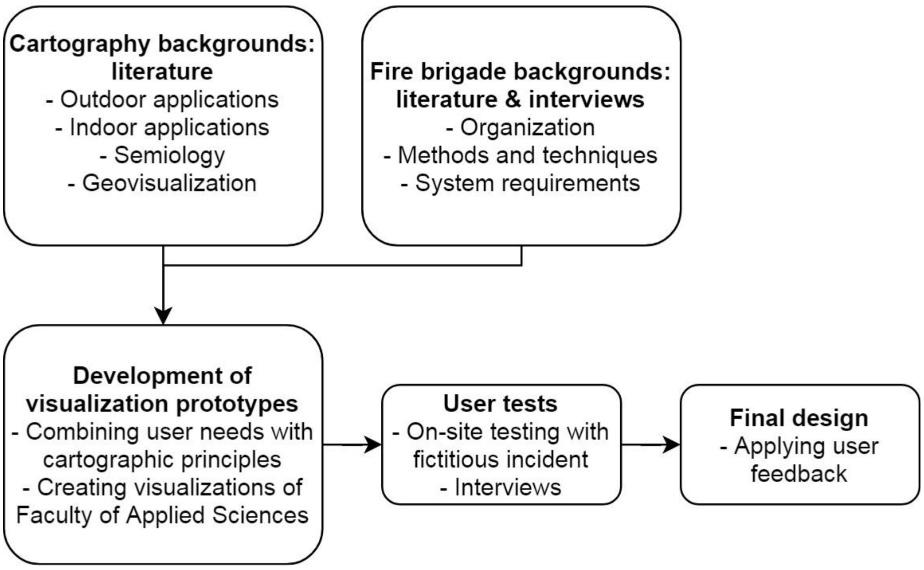


*Figure 1: Research process*

# 4. Fire brigade backgrounds

The Dutch fire brigade has many tasks ranging from animal rescue to cleaning dangerous substances. The goal of this research is to develop cartographic methods that assist them during indoor building fire deployments. This chapter is aimed at explaining their organizational structure, their methods and techniques and their requirements for an indoor spatial information system. It combines scientific literature and documentation from the organization itself with findings from interviews with firefighters. It is important to note that safety regions can have different methods, and most of the interviewees are stationed in the safety region Rotterdam-Rijnmond.

## 4.1. Organizational structure during repressive scenarios

The Netherlands are divided in 25 safety regions. Each of these is responsible for their regional fire brigade tasks, disaster management and crisis control. Safety regions are governed by all mayors within the area during normal situations. During incidents that affect only one municipality there is one mayor in command of the heads of the operational teams such as the fire brigade or the medical emergency services. If more municipalities are affected then the chairman of the safety region takes command of the mayors concerned (NIFV Infopunt Veiligheid, 2011). Each safety region has a common set of tasks (Art. 10 Wet Veiligheidsregio's, 2018) and they have to comply with certain laws and standards, such as the maximum response times (Inspectie Veiligheid en Justitie, 2012). However safety regions still have freedom of choice when it comes to the fulfilment of these tasks and standards. They purchase equipment of their own choice within the legal requirements and the cooperation between emergency services can be organized in different ways. Also deployment methods and tactics can differ between safety regions, which makes communication during large scale incidents difficult. Currently efforts are made to improve cooperation and standardize operations. A nationwide organization of centralized control rooms is currently in development (Groet, 2012) and the fire brigade is currently standardizing deployments to improve effectivity and communication (Lanser, Hendriksen, van der Schuit, & van Rosmalen, 2013).

Incidents are either reported to the control room or they are found with automatic sensors such as smoke alarms. The control room is tasked with alarming the necessary emergency services, supplying them with information about the incident, taking command and control in case the necessary commanders are not present and facilitating and innovating the incident communication process (Taskforce Meldkamer – Repressie. 2013).

The repressive units of the Dutch fire brigade are organized hierarchically. They have a standard unit called the TS6. This unit consists of 6 firefighters and a multi-purpose vehicle with tools on board for several types of incidents. The TS6 has one commander who typically leads a team of 5 firefighters, each of which have a number (van Alphen & Jongerden, 2013):

- Driver / water pump operator: responsible for transporting the unit and the equipment to the incident and operating the water pump.
- An attack team of 2 persons: responsible for exploration of the incident, fighting fires or rescuing persons.
- Water unit of 2 persons: responsible for water supply from either a water tank on the vehicle, fire hydrants or water bodies.


*Figure 2: Standard unit vehicle TS6 with opened hatch (Ziegler Brandweertechniek, 2018)*

The fire brigade is experimenting with other solutions than the above mentioned standard unit. For example there are quick intervention units (called TS2) which operate in smaller vehicles with two persons. These units can either operate on their own, or they are accompanied by a larger TS4 or TS6 a couple of minutes later (van Alphen & Jongerden, 2013). There is also a number of specialized vehicles such as ladder trucks and specialized units such as the dive rescue team or Hazmat (Hazardous Materials) experts. These teams are also led by the commander of a water tender. If the situation calls for more units at once, the commanders of these teams are led by an officer from the fire brigade. If a large number of units is needed, several commanding officers are under command of a head officer. Should coordination between several emergency services be needed, a CoPI (Commando Plaats Incident) meeting is organized. During this meeting the head officers come together to discuss the operation. They are under command by a CoPI-leader who can have a background in any of the emergency services (IFV, 2018).

## 4.2. Timeline of a building fire deployment

No two fire incidents are the same. Procedures exist for certain types of incidents, but circumstances often require a tailor made approach. One commander stated:

> "During a deployment we strongly rely on personal judgement and common sense. There are a million factors that affect which method should be used, so it is not possible to create procedures that apply to every case."

However when moving to an abstract level it becomes possible to list the general steps of complex building fire deployments and the information that is gathered during this process. These steps are visualized in figure 14:

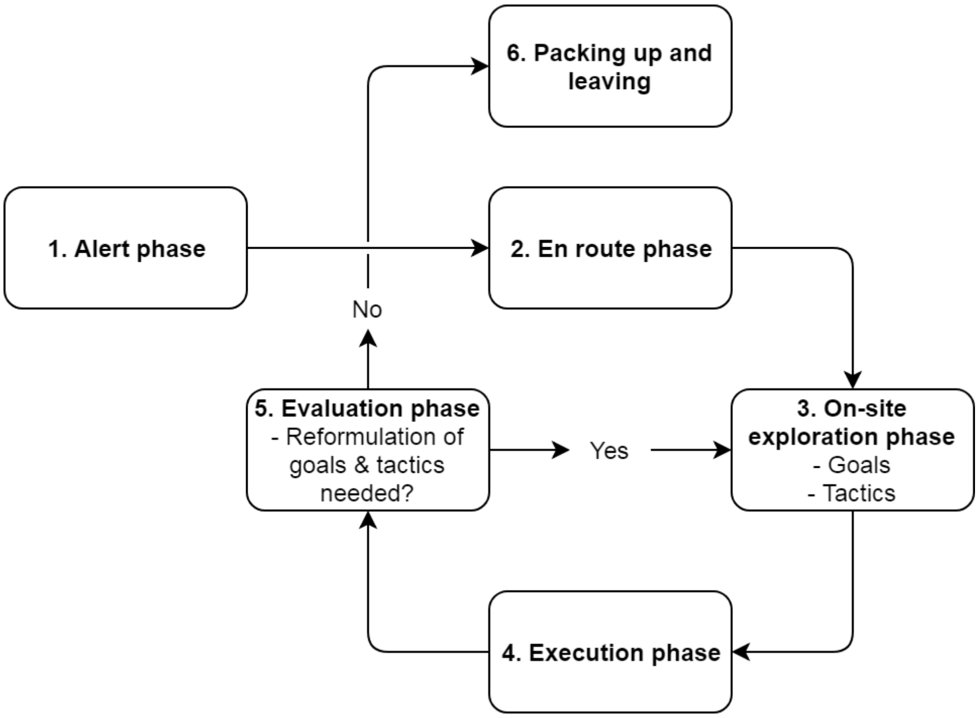



*Figure 3: Deployment phases during building fires*

### *Alert phase*

The deployment starts with either an automatic alert from a smoke detector or a confirmed fire alert called in through the control room. Automatic alarms are often false and in other cases they report fires quickly enough so a vehicle with 6 persons personnel is sufficient to extinguish the fire (Veiligheidsregio Brabant-Noord, 2016). When the fire is confirmed, the approach depends on the safety region. Safety region Rotterdam-Rijnmond formally labels these incidents as a small building fire, but they will deploy two vehicles. These two units will operate autonomously, an officer will only be deployed when the incident is classified as a medium building fire. Most other safety regions only deploy one vehicle during these small building fires (Oskam, V., personal communication, 22-06-2018).
Basic information is provided at the start according to an officer:

"At the start of a deployment our fire pager provides us with information about the address, which units are needed, the type of incident and the name of the building. It is up to the fire brigade to know whether this building has a special function that could affect the deployment, such as a psychiatric hospital."

Time is a crucial factor when fighting fires. The first vehicle assesses whether it is safe to focus on fighting the fire before evacuating the building. This approach can prevent panic, but also escalation of the fire because doors remain closed. A commander explaining this approach said:

"The first vehicle is focussed on delivering the *eerste klap* (the first blow); this means putting water on the fire source as soon as possible. The second vehicle has a more supportive function and focusses on aiding with water supply and evacuating surrounding rooms."

### *En Route phase*

After the alert the firefighters hurry to the vehicle, put on their protective outfit and start the next phase: *en route.* On the way to the incident one firefighter is tasked with navigating the driver quickly and safely to the incident. The commander collects information from the control room about incident characteristics in the scheme of characteristics. The *en route* phase of an incident is short; for most buildings the first vehicle has to arrive within 8 minutes after the alert. Objects that pose extra risks such as buildings with mixed functions or penitentiaries should be accessed within 5 minutes, and the first vehicle has at most 10 minutes to arrive at buildings such as offices or sport facilities (Brandweer, 2018).

### *On-Site / Exploration phase*

On-site the fire brigade collects information to determine the goal of the deployment. Depending on the scheme of characteristics this can be a variety of things; ranging from defensive outdoor deployments to offensive indoor deployments depending on risk & reward. The safety of the firefighters is a first concern during these choices according to an Officer on Duty:

"Safety of personnel is the number one priority. First we assess what dangers exist for ourselves such as dangerous substances, oxygen tanks or asbestos. Building information such as materials and constructional safety is important to us, but it is usually not available upon first arrival. We estimate the structural safety based on building materials and age. Wooden structures have a weaker fire- and smoke compartmentation and older buildings have a higher risk that these compartmentations have been compromised."

The reward-side of the equation represents the goal of the operation. This can be salvation of material, prevention of environmental damage or rescue of humans and animals. If rescue of people is possible, the fire brigade is willing to take extra risks and the Dutch occupational health regulations are more flexible when this is possible (Davits, van Beek & Koomans, 2013). When applicable, The fire brigade consults with in-house emergency response workers whether people could still be present. The fire brigade also makes an assessment whether it is possible that these people are still alive when they reach them.

An important tool for assessing incident factors is the *scheme of characteristics* (Figure 4). This scheme shows that there are three main factors that contribute to the degree of fire safety: human characteristics, building characteristics and fire characteristics.

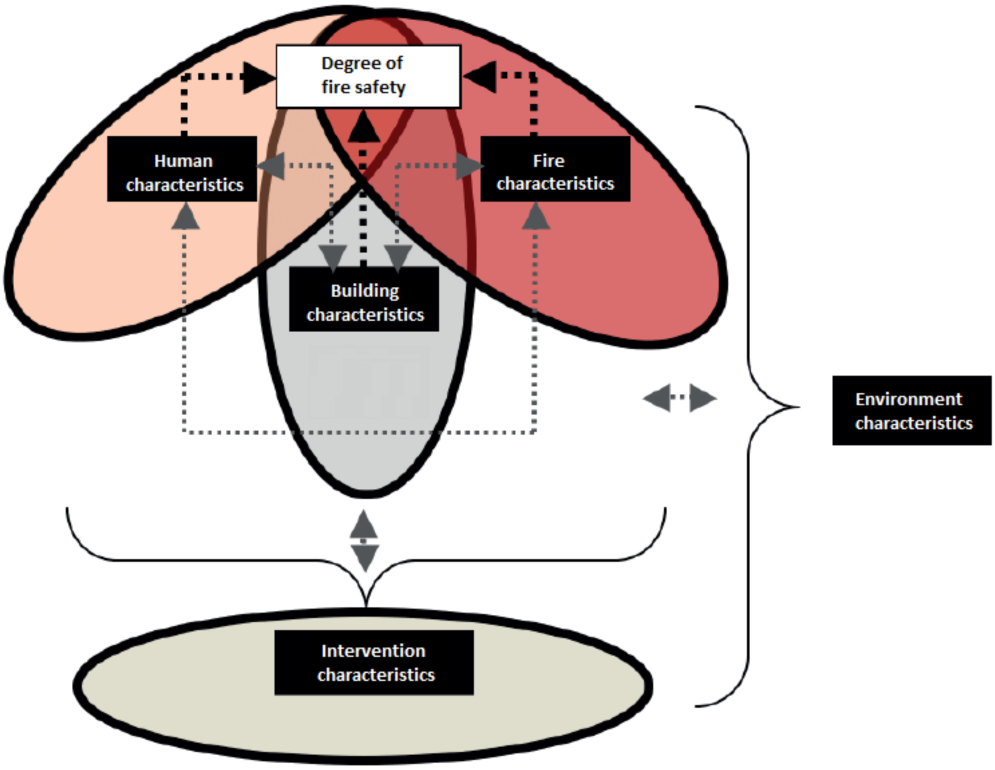



*Figure 4 Scheme of Characteristics (Hagen, Hendriks & Molenaar, 2014)*

**Human characteristics** describe the self-reliance and perceptivity of the people in the building as well as the chance that they are still alive during the deployment. Self-reliance can be affected by handicaps, age, psychological circumstances or alcohol and drug use. Perceptivity can be affected by the time of day, during the night they will be less perceptive. Organizational factors also play an important role; if there is no *bedrijfshulpverlening* (emergency response team) present then the fire brigade has extra tasks.

**Building characteristics** affect the development and the consequences of the building fire. Building height, complexity, volume and underground floor levels affect the tactics choice by the fire brigade. Higher buildings have a risk of 'wind driven fires' where the wind disperses the fire inside the building quickly (Hagen, Hendriks & Molenaar, 2014). All of the above mentioned characteristics affect the accessibility of material, the speed of access and the possibility to leave the building quickly if the incident escalates (van der Meer, 2016). Preventive measures also affect the degree of fire safety. There are passive and active measures. Passive measures are the choice for inflammable or flame retardant materials, or fire- and smoke compartments. These compartments slow down the fire expansion and allow the fire brigade to operate safely in nearby rooms. Firefighters have mixed views on these passive measures. A commander stated:

"During a deployment we can only assume that buildings comply with rules from the Dutch Building Act about collapse prevention and the presence of a good fire and smoke compartmentation. We do not have time to check this before delivering the first blow."

A lector in firefighting science warns about assumptions like these:

"The fire brigade assumes that buildings comply with the Dutch Building Act, but it is dangerous to say that compartmentations are always intact. Older buildings often have poor smoke compartmentation and industrial building interiors are often altered."

Active measures such as automatic sprinklers can affect the fire expansion, and emergency exits with effective placement and signage can affect the evacuation process. Each safety region uses its own source of building information, but the systems show similarities. Both the printed and digital maps show the accessibility of the building and features like dangerous substances and fire preventive measures (Janssens, 2015)(Dogodigi.nl, 2018)(Bronckhorst.nl, 2018). Figure 5 shows such a digital attack map.

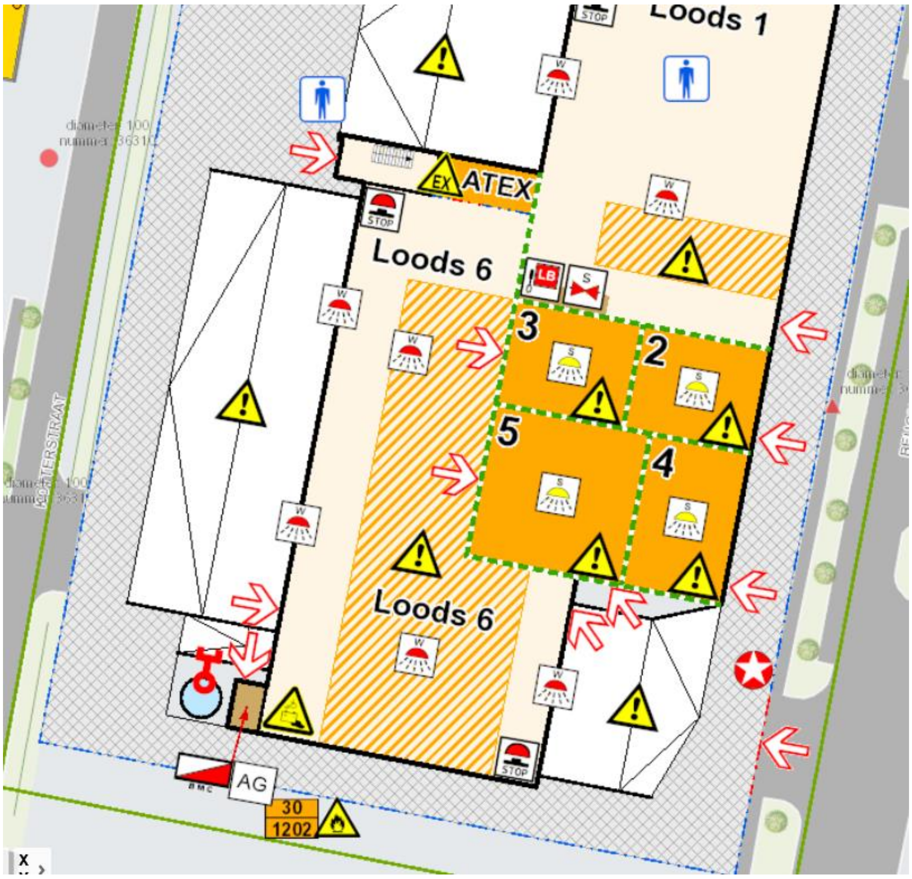



*Figure 5: Digital attack map of the Mobile Operational Information System of Rotterdam-Rijnmond (van der Meer, 2016)*

**Fire characteristics** explain the nature of the building fire. These building fires can be fuel controlled or ventilation controlled. If the size of the fire depends solely on the amount of fuel being burned, then the fire is fuel controlled. Many building fires start as fuel controlled fires. Once the fire grows and more fuel is ignited, more oxygen is needed to sustain the fire. Oxygen can become a limiting factor if the room is closed and the fire becomes ventilation controlled.
The fire brigade does not only look at the current state of the fire, but also at the potential development of the fire. The biggest danger during a deployment is a sudden supply of oxygen to a ventilation controlled fire, as this can cause rapid expansion of the fire or combustion of smoke gasses (Brandweeracademie, 2016). The BE-SAHF model (G-RSTV model in Dutch) is an important tool for this. It encompasses four indicators for fire potential: Smoke, Air-Track, Heat and Fire. These indicators are brought into context of Building and Environment (BE) factors. The SAHF model distinguishes between six different states:

- **Clean:** none of the SAHF indicators are present
- **Fuel:** thick smoke is an indicator for presence of flammable fire gases
- **Air-Track:** when air visibly flows towards a fire source and/or it is able to mix with smoke or fuel within a compartment we're speaking of *air-track*
- **Heat:** when smoke has a high temperature and / or an ignition source is present, we're speaking of *heat*
- **Fire hazard:** when fuel, air-track and heat are all present, there is a high risk of combustion.
- **Fire:** when flames are visible, the SAHF triangle is complete and we are speaking of a fire

**Intervention characteristics:** Besides this there are intervention characteristics such as the availability of personnel and materials.

Given the fact that all the characteristics are in turn comprised of several factors, there is a lot of information that needs to be processed by the fire brigade in a short time span. Some information is more suitable for representation in digital information systems. Many building characteristics are static, making them more reliable than case-dependent characteristics such as self-reliance of humans or fire air-track.

The first focus however is on making the fire manageable. Modern fires produce a lot of smoke due to the use of plastic building materials. This makes the search for people difficult, while the fire keeps developing. Only when the fire source is unknown and smoke is spreading rapidly, it could be necessary to evacuate the building first (Brandweeracademie, 2018).

Whereas commanders state that the first vehicle focuses on delivering the first blow and the second vehicle has more time to gather information, documentation from the Dutch fire brigade academy (*Brandweeracademie*)(Brandweeracademie, 2018) advices a different approach. If present, the firefighters should first consult the fire alarm control panel on-site before entering. This device shows either a schematic or a geometric representation of each building layer and its smoke alarms. Lights indicate which smoke alarms have detected smoke to show where they should start their deployment. On-site decision making then starts after a full outdoor exploration. Time pressure decreases the situational awareness of personnel; they are prone to miss certain details leading to possible incorrect decisions. Taking some extra time to assess the situation enables the fire brigade to collect important situational information (Brandweeracademie, 2015). A deployment should therefore start with an outdoor exploration *before* delivering the first blow. The *Hernieuwde kijk op brandbestrijding* (Renewed view on firefighting) urges firefighters to step back and plan the deployment. Fires in closed building structures (no air flow towards the fire source) do not spread rapidly and in many cases the fire brigade has more time to reflect than they think. Taking time to collect information and plan a deployment instead of using routine solutions is more effective, even when rescue is needed (Brandweeracademie, 2018). With fires in complex buildings there is a list of things that the fire brigade should know for a safe operation (Brandweer Rotterdam-Rijnmond, 2017):

- Fire behaviour of building construction and materials
- Fire preventive measures
- Fire repressive resources in the building
- Building use types
- Building height
- Number of building levels
- Building layout
- Location of water riser pipes
- Number of hose lengths between the water riser pipes and the fire
- Accessibility of rooms
- Number of staircases and their location
- Number of firefighter’s elevators and their location
- Location and capacity of fire hydrants
- Number of hose lengths between fire hydrant and vehicle

An important question during the exploration is whether the fire brigade has enough material and personnel to control the incident. There are four fire categories: small fire, medium fire, large fire and very large fire (respectively *kleine brand, middelbrand, grote brand & zeer grote brand* in Dutch). With a confirmed fire (not just an automatic alarm) in a complex building the standard approach is to classify this as a medium fire. Two water tenders and one officer are deployed to the incident. If evacuation or rescue is needed, a third water tender is deployed. On-site the fire brigade also makes an assessment whether their standard material is sufficient, or whether additional tools or water is needed (Veiligheidsregio Rotterdam-Rijnmond, 2010).

The fire brigade used to have two deployment tactics: the offensive indoor deployment and the defensive outdoor deployment. Incident environments have become increasingly complex and modern building materials have made deployments more difficult. For more tailored approaches to building fires and decreasing risks of firefighters the quadrant model for fighting building fires was introduced in the Brandweerdoctrine (Hagen et al., 2014).

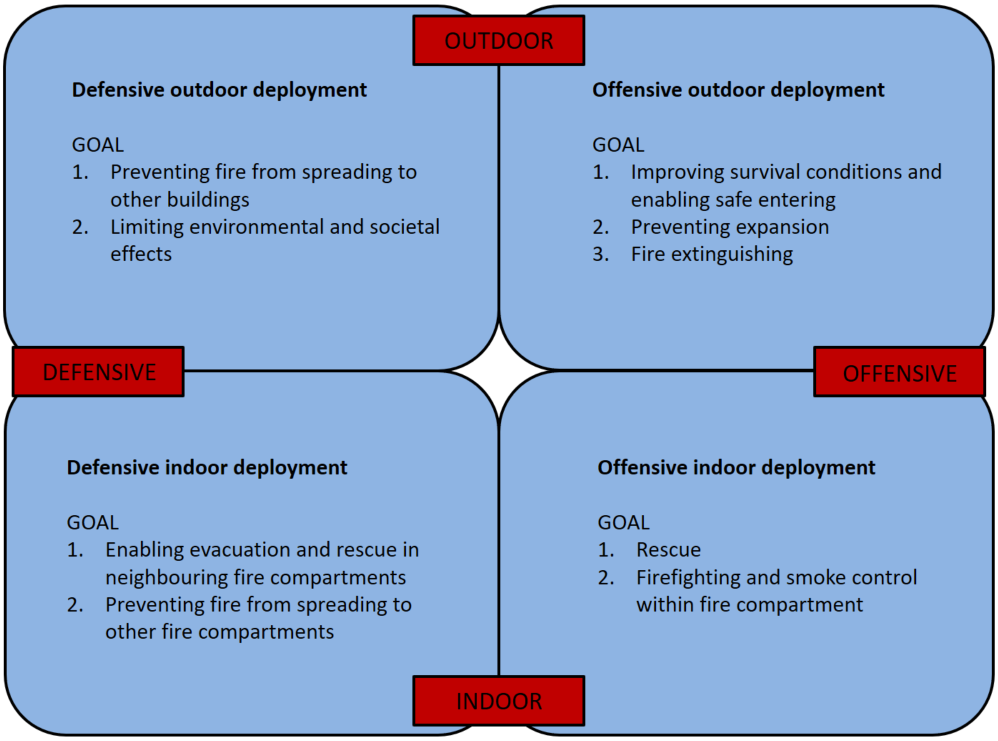



*Figure 6: Quadrant model for fighting building fires (Altered from Hagen, Hendriks & Molenaar, 2014)*

This model distinguishes between deployments where firefighters enter the building (indoor) or stay outside (outdoor), and where the goal is to control the fire within a compartment or building (offensive) or to limit fire expansion to other compartments or buildings (defensive).

The exploration on-site as advised by the Brandweeracademie (2018) is aimed at finding a suitable tactic. Appendix B shows a flowchart that aids the decision making process during building fires. It also shows how tactics can change; for example an offensive outdoor deployment can make indoor conditions safe enough for the firefighters to enter the building.

*Execution phase*

After goals and tactics are established, the execution phase starts. This research is focussed on deployments during complex building fires. The following features help with the identification of complex buildings, although this identification is incident-dependent (Veiligheidsregio Rotterdam-Rijnmond, 2010):

- Building properties require an automatic fire alarm
- Dry or wet pipes or risers are present
- Penetration depth (distance between the water tender and the fire or smoke compartment) is more than 60 meters
- Large fire compartments (> 1000 m2 surface area)
- Cluttered / unclear interior with for example differences between building layers or a lack of landmarks
- Orientation / exploration of indoor spaces by walking alongside a wall is impossible

These types of buildings pose extra threats for the firefighters. Large penetration depths cause longer retreat times and can make it more difficult to evacuate to a safe location in case of escalation. Communication through transceivers can be obstructed and it can be difficult to keep track of people and personnel throughout the building. Lastly it is difficult to keep track of fire expansion; complex buildings can have many ventilation ducts or hidden areas through which fire and smoke can disperse (Veiligheidsregio Rotterdam-Rijnmond, 2010).

Given that circumstances allow an indoor deployment in the first place, the fire brigade starts with an indoor exploration moving towards the fire source. Previously they have consulted digital or paper maps of the building, but these are not always present. An officer on this topic:

> "Relying on assumptions is dangerous. Often firefighters will assume that buildings of the same type also have the same interior, or that building levels are identical to each other. In reality this can be different so it is important to verify our assumptions during a deployment"

Firefighters try to make a mental map of the building by remembering landmarks and their route. Guaranteeing a safe return of the attack time is an important concern for the fire brigade. A lector in firefighting science said:

> "Changing situations during a deployment can pose great risks because escape routes become inaccessible or firefighters become disoriented because of smoke. A real-time plot of fire- and smoke expansion would therefore be of great value."

With low visibility the attack team navigates by following one wall to avoid disorientation. Another way to ensure a safe return is the use of a lifeline (Brandweer Rotterdam-Rijnmond, 2017).

During the indoor exploration the attack team tries to answer the following questions (Brandweer Rotteram-Rijnmond, 2017):

- Where is the incident?
- What attack route should be used?
- Can we quickly extinguish the fire with already present hose reels?

Using hose reels is not official practices but it can be effective. A lector on firefighting science said:

> "Hose reels are primarily meant for people in the building, but the fire brigade often uses it because it allows for a quick intervention with small fires. Larger fires require more water than these can supply, so in these cases we need to use our own equipment."

If the firefighters are uncertain that hose reels are sufficient, the commander will compose a deployment plan and choose tactics. With an offensive deployment the firefighters target the fire source directly, and a defensive deployment is aimed at prevention of fire expansion or creating suitable conditions for an offensive deployment.

In the meantime the water unit has arranged water supply to the pump on the water tender. This water can either come from a tank on the water tender, a fire hydrant on site or an open water body. The commander communicates which water riser they need to use and the pump operator ensures that their pump is connected to it. One member of the water unit will then stay with the fire alarm control panel to check whether fire and smoke is spreading to other compartments. The other water unit member will accompany the pump operator to ensure water supply to the attack team. Once the second water tender arrives, the water unit will report to the commander at the beachhead, a safe location from where the deployment is executed. Here they can assist with the deployment or take turns with the attack team once they have run out of air supply. (Brandweer Cluster Amerstreek, 2010)(Veiligheidsregio Rotterdam-Rijnmond, 2010).

As discussed before, complex building fires always require at least two water tenders. When more than one water tender is on-site, their deployment depends on the incident. The situation could call for additional attack teams to assist the first attack team on the same location, or they could be deployed on other locations in the building as well. Another common task for the second water tender is to supply the beachhead with extra material. These tasks are delegated by the officer. Communication is key during these situations: the commander needs to know the location and condition of his attack team and the commander in charge needs to know what the teams are doing.

The attack team uses the SAHB model to assess the situation in each room and compose a fitting solution. Opening doors is dangerous because it can cause a quick supply of oxygen to ventilation controlled fires. High temperatures cause pyrolysis, so they feel the door handle first. If they expect smoke and high temperatures in the room, they open the door with pulses of water to shield themselves from heat and to cool the smoke gases coming out of the room. They assess the situation and close the door again. If the temperature is low enough for entry they can extinguish the fire. With high temperatures they need to cool down the room first by opening the door for short periods of time and spraying pulses of water inside. The firefighters have specific procedures for this, describing timing, nozzle settings and spraying angles for each situation (Spithorst, 2015).

Next they quickly check if the room is clean, they proceed to the next one. If there is thick smoke in the room, they check whether the indoor temperature is high enough for the production of flammable smoke gases.

## 4.3. System requirements

Defining system requirements in this context is a challenging task. During interviews it became clear that visions and requirements about information systems not only vary vertically among different positions within the fire brigade, but also horizontally among different persons. The team leader in the Operational Information department of the safety region Rotterdam-Rijnmond stated:

> "There are old school and new school firefighters. Old school firefighters typically want to jump into action as soon as possible, and focus on extinguishing the fire source from the start. New school firefighters are more likely to take extra time to consult [digital] information systems and generally have a more accepting attitude towards them"

These old school firefighters rely on methods that have proven to be successful in the past, and rightfully so. They work in dangerous environments to save lives so it is logical that they have a hesitant attitude towards things that could potentially slow them down. However outcomes in 'The Renewed View on Firefighting' (Brandweeracademie, 2018) prove that a more information-driven approach is safer and more effective when fighting building fires. System requirements for the indoor cartography development of this research is based on these outcomes. This means that the results will not appeal to all end users but an attempt will be made to consider their needs as best as possible. One officer and knowledge director from the fire brigade stated:

> "Effectivity is quality multiplied by acceptance. We must not only invest in the quality of the innovation itself, but also in the acceptance by the end user. It is important to thoroughly explain the functionality of the innovation and how this can help the user. This process is called the soft side of innovation and requires a lot of experience with firefighters."

Several interviewees stated that their current information systems often supply too much information at once, but they also agree that all features in the system are useful in some part of the process. Dosage of information in the right form, at the right time and to the right person is important. Assuming that the Renewed View on Firefighting (Brandweeracademie, 2018) will be the national norm in firefighting in the future, an indoor information system could be a good addition to deployments. It could help firefighters adopt a data-driven approach with customized deployment plans for each incident. Moreover firefighters stated that it would be useful to keep track of fire expansion and personnel. The purpose of the indoor visualizations will therefore be twofold:

- Assisting during on-site and indoor exploration to help formulate an effective deployment plan
- Tracking fire expansion and personnel during a deployment

The system requirements of the interviewees could be summed up as follows:

- The hardware should be functional in harsh conditions. It should be able to withstand water, heat, shocks, soot and grime
- Wearing or operating the system should not impede firefighters in their tasks.
- Building information changes often and the system should not give false information
- Information should be dosed to users and incident phases
- 2D and 3D indoor maps both have strong points and weak points. 2D floor maps give a good overview of separate building layers, but their perspective within the whole building is not visible. 3D maps are good for showing the shape of the building, routes over several floor levels and features within perspective of the whole building.
- Doctrines are mainly useful for standard deployments. Divergent deployments require personal judgement of the situation. The system should provide information and provoke thinking instead of supplying specific procedures.

### *System users*

In order to develop effective visualizations, we must also identify the users. During a complex building fire deployment (medium or large fire) the firefighters are hierarchically organized in four categories: crew, commander, officer and head officer. These different actors have different information needs. A knowledge director and commander said on this topic:

> "The attack team needs information for operational tasks, such as the location of a fire and fire hose connectors in the building. Commanders are operating on a higher abstraction level to delegate tasks among crew members. An officer looks at the building as a whole and is also interested in environment characteristics. He wants to know which crew is doing what, and is less interested in detailed information for practical tasks"

The crew consists of the attack team, water unit and pump operator. Specialized crews also exist. Interviewees stated that the attack team is too heavily packed and too much concerned with safely executing commands from the commander to consult a mobile information system. A lector on firefighting science proposed the following:

> "It is important to be flexible when it comes to deployment procedures, and not to be afraid to change these if that causes more effectivity and safety. It would for example be possible to deploy a third person with the attack team as a navigator"

In some cases a third person already accompanies the attack team with a thermal imager. Another person mans the fire alarm control panel to warn others in case of fire expansion. If this control panel were linked to the spatial information system, all users would have direct access to this information. The firefighter previously manning the fire alarm control panel could then assist the attack team as a navigator. This navigator would be the first user. He or she operates the information system and provides the commander and attack team with operational information. The navigator would accompany the attack team towards the incident and help with indoor wayfinding. He or she can also input exploration results into the information system to inform all other personnel about their progress.

**The Navigator** has the following system requirements:

- The system should be able to track firefighters indoors
- The system should provide information about fire- and smoke expansion
- The system should provide clear information on building shape and size, fire preventive measures, hydrants, entrances, compartmentation, dangerous substances and (escape) routes
- A single crew operates on a single building level or section at once. They are mainly interested in building information that applies to their area.
- A 2D representation that provides a relatively detailed overview of separate building layers and their features
- A 3D representation that shows the shape, size and complexity of the building as well as routes and features over multiple building levels with lower levels of detail

**The officer** and the **head officer** manage several teams in different parts in the building and outside of it. Because of the similarities in their user needs they are treated as a single group. Their system requirements differ from those of the commander and the navigator:

- They are both interested in maps with a higher abstraction level, so details about hose connector types are not needed.
- The system should be able to track firefighters indoors
- The system should provide live information about fire- and smoke expansion
- The system should provide clear information on building shape and size, entrances, compartmentation, dangerous substances and (escape) routes
- The system should provide information about how different areas and building levels are compartmented or through which ways smoke and fire could disperse through the building. Hidden shafts should be displayed.

## 5. Backgrounds in cartography

Maps are created during the cartographic visualization process. This process comprises all steps in the transformation of geographic data from a database into graphics. It is guided by the phrase 'How do I say what to whom, and is it effective?', which holds four keywords:

- *How:* cartographic methods and techniques
- *What:* the geographic data
- *Whom:* the map audience and the purpose of the map
- *Effective:* usefulness of the map

This phrase contains four questions that encompass all cartographic domains, ranging from traditional paper maps to digital 3D indoor models. This chapter first focusses on traditional cartographic methods and techniques such as map design and semiotics, and map ergonomics that ensure the fulfilment of the user's needs. After that the modern developments in cartography are discussed in a subchapter called *geovisualization*. Finally a subchapter is devoted to indoor cartography, where previous findings from literature are described and where outdoor methods are assessed by their suitability for indoor applications.

### 5.1. Cartographic methods and techniques

Information that users derive from maps will never completely coincide with the original information that served as input for the map. During the communication process some data may have been left out on purpose, mistakes could have been made or the map reader may interpret the data in the wrong way. Cartography aims to eliminate these sources of errors by presenting such graphic presentations that the map reader is able to draw the right conclusions (Kraak & Ormeling, 2010). The cartographic communication process compares the information derived by the user with the intended message to be communicated (Figure 7). If the information derived by the user is different than the intended message, than the cartographer needs to go back to the cartographic process to produce a map that communicates the message more effectively.

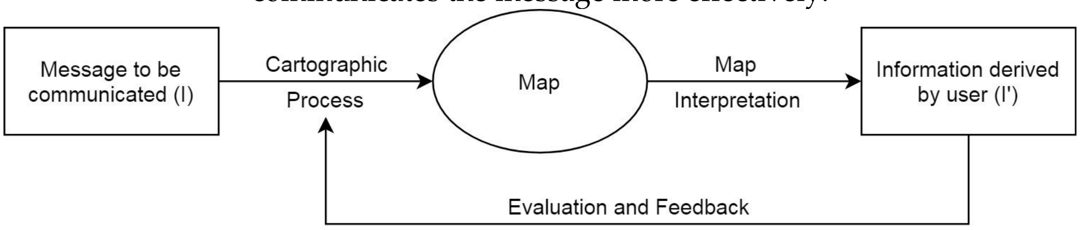



*Figure 7: Model of the cartographic communication process (Altered from Kraak & Ormeling, 2010)*

Maceachren (1994) distinguishes map uses in four main categories:
- Exploration and examination of spatial data
- Confirmation of assumptions, questions and hypotheses
- Synthesis of ideas and spatial relationships
- Presentation of the location features and relationships

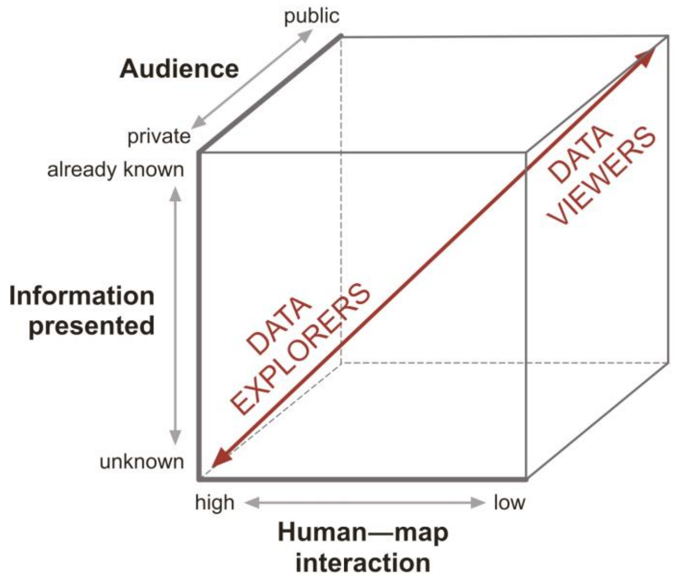



*Figure 8: The map use cube (Macheachren, 1994; Neset, Opach, Lion, Lilja & Johansson, 2015)*

Each of these purposes has different audience characteristics, a difference in need for user interaction and differences in data familiarity. Figure 8 shows these differences in the map use cube. Data explorers are typically from the private realm of an individual researcher or small groups of researchers. They investigate a dataset of which the meaning is yet unknown, and they require a relatively large degree of user interaction to explore this data. Data viewers on the other hand typically work with published maps in the public domain. The meaning of the data is clear, so the map depicts a clear message. User interaction is also lower for data viewers because the intended message of the map is clear from the beginning – the user does not need to alter it to derive that message (Maceachren, 1994)

### *4.1.1 Data acquisition & processing*

The cartographic process starts with the information, or the message to be communicated (I). Data could come from many sources. Traditionally topographers and geodesists mainly supply x- and y-coordinates. Z-coordinates (representing the values at these locations, except altitudinal data), are defined by others such as soil scientists and census takers. Nowadays this division might not be so sharp anymore. User-generated web content has become an important source of geographical information. Goodchild (2007) referred to this as Volunteered Geographic Information [VGI]. Projects like OpenStreetMaps or Wikimapia allow any user to collect spatial data without the intervention of GI specialists (Elwood, Goodchild & Sui, 2012). In smaller scale applications such as the mapping of indoor environments, data are collected by scanning systems such as RGB-D scanners that collect pixel depth and colour, or laser scanners that collect point clouds (Henry, Krainin, Herbst, Ren & Fox, 2012). For these indoor applications the collection of both the locational data and the values is typically done by GI specialists.

Data from these sources is usually not ready for cartographic presentation, it needs to be processed first. Data can be classified, their correlation with other data can be shown or their statistical qualities could be presented. This data processing changes raw data into meaningful information.

## 5.2. Map design

Information needs to be presented effectively to the user. Presenting it in diagrams would allow various possibilities such as histograms, line diagrams or logarithmic presentations, however the opportunity to show relations to other geographic phenomena is lost. Maps offer the possibility to draw geographic conclusions. The Oxford English Dictionary (2018) describes a map as '*A drawing or other representation of the earth's surface or a part of it made on a flat surface, showing the distribution of physical or geographical features(…)'*. Historically the maps printed on flat paper are most common but maps were also produced as globes or relief maps. Current day maps are often not printed at all. Although digital maps are indeed displayed on 'flat' computer monitors or smartphone screens, they have more possibilities than the traditional printed map. Digital maps can be zoomed, panned or rotated and their content can be altered. 3D-models showing the shape of mountains or buildings are also considered maps. Longley, Goodchild, Maguire & Rhind (2011) make a distinction between two types of maps: the formal maps versus transitory maps and map-like visualizations. The first kind is created according to well-established cartographic conventions such as military maps or topographic maps. Transitory maps and map-like visualizations are used simply to display, edit or analyse geographic information such as routing information or results of database queries. During this research all representations of the earth's surface and its features are considered maps.

Robinson, Morrison, Muehrcke & Kimerling (1995) identified seven controls in the map design process:

- Purpose of the map affects what should be mapped and how the information is portrayed.
- Reality of the mapped phenomena can impose constraints on the map design. Areas with oblong shape such as Chile will be mapped differently than more compact shapes. Also indoor environments require different mapping techniques.
- Characteristics of the available data (such as vector or raster, continuous or discrete, 2D or 3D) will affect the design.
- Map scale affects the size of the area that can be seen at once, but also the level of detail of the map.
- Different audiences want different types of information on a map, and expect to see different presentations of that information. This mainly translates into the level of detail.
- Conditions of use will impose significant constraints. Maps for use in low or high light conditions should be designed differently than those designed for normal indoor use for example.
- Technical limits are imposed by the display medium.

The map composition choices are affected by two arrangement approaches: the *planar organization* and the *hierarchical organization.* The planar organization tackles the arrangement of map elements at a given level, and the hierarchical organization focusses on the arrangement between element levels (Dent, 2008).
Balance is an aspect of planar organization. It stands for the visual impact of the arrangement of image units within a map. The image space has two centres: the optical centre and the geometrical centre. The optical centre resides just above the geometric centre, and map elements should be balanced visually around this optical centre (Dent, 2008).

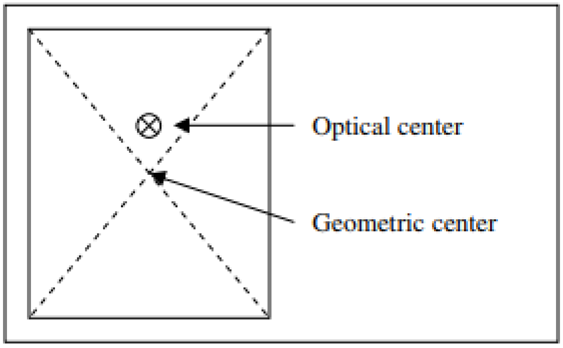



*Figure 9: Geometric centre and optical centre (Dent, 2008)*

Rudolf Arnheim suggested that in visual arts there are several factors that affect the visual balance (Arnheim, 1988). From his findings a list of effects that are applicable in the field of cartography were listed, divided by the effects of element shape and position.

| **Factor** | **Effects on visual balance** |
|---|---|
| Element shape | Larger elements appear heavier |
| | Colour affects visual weight. Red is heavier than blue, and bright colours are heavier than dark ones |
| | elements of regular shape appear heavier than irregularly shaped elements |
| | Compact shapes appear heavier |
| Element location | The weight of elements increases in proportion to its distance from the centre |
| | Elements in the upper part of a composition appear heavier than those in lower parts |
| | Elements on the right part of a composition appear heavier than those on the left |
| | Isolated elements appear heavier than those surrounded by other elements |
| | The weight of elements attracts neighbourhood elements |

*Table 1: Effects on visual balance (Arnheim, 1988)*

Another approach for achieving visual balance using unequal division of space, based on the golden rule. This unequal division of space are more interesting to the user, and small spaces struggling against large ones are more vivid (figure 10).

Arnheim (1988) advices not to forsake the content to create a visual balance; the meaning of the image is more important. This is even more prevalent in the practice of cartography, where the artistic freedom of arranging elements at is very limited. Dent (2008) stated that shapes and their location are often imposed by their geographical facts, but he suggested that the guidelines by Arnheim (1988) should only be applied when this doesn't affect the meaning of the image.

Hierarchical organization can be divided into two elements: intellectual hierarchy and visual hierarchy. Intellectual hierarchy stands for the order of importance of all the map elements related to the map's purpose (Krygier & Wood, 2011). Based on this intellectual hierarchy a visual hierarchy can be created, where the most important elements stand out from the others. This can be achieved by making design decisions that improve the so-called figure-ground relationships. Objects that stand out in the image are called the figures and the rest of the display is called the ground. There is a number of techniques for making the figure stand out from the ground (Krygier & Wood, 2011; Kraak & Ormeling, 2010):

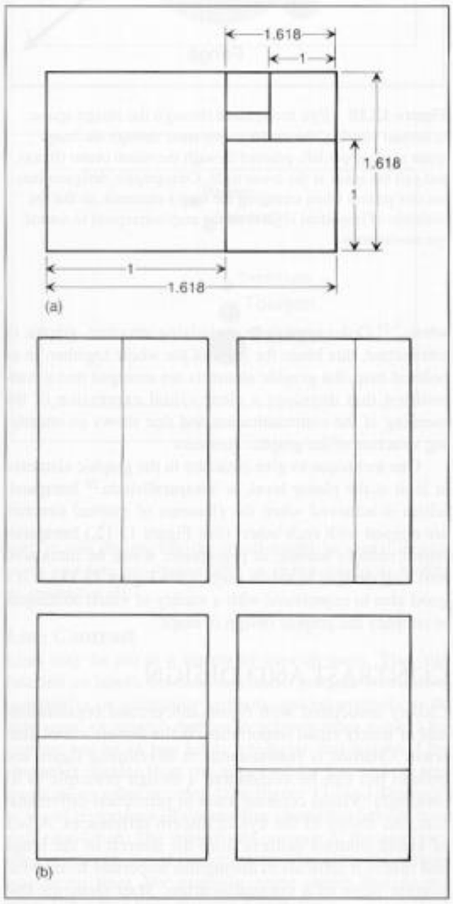


*Figure 10: Division of space according to the golden rule (a) and equal vs. unequal distributions of space (b). Note how unequal distribution is more appealing to the viewer (Dent, 2008)*

- Colour: contrasting figures are created with intense colour such as reds or highly contrasting hues such as yellow-black or blue-orange.
- Shape and size of graphic values or objects
- Direction
- texture or pattern
- Contour: shadows, outer glow or thicker borders for figures. Grey, white or blurred edges move objects to the lower visual level
- Closure: closed objects tend to stand out
- text: spacing, case, size, boldness, width or grey value
- Texture difference
- Detail / articulation: ground has less detail than figure
- Layering / interposition: visual depth is enhanced when the ground continues behind the figure. This can for example be achieved by drawing grids of latitude and longitude behind the figure.
- Proximity: Objects close together tend to stand out as a figure
- Simplicity: simple objects are higher in visual hierarchy
- Familiarity: objects that are recognizable to the reader jump out as a figure

Visual examples of these figure-ground techniques are shown in figure 11.

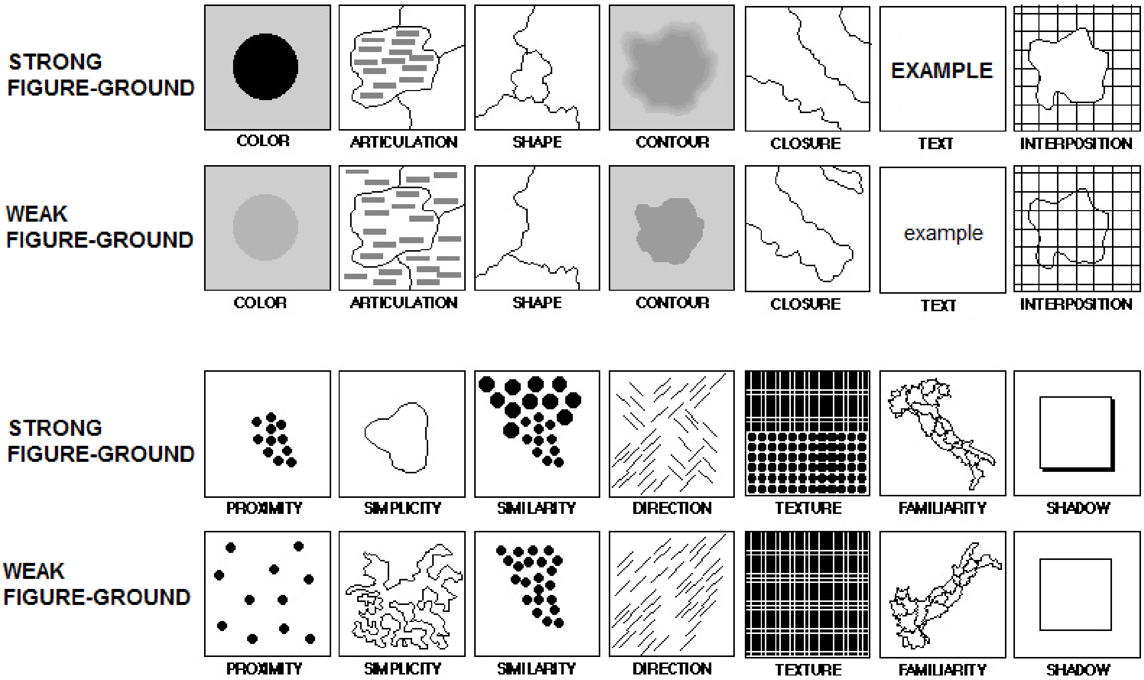



*Figure 11: Techniques for establishing strong figure-ground (altered from Krygier & Wood, 2011)*

## 5.3. Signs & symbols

Semiotics and semiology are about the study of signs. These fields can be applied to all sorts of human endeavours such as theatre, politics, history and religion (Seiler, 2001). The signs can be of a great variety too, they can range from a white flag as a symbol for surrender to the unfriendly middle finger in traffic.

Semiology was introduced by Ferdinand de Saussure in 1915. De Saussure never published his findings himself, instead his students assembled their notes and published a book called 'Course in General Linguistics' in 1916. He was the first to elaborate the tripartite relationship:

signifier + signified = sign

- The **signifier** has a physical existence and carries the meaning. This is the sign as perceived by the reader, for example a hand gesture or marks on paper.
- The **signified** is the meaning of the signified. The signified is common to members of the same culture and people who share the same language.
- The **sign** is the associative total of the signified and the signifier.

For example, the three black marks 'c-a-t' serve as a signifier for a cat. Together they comprise the sign. The relationship between the signifier and the signified is arbitrary, and neither of these entities exist outside of the construct called a sign (Seiler, 2001).

Roland Barthes (1997) distinguishes between motivated signs and unmotivated signs. Motivated signs are iconic; they have a natural relation between signifier and signified. For example a photograph of a person is iconic, because the signifier naturally resembles the signified. Unmotivated signs relate between signifiers and signifieds by convention alone. Agreements are made by the users of the sign. For example a no parking sign has a blue background in the Netherlands, while the colour blue has nothing to do with car parking directly. Users agreed to associate this sign with no parking zones, and communicated this convention through driving lessons and governmental organizations. De Saussure focussed on the denotative function of signs, Barthes (1997) made a distinction between the denotative and the connotative meaning of signs. Denotation means the obvious meaning of the sign, or the common sense. Seiler (2001) demonstrated this with an example with a photograph of a street. The denotative meaning of this image is the street itself, and nothing else. If the photographer used a soft filter and took the picture on a sunny day, the street would look warm and hospitable. The denotative meaning is unchanged (the meaning of the sign is still the same street), but the way that the street is displayed affects the connotative meaning of the sign.

Whereas de Saussure assumed a common understanding about the meaning of signs within a group of people who speak the same language, Charles Sanders Pierce (1839 – 1914) believed that there is no such direct link. He thought that the meaning of signs depends on the mind of the viewer. He is the founder of another branch in the study of signs: semiotics. Pierce defined a sign as 'something which stands to somebody for something'. This 'somebody' explains the difference between the semiology of de Saussure and the semiotics of Pearce. He adds the interpreter to the equation of de Saussure (van der Schans, 2001):

$$\text{signifier} + \text{signified} + \text{interpreter} = \text{sign}$$

Motivated signs should be used in mapping whenever possible, because the user can instantly derive their meaning without explanation. However convention plays an important role in topographic mapping. Map users will generally associate blue colours with water and dark green colours with forest areas for example, while the natural colours of these areas can be different. The convention for representing spatial features with specific symbols originates from the French topographic mapping practice in the eighteenth century. The result of this is that there is a large collection of semi-standardized symbols for topographic maps. These symbols cover subjects like hydrography, infrastructure, buildings and administration (Kraak & Ormeling, 2010). However there is an increasing number of maps that do not describe terrain or fixed assets. Thematic maps show ever-changing themes, and cartographic efforts for indoor environments have been lacking relatively to outdoor applications (Nossum, 2011). The French geographer Bertin who started using variations in graphical aspects in a logical structure in order to represent various sensations in thematic maps (Bertin, 1983). He proposed a collection of basic graphic variables: size, value, grain/texture, colour, orientation and shape. Kraak (2003) showed how these variables can be applied to visualize point or line features, or areas (Figure 12)

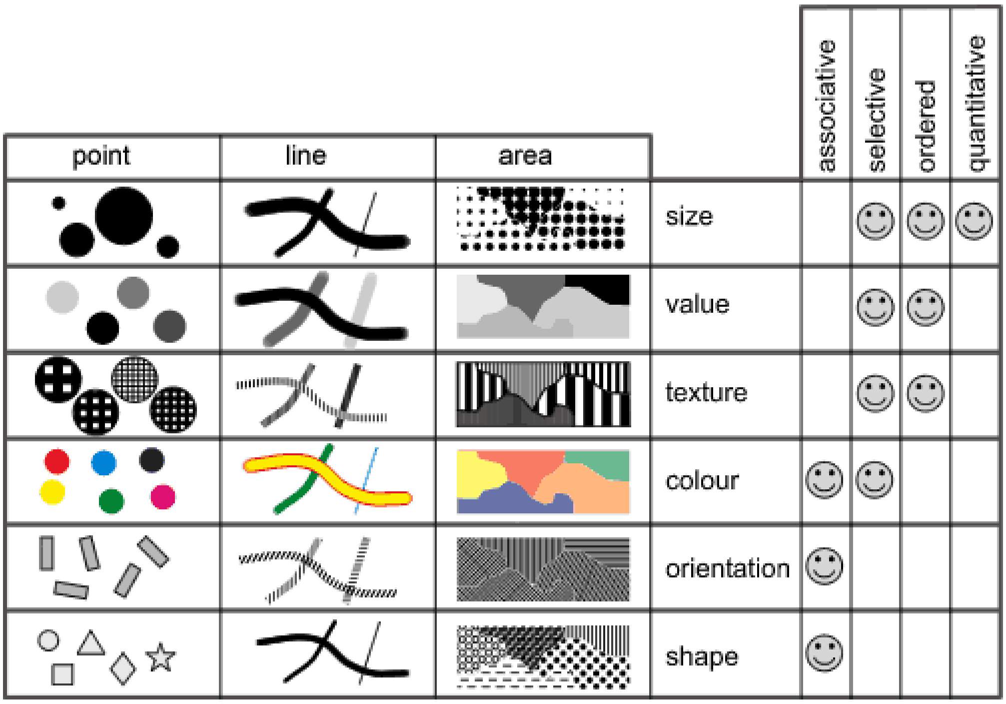


*Figure 12: Basic visual variables by Bertin (1983) and their uses (Kraak, 2003)*

Some fields require a standard approach for symbol communication. Emergency responders need to interpret crisis maps quickly and under pressure, which can only be done with a universal emergency symbol standard. The user environment of these emergency responders gives little time to refer to a map legend (Akella, 2009), risking that the message interpreted by the user does not match the intended message by the cartographer. After the 9/11 tragedies in New York City the Federal Geographic Data Committee Homeland Security Working Group (FGDC HSWG) proposed a universal system for map symbols for all levels of emergency responders. Emergency responders were asked to explain the meaning of 28 of these symbols in both the Operations and Incidents category. Only six of the symbols met the 85 % comprehension rate by ANSI (2002).

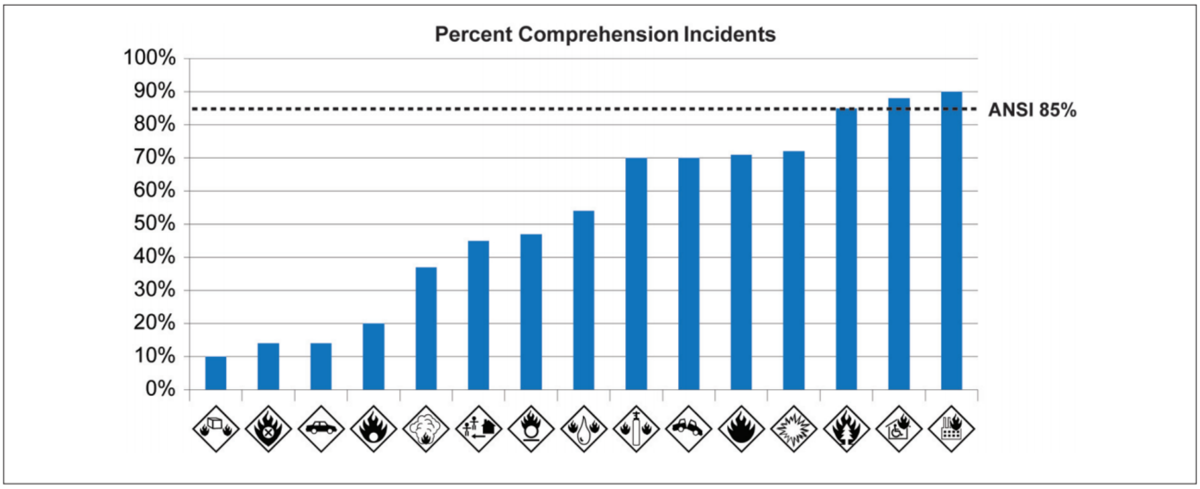



*Figure 13: Percent correct responses per Incidents symbol (Akella, 2009)*

Figure 13 shows the comprehension rate of symbols in the Incidents category. The symbols for Wild Fire, Special Needs Fire and Non Residential Fire were well comprehended by the emergency responders because they have *direct pictorial representations* that are strongly associated with their referents. Symbols that were not identified correctly either had *indirect pictorial* representations or *indirect associative representations*. These symbol types often led to critical confusion, for example the Fire Origin symbol (14% comprehension) was incorrectly identified as 'no fire' or 'fire extinguished' by 38% of respondents and the Vehicle Accident symbol (14% comprehension) was incorrectly identified as 'safe route for vehicles' by 22% of respondents. Interestingly no colour is used in these symbols and the effect of symbol colouration on comprehension is not assessed by Akella (2009). Clarke (1989) states the usefulness of colour to create a visual hierarchy, but the contribution of colour to symbol comprehension is not mentioned. Forrest & Castner (1985) briefly mention that colour would help the user with sorting between basic symbol categories. Colour coding of symbols is currently standard practice for categorization (ISO, 2015) (OSHA, 2018), but it is currently unknown whether symbol colour can improve comprehension percentages.

## 5.4. Geovisualization

Traditional maps allow readers to answer 'what', 'where' and 'when'- questions easily. However there are some limitations: the 'what' should be a feature of limited complexity, the 'where' is preferably an area that allows top-down viewing and the when is usually a snapshot in time. For more complex questions these static maps do not suffice. Today's visualization is about interaction and dynamics, and users expect real-time access to data. This interaction adds a new function to maps: it stimulates thinking and decision making by the user (Kraak, 2015). Morrison (1997) describes this process as the 'democratization of cartography': with geographical information systems the user no longer depends on what the cartographer decides to put on the map. They are able to choose visualizations and analyses that satisfy their needs.

Modern data sources are much more voluminous, complex, and structurally complex than before. Geovisualization techniques differ from traditional map making techniques in that they use interactive computer environments for data exploration. It also entails the creation of several representations of large and complex datasets on the fly, and allows for the representation of changes over time. In technical terms, geovisualization builds upon the traditional map making methods and display. Today's geovisualization has become an area of activity that leverages geographic data to meet various scientific and societal needs. It provides additional options to visualize data such as cartograms or dasymetric maps (Longley et al., 2011).

The digital nature of geovisualization techniques also allows for additional options for display media. Kraak (2015) mentioned a number of functions that need high interactivity options in exploratory visualization environments, where the goal is to let the user look at the data in any combination and at any scale with the aim of finding new patterns. Basic display functions of the digital map include panning, zooming, scaling, transforming and rotating. These functions should be available in both 2D and 3D representations. Moreover users should be able to query data from the underlying geographic database, and multi-scale options should provide the possibility to access data with different levels of abstraction or detail. It should also allow data manipulation in order to stimulate visual thinking. Examples are the choice of data classification or prism maps that use the height of an area to display the attribute value. Different data types could be displayed in different windows, all representing related aspects of the data. These windows can contain a wide range of data types such maps, video, sound and text. Dynamically linked views allow the user to click an object to show its geographic relations with objects in other windows. Finally Kraak (2015) mentions animations as a way of mapping complex processes, either temporal or nontemporal. The user should be able to control the flow of this animation as well.

Mobile GIS applications allow the user to do so anywhere. Other innovations such as virtual reality displays immerse the user in the data model by displaying it everywhere around him through special headsets with built-in displays. Augmented reality systems work by overlaying the data onto the real world instead of substituting it. This allows the user to view the environment around him, but enriched with information that would otherwise be invisible to the eye (Koch, Neges, König & Abramovici, 2014).

### 5.5. Dynamic features

Not all building features are static. Depending on the purpose of the map the user might be interested in the movement of people or changing accessibility after a certain hour. Building information during fire incidents isn't static either. Fire can and smoke can spread dynamically, accessibility can change and firefighters move through the building. But how does one display change in a map? Previous research has come up with solutions for this in the shape of static graphics and animations. The literature review of Morrison et al. (2000) concluded that static graphics such as flow lines, arrows or static images of a number of time intervals are usually best suitable to support learning. If it is necessary to see micro steps between large changes then animations are more suitable. However, this review does not take into account the current day importance of real-time data. Blok (2005) describes how animations are not only suitable for detecting micro changes, but it also allows the user to detect in what manner these changes occur. For example they can infer if the changes are abrupt or gradual, or whether outliers occur during the process. Pitfalls of animations are also mentioned. The interpretation of events depends on the user, and there is a risk of information overload because the user has to monitor several changes within the area. Moreover *change blindness* can occur when the view is interrupted or when the visual variables in the field are too weak or too slow to be noticed. Careful animation design is needed, including the provision of controls.

Blok (2005) extended graphic variables as listed in chapter 5.3 with four dynamic visualization variables:

- **Moment of display**: moment of a representation state or change in display time
- **Order**: Sequence of changes or states in the representation in display time. This sequence is structured by a chosen criterion (e.g. chronological or based on a particular attribute)
- **Duration**: length of display time
- **Frequency**: repetition of changes or states in the representation over display time

From a design perspective there is still a variety of options within these dynamic visualization variables. Within interactive environments there is also a number of control variables which allow the user to change the display. Examples of interactions in dynamic visualizations are selection of attributes and time intervals, changing animation speed or the graphic representation or repeating an animation (Blok, 2005).

## 5.6. Devices

Cartographic principles are not applicable to all display devices. Nagi (2004) validated these principles for use in mobile devices (Table 2). Some of the limitations of these devices such as slow connectedness, limited storage, restricted processing power and limited resolution and colour range have been solved by technological advancements. Nagi (2004) stated that the most important limitations of mobile devices are the screen size and the user environment, and these issues still apply today. Users of mobile maps can be outside where hazards and distractions limit their focus and the amount of possible user interaction. The lack of peripherals also limits the interaction possibilities; mobile devices rely mainly on touch interfaces. Maps for mobile devices should be more generalized than those viewed on personal computers, while still communicating the intended message. There is little room for legends, so symbols on the map should be self-explanatory with minimal use of text and labels. Conventional rules for the sizes of screens, symbols and labels can’t always be applied to mobile applications. For example the guidelines for text and symbol size by Buckley (2008) are based on viewing distances from 46 centimeters onwards. The average viewing distance for mobile devices is 32 centimeters when reading text messages, and 36 centimeters when reading web pages (Bababekova, Rosenfield, Hue & Huang, 2011). This would indicate minimum text and label sizes of 5.3 pt, which is difficult to read in dynamic environments. Moreover Taylor and Hopkin (1975) proposed 9° as the optimal visual angle. With a viewing distance of 36 centimeter this would mean that the optimal screen size is 8 centimeters diagonally in case of a square display. This is smaller than most current smartphone display sizes and would further limit the amount of information that can be displayed on the map.

| **Display:** | **Performance:** |
| --- | --- |
| Small screen size [D] | Slow connectedness [N] |
| Limited resolution [D] | High latencies [N] |
| Low (if any) colour range [D] | Limited storage [D, N] |
| **Interaction:** | Restricted processing power [D, N] |
| Limited input opportunities [D] | |
| Restricted output capabilities [D] | |

**D**: Device, **N**: Network
**Source:** (Urquhart *et al*., 2004)

*Table 2: limitations of mobile devices (note, some of these might be solved)*

## 5.7. Indoor cartography

Cartographic methods and geovisualization are developed for a wide range of scales, from global maps to maps of small neighbourhoods. When mapping indoor environments these methods might not always apply. Maps of indoor environments will usually represent a smaller area in the real world, allowing for a larger scale with a higher level of detail. Buildings often have several levels making it difficult to map them in a single top-down view. Indoor cartography is still in its infancy. For example there is currently no consensus on the type of information that is needed to support indoor navigation, and it is still unclear how the use of landmarks differ between outdoor and indoor environments (Giudice, Walton & Worboys, 2010). Lorenz, Thierbach, Baur and Kolbe (2013) make two statements on the state of indoor cartography with the purpose of indoor navigation. First, findings from cartography and cognitive science are not being adequately applied. Most approaches use existing floor plans and superimpose route information. Second, there is no unified theory for the design of more effective indoor maps. A lot of research effort is currently dedicated to the technical aspects of indoor wayfinding, but indoor map design is still lagging behind.

Lorenz et al. (2013) conducted a research on the effect of map perspective (2D top view versus 3D oblique view) and landmarks on user satisfaction with indoor navigation maps. Their visualizations can be seen in figures 14 & 15. With these two map design factors they explained about 30 % of variance in user satisfaction with maps. 3D representations performed better because they enhance spatial understanding. Because humans have a special ability in remembering images (Siegel, White & Reese, 1970), landmarks that contrast with the environment are easily remembered. Lynch (1960) states that the uniqueness of these landmarks is a result of a strong figure-ground, as well as spatial prominence, their location at junctions, historical associations and visual dominance. Sihombing & Cours (2018) created both 2D and 3D visualizations of separate floor levels, but did not study differences in effectivity. In the research of Lorenz et al. (2013) landmarks had the largest effect among 3D map users. The number of landmarks, their kind and their representation did not have a significant influence, smaller numbers of landmarks were considered just as beneficial as more larger numbers of them.

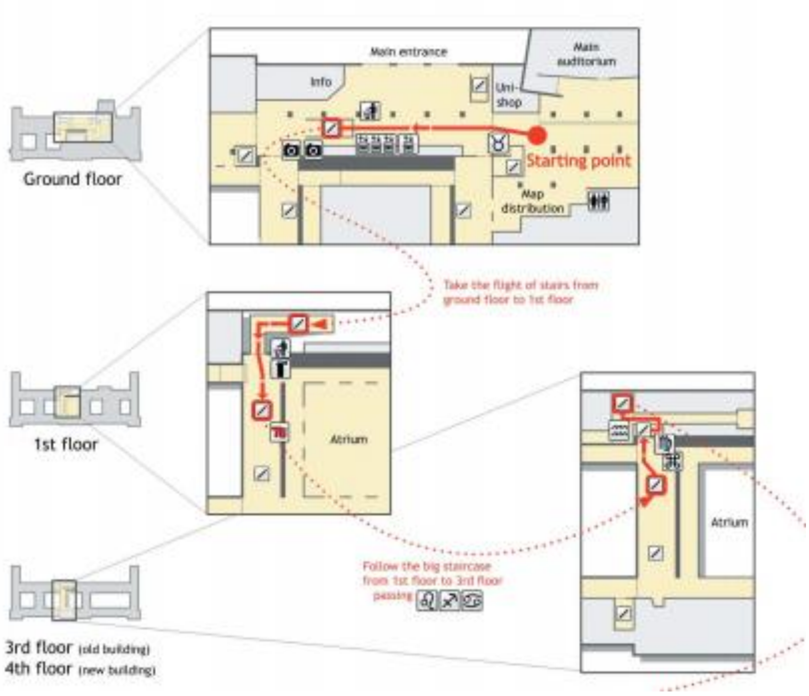



*Figure 2: 2D Top-down view of multi-level building (Lorenz et al., 2013)*

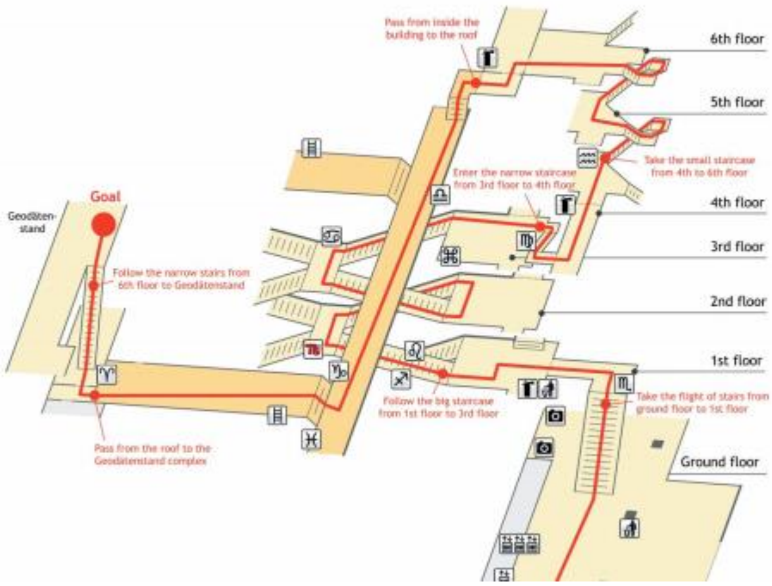



*Figure 35: 3D Oblique view of multi-level building (Lorenz et al., 2013)*

Most efforts within indoor cartography show a single floor per map. Lorenz et al. (2013) made an exception with their 3D Oblique routing map (Figure 14). They left out the areas that do not belong to the route in order to prevent blocking the view of lower building levels. Nossum (2011) discusses the use of traditional cartography versus displaying 3-dimensional virtual environments. He states that virtual environments are capable of displaying very accurate representations of the indoor environment, but he is uncertain that they are suitable for all purposes in indoor environments. Traditional outdoor maps excel at giving a fast overview of large areas due to the abstraction of the area. Virtual environments do not show these abstractions, which calls for the development of new visual representation methods for indoor maps.

In current efforts users express issues of easy perception of several building floors, getting an overview of one or several floors, the level of detail in the map (this is usually too high) and the general perception of these kinds of maps. Nossum (2011) also states that current efforts are mainly aimed at personal navigation, while the use cases of indoor maps are wider than that. The development of hand-held devices with high resolution screens has opened up other possibilities with indoor mapping, and present day users require real-time location and user specific information. For indoor maps topology is more important than geometry. This means that the cartographer can deviate from the geometry slightly for the sake of aesthetics and readability. Furthermore design choices depend on the map users; different users have different requirements. Nossum (2011) distinguishes two user factors for map design: user familiarity and user tasks. For example a hospital coordinator that is familiar with the building has more interest in the real time information of workers and their position, while a patient that visits the hospital for the first time has more interest in the route to his destination. User tasks can range from navigating from a to b, getting a building overview to getting detailed information. Different users also have different needs in terms of activity, three interactivity groups are distinguished:

1. No interactivity: viewing only
2. Little interactivity: the user is able to manipulate the viewport through pan or zoom
3. Full interactivity: The user can for example rotate and manipulate the viewport, look up detailed information, perform route manipulation and step-by-step navigation and add information to the map

Nossum (2011) proposed a new indoor map style called IndoorTubes. This style is based on metro system maps which show the topological ordering of stations with coloured lines. By overlaying corridors and transfer areas the user can see all building floors at once in a single representation. Different colours represent different floors, and overlapping corridors are also used to give visual cues about the topological ordering of floors. IndoorTubes also display only the absolutely necessary to prevent visual clutter: corridors, rooms, elevators and stairs. Rooms are depicted with a small line and a text label. Crossing lines can be resolved by adjusting them graphically, since it is expected that users find topology more supporting than geometrical accuracy. However if this distortion is too high, there is a risk of users not being able to recognize the space or estimate distances.

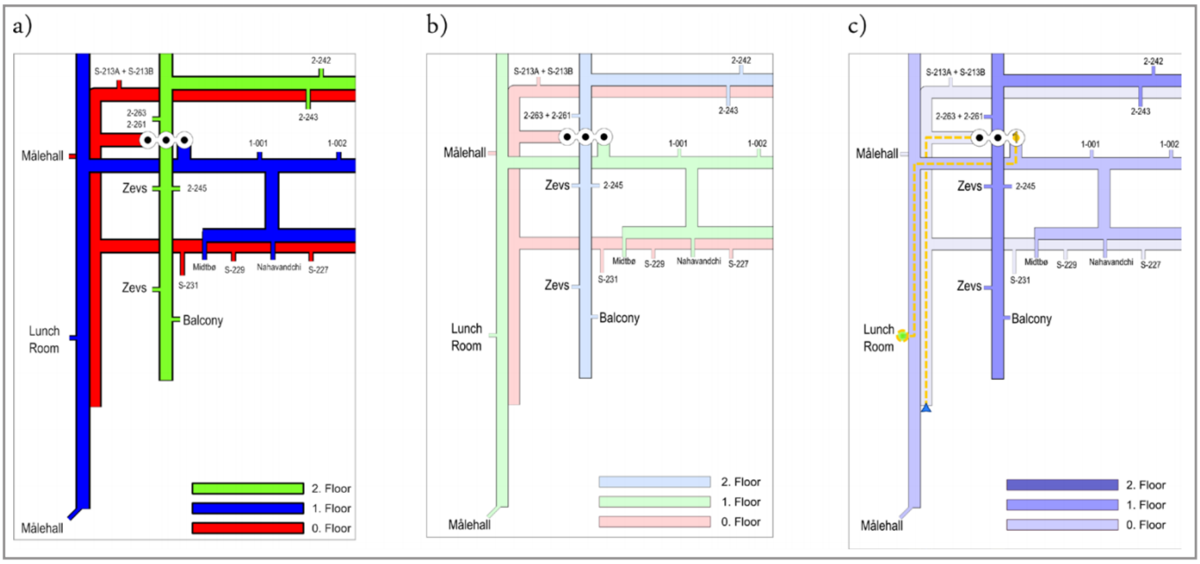



*Figure 16: IndoorTubes (Nossum, 2011).*

Figure 16 shows IndoorTubes with different colour schemes. Each scheme has its own advantages and disadvantages (Nossum, 2011):

a) Shows a qualitative colour scheme with strong colours that make visual separation of floor levels easy. The corridors are the figure in this image, and the overlaid information is the ground. This scheme is useful for giving a quick overview of the environment but is not suitable for displaying dynamic building information.

b) Shows a qualitative colour scheme with dampened colours, making the overlaid information stand out better.

c) Shows a quantitative colour scheme where a sequential palette represents the building floor. The darkest shade is the top level and the lightest shade is the floor level. This scheme is especially useful for navigation tasks because the visual queue hopefully allows the user to distinguish at what part of the building he or she is located. However it is more difficult to differentiate between two building floors, especially when a large number of floors is visualized. This problem could be solved by only showing the user the two floors above and below his position.

IndoorTube are an innovative take on presenting indoor building information. The design was tested by letting groups of users navigate through a hospital with either the IndoorTube, traditional floor maps of each separate building floor or no maps at all. Most users preferred the traditional floor maps for indoor navigation. However they expressed that they received insufficient explanation about the IndoorTube for using them effectively. They said that they got used to the design after some time and thought they could be useful for applications where the user is familiar with the environment (Nossum et al., 2012). Hypothetically the preference for floor maps could be explained by the fact that people are more used to traditional mapping methods, and additional training and experience with IndoorTube could lead to higher user satisfaction.

Toutziaris (2017) performed a survey among both experts in cartography and laymen to compare the usefulness of several map types for indoor navigation and route planning. The level of detail of IndoorTubes was considered too low for these purposes, and the researcher stated that this method is less suited for large buildings where the building floors are similar to each other. A new design was proposed where building floors were shown separately. Toutziaris (2017) stated a number of outcomes as guidelines for indoor cartographers:

- Focus primarily on the corridors and try to preserve their geometry as best as possible
- Use colours to distinguish corridors, floor connections and room functionalities. Limit the total number of colours to a minimum
- Include landmarks such as large indoor areas, elevators, staircases and toilets. Use generic symbols for these landmarks instead of their true shape.
- Use self-explanatory symbols that are as simple as possible

While Toutziaris (2017) states that simple symbols should be used for landmarks, Puikkonen et al. (2009) have a different view on this subject. Their user study on a mobile application for indoor navigation in a shopping centre showed that users often do not recognize their own position within the map. They propose tailored mapping solution for every indoor environment where landmarks are represented with their actual shape, and they even propose to base symbol colours on the actual colours in the building. Some of these issues may be explained by the issues they had with positioning the users: their system based on comparing a WLAN scan to an access point database. This method would sometimes locate users on the wrong floor, leading to confusion. Also in their research it was stated that landmark icons were not recognized, but it does not tell which icons they used.

## 5.7. Display device

Finally there is the choice of display device. This has to be a mobile device, because the two user groups should be able to use the system indoors. Three possible options come to mind: an Augmented Reality display in the SCBA, a wrist-mounted smartphone or a handheld tablet. The AR display appealed to the imagination of both commanders and officers; they envisioned a system that projects routes and building features on top of the real world. However this would require indoor positioning techniques that not only record a person's exact position, but also his viewing direction. This is expensive and complicated to achieve in a large number of complex buildings (Brassil, 2014), and this solution can obstruct the view of the firefighters. Wrist-mounted smartphones would allow the firefighters to keep their hands free but the screen size is a limiting factor for the amount of detail that can be displayed. The choice was made to focus on handheld tablets to be able to display higher detail levels. The introduction of a navigator allows the attack team to focus on their conventional core tasks, the navigator operates the system for them. The other user group, officers and head officers, are less occupied with operational tasks. Because of this they are able to operate a handheld device.

## 6. Development of visualization techniques

The previous two chapters were dedicated to cartographic backgrounds and the requirements of the fire brigade. This chapter combines these findings in an effort to develop effective visualizations to aid the fire brigade during complex building fire deployments.

The firefighters are a private audience that consults unknown information; they need to draw their own conclusions from it instead of being presented with a procedure. The fact that little user interaction is possible during a deployment brings them in an interesting position within the map use cube (figure 17). This brings an extra challenge to the development of indoor cartographic methods: clever solutions are needed that allow the fire brigade to explore the data with minimal user interaction. The fact that the intended message (I) in the cartographic communication process is not known by the cartographer makes it also more difficult to verify the effectivity of the maps.

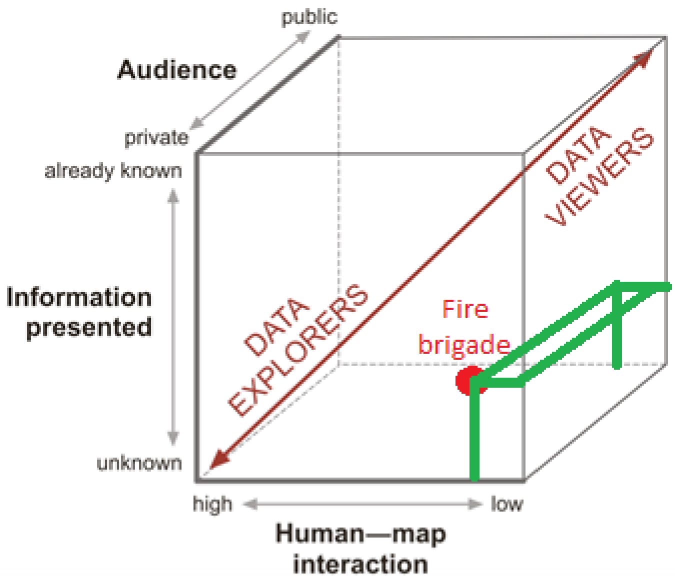



*Figure 17: Position of the fire brigade within the map use cube (Neset, Opach, Lion, Lilja & Johansson, 2015) (Maceachren, 1994)*

Indoor cartography faces a number of challenges and design choices. Previous research has shown a number of possibilities depending on the purpose of the map, the medium used and the expert level of the user. Solutions were often either focussed on routing (Lorenz et al, 2013) or on the location of features within the building (Nossum, 2011). However the fire brigade wants to do both; for example they want to find the location of fire compartmentation as well as the route towards a fire source.

Another challenge is giving an overview of all building levels within a single view. Current efforts often let the user switch between building levels (Nagi, 2014) (Toutziaris, 2017). Lorenz et al (2013) proposed a single oblique 3D view of only corridors which proved effective for navigation, but this solution will not be suitable for all buildings due to occlusion. The fire brigade has specific needs compared to users in everyday situations. Factors like stress, relatively intricate data requirements and difficult conditions of use make them an interesting end user. Their demands have been translated into the seven map controls (Robinson, Morrison, Muehrcke & Kimerling, 1995) in table 3.

| Map design control | Variable |
|---|---|
| 1. Map purpose | - Assisting during on-site and indoor exploration to help formulate an effective deployment plan<br>- Tracking fire expansion and personnel during a deployment |
| 2. Reality of the mapped phenomena | - Indoor environments of complex buildings. Size and shape will vary between incidents |
| 3. Data characteristics | - Both 2D floor maps and 3D indoor models<br>- Both representations have point data, line data and polygon data. 3D representation also has 3D data<br>- Dynamic data on fire expansion and personnel movement<br>- fire preventive measures, hydrants, entrances, compartmentation, dangerous substances and (escape) routes |
| 4. Map scale | - Navigator & commander need a large scale map of their own working area<br>- (Head) officer needs a smalls scale map of the building as a whole<br>- Consideration: variable scale? |
| 5. Audience | - Navigators<br>- (Head) officers |
| 6. Condition of use | - Stressful circumstances<br>- Limited vision because of smoke<br>- Material limits interaction possibilities<br>- Heat, water, shocks, soot & grime |
| 7. Technical limits of the display medium | - Handheld tablet<br>- Limited interaction possibilities<br>- Consideration: physical buttons? |

*Table 3: Map design controls in the context of the fire brigade*

Interviewees explained the added value of both 2D and 3D representations. 2D shows detail per building level, but it is difficult to bring this information into the context of the building as a whole. 3D models are useful for showing building complexity and vertical movement options. Also some objects such as ventilation shafts are better suited for display in 3D. One possible solution would be to build an information system with a 3D model of the building and separate 2D maps of all the building floors. This would provide the users with a wealth of building information, but it has some limitations. Object information derived from a 2D building floor can only be seen on that particular map, it is difficult for the user to see its position within the building as a whole. For example a navigator and his attack team on a third floor might think that they are close to an emergency exit because they see one on the ground floor directly below them. A 3D model could reveal that that their nearest staircase doesn't connect to the ground floor, meaning that they have to take a longer route than expected. In this case the user would have to switch between separate building floors and the 3D model to make this discovery.

Vice versa a 3D model shows complexity and vertical movement options, but this can only be done with abstractions of the building. Showing complete building models in 3D would merely allow the user to see the outer shell, and a building floor model still has occlusion issues. A 3D model of corridors and staircases as used by Lorenz et al. (2013) is useful for showing complexity and routing with minor occlusion. Still some information like the position of a staircase can be hidden depending on the viewing angle. Users would have to switch to a 2D building floor to see an overview of all staircases.

Given the fact that indoor cartography is in its infancy and the fire brigade has relatively complex system requirements, it is important to think outside the box. In an attempt to solve the issues described above, a novel visualization technique is developed in this research called ToggleMaps. Instead of separating 2D and 3D representations, ToggleMaps combine two mapping panes in a single interface. This interface consists of a main mapping pane and a reference pane, both in either 2D or 3D. The user can toggle between two states: a 3D main mapping pane with a 2D reference pane or vice versa (figure 19).

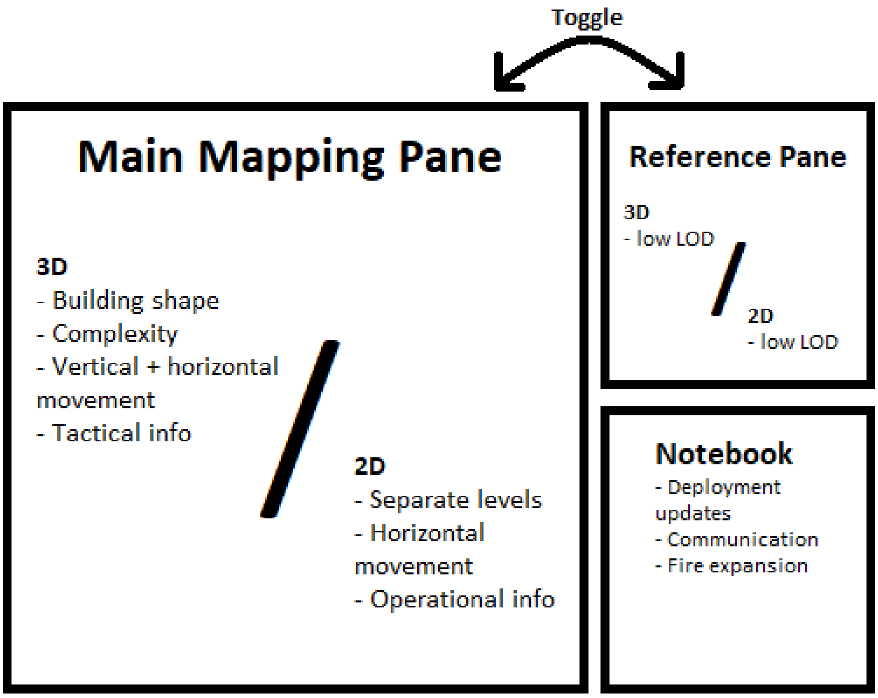



*Figure 19: Proposed layout for ToggleMaps*

ToggleMaps are designed to allow the user to view detailed information about a single floor in 2D and basic routing information in 3D in a single view, and he can toggle to view a more detailed 3D model with a basic 2D model that shows only corridors, exits and staircases. The 2D main map displays a lot of operational information, which is of interest to the navigator. The 3D main map shows building complexity and the position of several units. This tactical information is useful to the second user group: (head) officers. However with this solution neither of the user groups are isolated from any of the building information. A head officer for example is not distracted by detailed operational information per building level when he is using the 3D view, but should he want to know a specific room number then he can toggle to the 2D view. The same goes for the navigator. He or she can focus on operational tasks per building level in the 2D view. Should he want to know vertical movement options in case of an emergency, he or she can toggle to the 3D view.

Linked map views have been applied in outdoor applications before to allow users to visually inspect relations between separate map layers (Roberts, 2005). With ToggleMaps there is a difference in hierarchy: the main mapping pane is used for the finding the information that the user needs, and the reference pane is meant for bringing that information in perspective. This perspective is either within the building as a whole in 3D view or within a single building level.

The main mapping panes are designed for detailed object localization and wayfinding, reference panes are designed with a low level of detail to lay the focus on the 2D / 3D shape and movement options. Table 4 shows the information that will be displayed in each mapping pane.

| | **Main mapping pane** | **Reference pane** |
|---|---|---|
| **3D** | - Corridors<br>- Water riser pipes<br>- Staircases<br>- Elevators<br>- Fire location (dynamic)<br>- Personnel location (dynamic) | - Corridors<br>- Staircases<br>- Elevators |
| **2D** | - Rooms<br>- Corridors<br>- Staircases<br>- Elevators<br>- Fire brigade entrances<br>- Fire preventive measures<br>- Fire repressive resources<br>- Special room functions (e.g. laboratory)<br>- Hazmat info<br>- Fire compartmentation<br>- Fire location (dynamic)<br>- Personnel location (dynamic) | - Rooms<br>- Corridors<br>- Staircases<br>- Elevators |

*Table 4: Information displayed per mapping pane in ToggleMaps*

Applying map design principles to ToggleMaps is challenging. For example visual balance within the mapping panes cannot be achieved because user interaction alters the image. However the unequal division of space as described by Dent (2008) is applied in the interface by designing a large main mapping pane with a smaller reference pane and notebook. This creates an overall more interesting interface for the user. Another challenge is establishing figure-ground relationships. 3D models and indoor 2D maps don't make good grounds as they are relatively complex. Moreover the fire brigade demands a wide variety of building data, with no intellectual hierarchy among them. For example a hose reel is not necessarily more or less important than the location of fire compartmentation.

With good design we can prevent some of the issues described above. Symbol choice will have an effect on the appearance of the ToggleMaps and the legibility of the mapping panes. Symbolization is an important topic for the fire brigade because they need information about a wide variety of topics and they do not have time to refer to legends. One key assumption is that the interpreters of these signs, the navigator and the commander, know more about fire preventive measures and other building aspects than the layman. Some signs are motivated signs to firefighters but unmotivated signs to others, because they work with this information on a day-to-day basis. Wherever possible these motivated signs should be used because the firefighters can infer their meaning by heart. Sticking to symbol convention can also help with comprehension rates. Conventions for 3D representations are lacking because the Dutch fire brigade does not use 3D building models in their information systems. Attempts will be made to translate 2D conventions into 3D symbols, for example by using the same colour codes. The visual variables by Bertin (1983) are originally meant for 2D maps, they will be used for the 3D maps as well.

ToggleMaps show two types of live dynamic data: personnel location and fire expansion. Because this information is live, it needs to be perceived by the user as it is happening. Based on the interviews it is assumed that the map reader doesn't need a warning for movement of personnel, they can just consult the map when they need to know this. Fire expansion is crucial information as it is directly related to the safety of personnel. Therefore three mechanisms are proposed to notify the user. First of all a sound alarm should notify the user of fire expansion when he is not looking at the screen. Secondly a blinking fire icon in both main mapping panes is used to show the reader where the fire expansion took place. Thirdly the notebook is used to write down the details of the fire expansion.

## 7. Production of ToggleMaps prototypes

In this chapter prototype visualizations are created. The Delft University of Technology Faculty of Applied Sciences is used for this case study. Alattas et al. (2018) produced a building model that serves as the basis for the ToggleMaps.

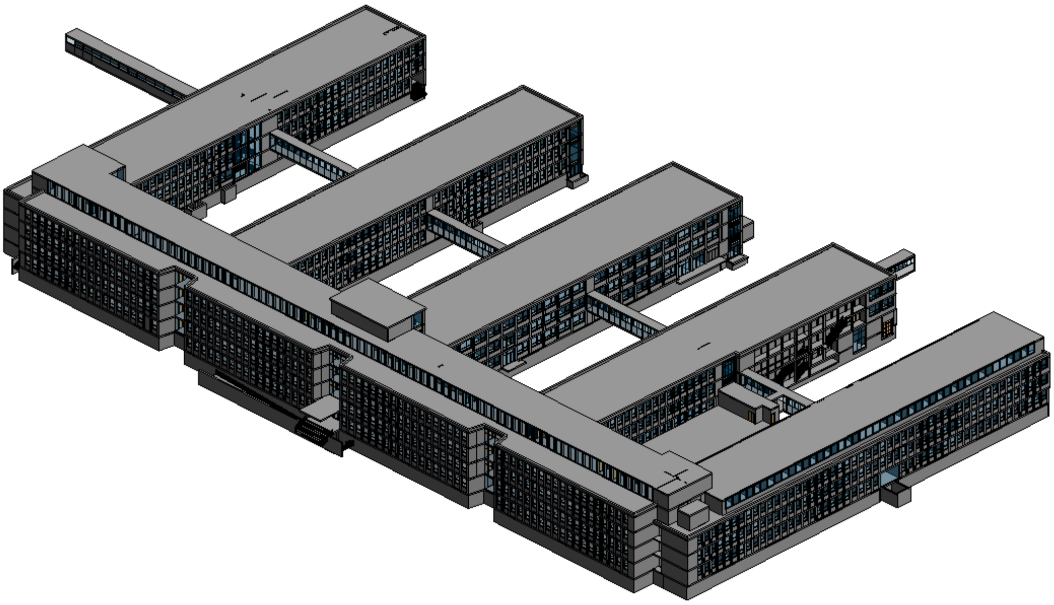


*Figure 20: Building model of the Faculty of Applied Science (Alattas et al., 2018)*

This building can be seen as complex by several of the standards of the fire brigade. With four to five building levels above ground the building is not particularly tall, but it has a large footprint. Attack distances between entrances and potential fire sources are larger than 60 meters and the building level layouts are unequal. Furthermore the building has an underground level and mixed space functions (lecture rooms, offices, storage rooms and laboratories). The model does not contain all information that is relevant for the fire brigade. Objects like fire brigade entrances, water hoses and fire compartmentation are not modelled inside the building. In order to create realistic visualizations the choice was made to use a fictional set of objects inside the building. Their placement was decided in collaboration with an Officer to mimic an incident environment like one they could encounter in real life.

The first step was to create a 3D main mapping pane. This view shows all building levels at once and is meant for showing a limited selection of objects as well as options for vertical movement (staircases and elevators) and horizontal movement. All objects that obstruct the view and are not absolutely necessary for this were stripped; in the case of this particular model that meant removing windows, walls and doors. This results in a model with only floors, staircases and ramps (Fig 22)

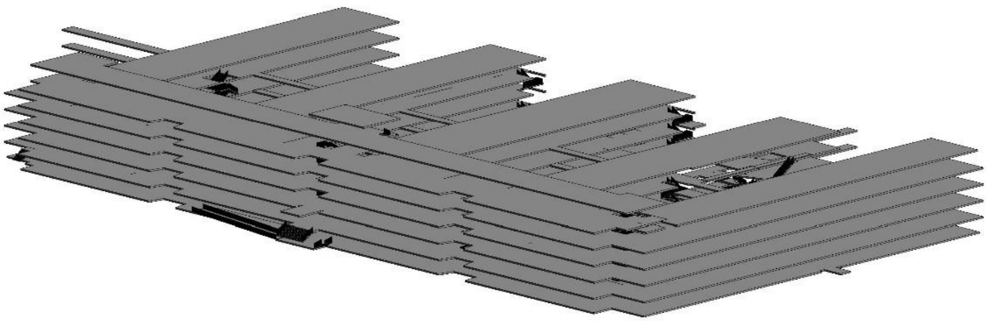


*Figure 22: Unedited building model with only floors, stairs and ramps*

This image has occlusion issues: many staircases and large parts of the floor space are invisible. The lack of colour coding also leads to an overall cluttered image. To prevent occlusion the choice was made to display only corridors. The model does not distinguish corridor floors from room floors, each building level was modelled as a single entity. To solve this the corridors were traced by hand. Some rooms are not directly accessible from the corridors, first the user would have to enter another room. These spaces are called *TransitionSpaces* and other rooms can be listed as *GeneralSpaces* by OGC IndoorGML standards (Zlatanova et al., 2016). During the indoor exploration the firefighters navigate through the corridors to inspect the rooms one by one. If firefighters would solely rely on the corridors for exploration there is a risk of skipping rooms. The choice was made to include TransitionSpaces in the corridor model in order to give more detail about the space to be navigated during indoor explorations.

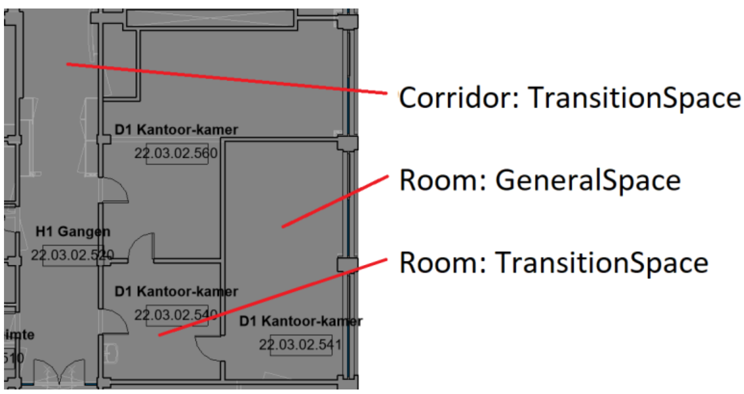



*Figure 13: Explanation of corridor extraction. All transitionspaces are displayed as corridors in the 3D models.*

In order to help the user to tell different floor levels apart the choice was made to use colour coding. Different floor levels have different brightness levels, which is a suitable visual variable for ordered data. The arbitrary choice was made to use the colour blue. The underground building level was coloured in red to create a distinction from the upper floor levels. Different brightness levels of red could be used for buildings with several underground levels. All floor colours are as desaturated as possible while still enabling the user to tell them apart. These desaturated colours were aimed at creating a stronger figure-ground relation with overlaid symbols in later stages. All options for vertical movement were coloured orange because it provides a good contrast with the blue floors. Staircases are displayed geometrically correct, but without handrails. Elevators are displayed as simple vertical columns which are thinner than their true geometry to prevent occlusion. The choice was made to model the (fictional) water riser pipes as well, because the 3D model is very suitable for showing their range. These are displayed as red vertical pipes in this particular case, but in other cases they can run horizontally or vertically as well. A fire symbol with a leader line is added to depict where smoke was detected. This is an indirect pictorial representation, because the signal represents smoke instead of fire. By linking the fire detection system to the ToggleMaps the user could see the fire expansion process from a screen, making it unnecessary to deploy someone at the fire control panel. Fire expansion is a crucial piece of dynamic information as it affects the safety of personnel. To avoid change blindness a threefold solution is proposed. New symbols should blink on screen, and the user should be alerted with a sound alarm. The interface should also show a textual explanation of the fire expansion.

After adding building level numbering and a symbol for the fire source location, the concept version of the 3D main mapping pane of ToggleMaps was done (Figure 24)

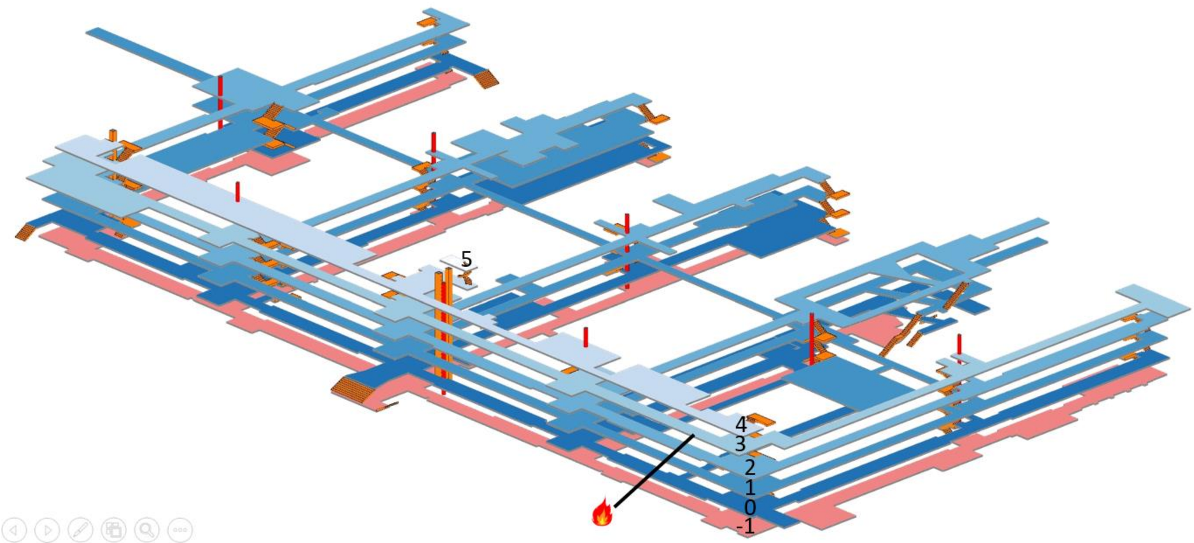



*Figure 24: Concept 3D main mapping pane of ToggleMaps*

As discussed in the introduction of ToggleMaps, there are two 3D views and two 2D views. Reference 3D view is meant for bringing objects from the 2D View into context of the 3D building as a whole. The same model was used as the 3D main mapping pane, but without level numbering because these would become too small to read. Furthermore the choice was made to make the building layer currently selected in 2D view better visible in the 3D reference map. This was done by making the floor levels above it transparent (figure 25).

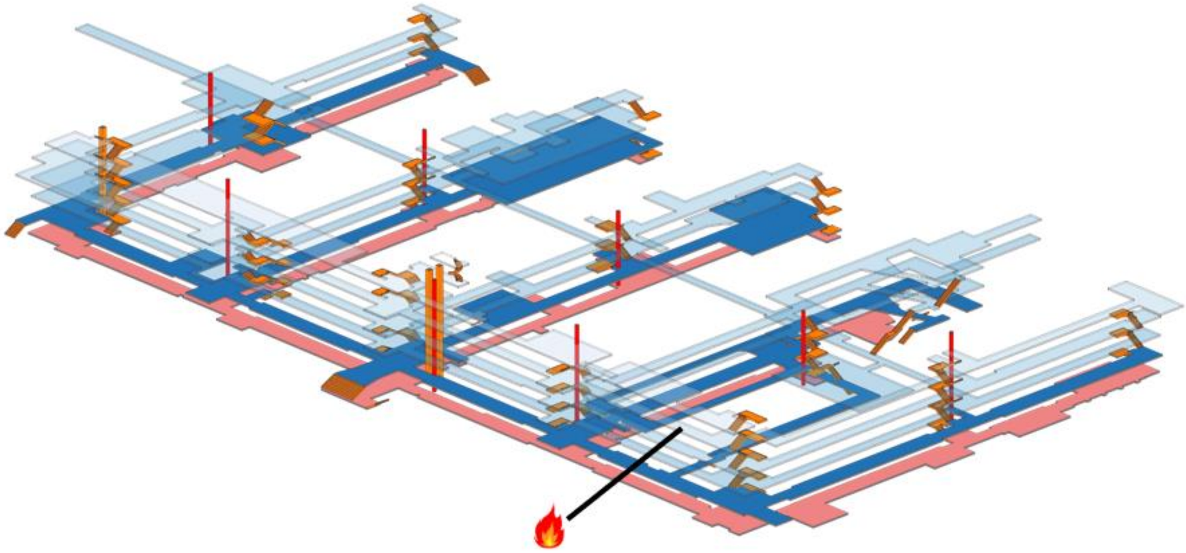


*Figure 25: Concept 3D reference map - ground floor selected in 2D view*

The 2D main mapping pane is meant for showing detail per building level. This mapping pane shows corridors, rooms, entrances and many other symbols. Establishing strong figure-ground relations is challenging. Traditional thematic maps usually show a single topic as figure, and the map geometry as ground. In the case of the 2D main mapping panes this distinction is less clear. The map geometry already needs to show the floor footprint, room divisions, corridors and fire compartmentation. Above all there is no clear hierarchy between all the objects; the position of stairs is no less important than the location of fire compartmentation or fire hoses.

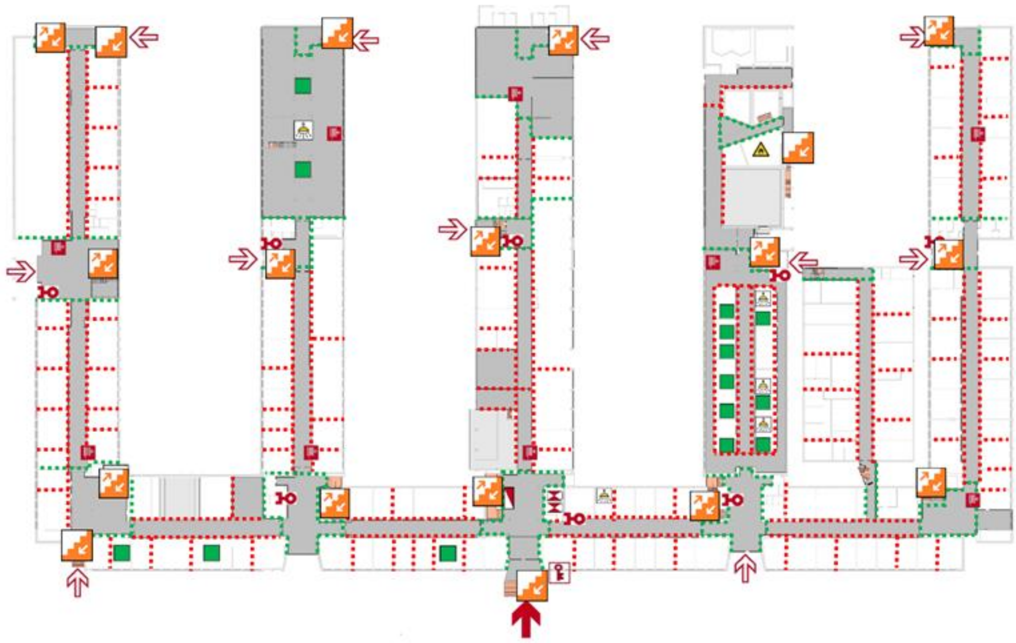


*Figure 26: Concept 2D main map - ground floor*

In an attempt to create a map that displays all objects as clearly as possible, colour coding and convention were used to allow the user to recognize and categorize symbols. The Dutch emergency services use standard symbols published by the NEN, the Dutch service for standardization (Veiligheidsregio Rotterdam-Rijnmond, 2018). Most of the symbols used by the fire brigade belong to a certain category (Table 5)

| | | | |
|---|---|---|---|
| **E** | Evacuation | Green square sign |  |
| **F** | Fire equipment | Red square sign<br>With exceptions! |  |
| **M** | Mandatory action | Blue circle |  |
| **P** | Prohibition | Red circel, object crossed with single line |  |
| **W** | Warning | Yellow triangle |  |

*Figure 5: Categorization and coding NEN-EN-ISO 7010:2012 (Veiligheidsregio Rotterdam-Rijnmond, 2018)*

The Dutch fire brigade currently makes a distinction between evacuation maps and attack plans. Evacuation maps show vertical and horizontal escape routes, emergency exits and basic firefighting appliances. Attack plans contain more detailed information about the building, and they do not show evacuation routes. Emergency services consult them for information such as fire brigade entrances, staircases, fire compartmentation, fire preventive measures and firefighting appliances (NEN, 2007). Evacuation is the responsibility of the local emergency response officers, so evacuation maps are designed for them. However there is are similarities between the two maps; they both show staircases and corridors. Emergency exits often are side entrances for emergency services as well. The choice was made to show only entrances in ToggleMaps to avoid having to place two symbols on a single object. Furthermore standard practice by NEN is to display the true geometry of staircases with overlaid arrows indicating whether the staircase goes up, down or both up and down. This allows the user to see the width of the staircase or the type of staircase. This way the fire brigade can see whether the staircase is suitable for carrying heavy materials or victims. The downside is that it is difficult to see the direction of these staircases. The choice was made to use a symbol to display staircases in 2D. This symbol has the same colour coding as the vertical movement options in 3D (orange) and show the direction of the stairs. Also the symbol is a direct pictorial reference, which increases the comprehension rate (Akella, 2009). Should the fire brigade want to see the geometry of the stairs, then this information is available in the 3D main mapping pane.

With the two main mapping panes and the two reference panes described above we can create concept ToggleMaps for the ground floor of the Faculty of Applied Physics (Figure 27). Map composition rules are difficult to apply to ToggleMaps. In the first place they are meant to be two dynamic interfaces, visual balance cannot be achieved if the user can freely manipulate the images. However the unequal division of space in the interface makes the overall image more appealing to the viewer.

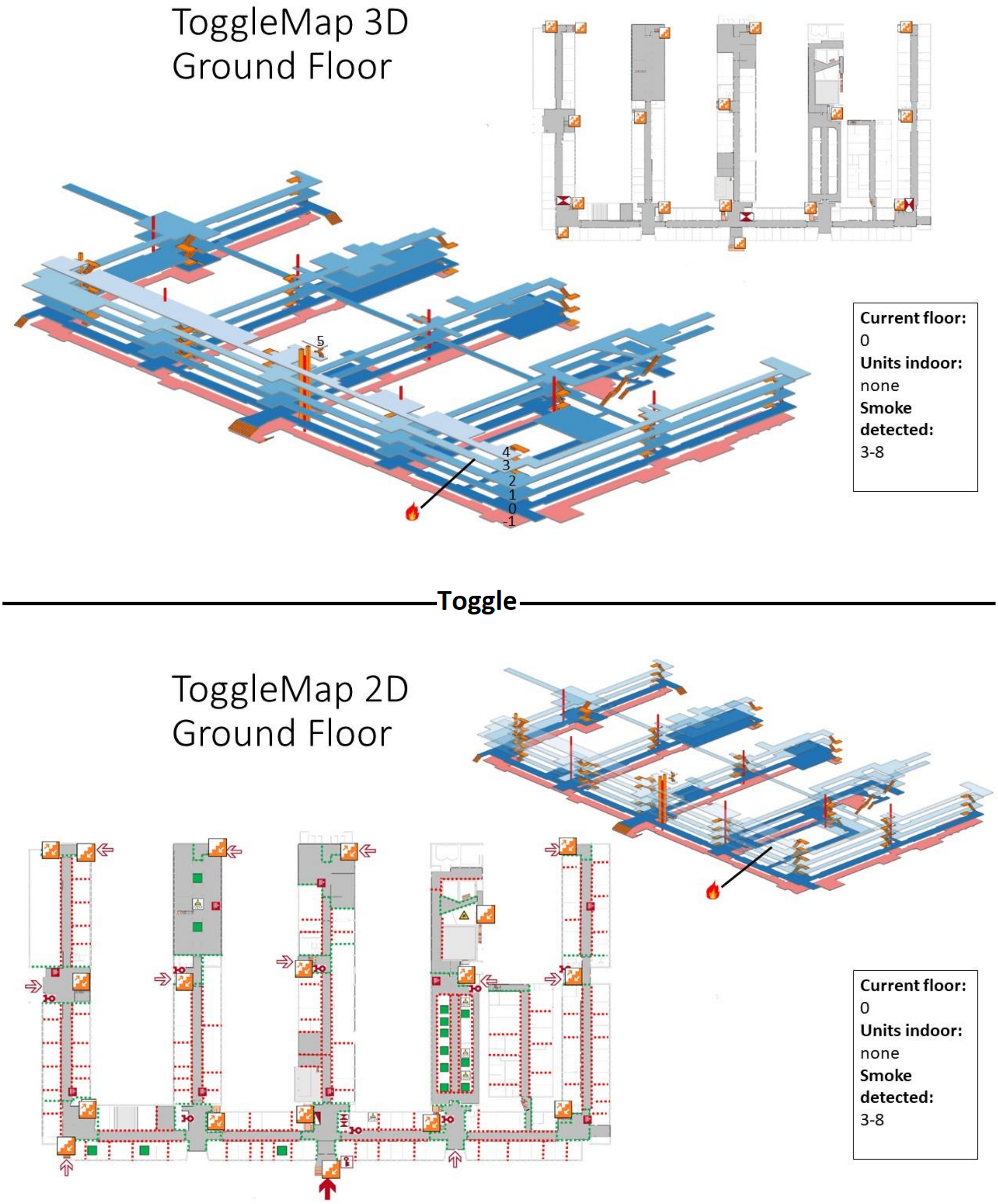



*Figure 27: Concept ToggleMaps with the ground floor selected (page-sized images of all concept ToggleMaps in attachment C)*

The concept ToggleMaps above show two displays: a 3D view and a 2D view. The first display allows the user to see the shape and complexity of the building corridors, as well as the position of the building fire within the building as a whole. The user can refer to the 2D reference map to see occluded areas of the selected building level. For more detail of the selected building level the user can toggle to the 2D view. The 3D reference map in the 2D main view can be used for bringing objects in perspective within the building as a whole. For example a commander can see the position of his attack team precisely within the building floor, and he or she can refer to the 3D reference map to see the route they have to take to get to the exits on the ground floor.
During the interviews firefighters explained that it is important that the information system does not hinder firefighters in their movement. A small wrist mounted tablet was proposed as a hardware solution. With these concept maps it becomes clear that it is not possible to show the whole building while still having legible content. Two solutions are possible: using larger display devices or zooming in to specific parts of the building. These options will be discussed during the user tests.

## 8. User testing

The concept ToggleMaps were based on the requirements of the fire brigade, but they were manufactured in isolation of firefighting professionals. It is therefore inevitable that changes are needed. The ToggleMaps were tested on site by having firefighters develop a deployment strategy for a fictitious incident on site. The visualizations were tested by four firefighters; two officers, one officer / GIS drafter from Operational Information and one officer / knowledge director. These test subjects are from another safety region to ensure that they were unfamiliar with the Faculty of Applied Sciences. On-site testing started with explaining the idea of ToggleMaps as described in chapter 6. The firefighters were handed printed ToggleMaps of the ground floor and building level 3 and 4. A fictitious fire scenario was described to them, and the details about this were included in their handout. The scenario was as follows:

*There is a fire in the Faculty of Applied Sciences. This is a university building with mixed room functions: there are lecture rooms, offices, storage areas and laboratories. The automatic smoke detection system detected smoke on the third building, no sprinklers are present on this particular location. The fire was probably caused by a short circuit, but it is uncertain what is currently on fire inside the room. Next to the room where smoke was detected is a medium risk laboratory. The emergency response officers attempted to extinguish the fire, but they had to abort due to high temperatures. They also started evacuating the building but it is uncertain whether the evacuation is complete. People saw smoke on the fourth floor as well, but this has not been detected by the smoke detectors.*

Firefighters were given the time to consult the maps and formulate a deployment strategy. Notes were taken about their thought process and about the map components they consulted. After they had finalized their deployment strategy, the test subjects were asked to navigate to the beachhead head and then to the fire source. The fire fighters were asked to think aloud about how they composed their route based on the ToggleMaps. Finally open interviews were held so the firefighters could express their opinions about the ToggleMaps concept in general, and the effectiveness and completeness of the given information.

### *Test results*

From the start the firefighters explained their assumptions about the incident. For example they stated that they assumed that the fire was still contained inside the building (no flames visible from the outside) and that compartmentation was intact. In real life this would be part of the indoor and outdoor exploration. All test subjects would request two extra units, they considered this a large building fire due to the complexity of the building and the fact that smoke was observed on the upper floor level. They would then consult the fire control panel downstairs (figure 28 – Area 1) to see which smoke detectors had detected fire. One person would stay here to see if the fire is spreading. They mentioned that they would like to see the entrances and the fire control panel in the 3D Main view.

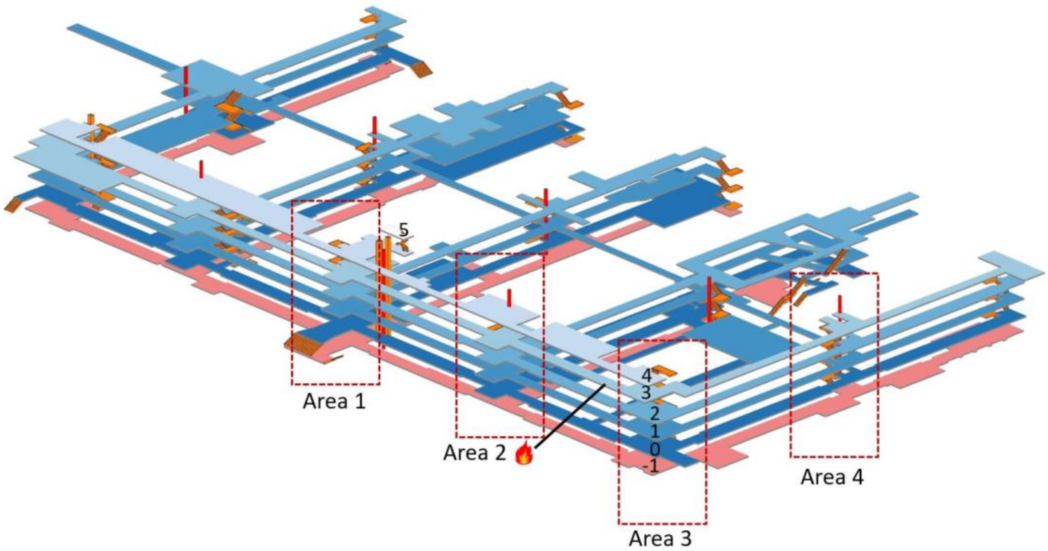



*Figure 28: Areas of interest during the ToggleMaps tests*

After this there were some minor differences in strategy. The firefighters had different positions for their first beachhead. Two test subjects would position their first unit on the third floor at the nearest staircase (Area 2) and one would position them one staircase further away (Area 1). The fourth stated that official regulations say that the beachhead should be located two floors below the fire source. He would position the beachhead in Area 2 on the first floor. This is not only a consideration between effectivity and safety, it is also a sign that a more unambiguous information supply could be needed. Differences could also have arisen because the firefighters made different assumptions about this fictitious incident.

Further steps were largely the same. The firefighters would instruct the local emergency response officers to continue evacuating the building and to guard the entrances to prevent people from entering. The first attack team would explore the direct surroundings of the fire and start extinguishing. The second unit would form a beachhead in Area 1 on the fourth floor. They would explore the fourth floor to find the source of the smoke and see if action is needed. The third unit uses the staircase in Area 4 on the third floor. They explore the floor level and enclose the fire source by navigating towards the first unit.

In general they were positive about the concept of ToggleMaps. The GIS drafter / Officer said the following about the visualizations:

*The 2D view of the ground floor is basically what we have now. Our system only shows the ground floor, the interior of the rest of the building is up to our imagination. For an incident like this we need to see the building as a whole. We need to see the complexity and the options for vertical navigation. These 3D visualizations are very useful for that.*

However ToggleMaps should not be valued in comparison with current information systems as these are different for each safety region. The aim is to develop visualizations that help the Dutch fire brigade as a whole, therefore it is necessary to also assess the quality of ToggleMaps independently. One Officer stated the following about the visualizations:

*The 3D model helps me a lot when planning the deployment. It gives me a quick overview of the reach of water riser pipes and staircases. For this particular incident it showed me that this staircase [Area 2] does not reach the fourth floor. If I hadn't seen this I would have given my second unit wrong instructions, which would have cost precious time.*

During the previous interviews firefighters stated that it is important to have information dosage. One Officer stated the following:

*The different views are useful for different persons. The 3D model is useful for the Officer, it is a solid overview for creating a deployment strategy and for positioning water tenders around the building. The 2D maps offer practical overviews for commanders, who operate on separate building levels.*

However each individual map still offers the same information for each user. To further allow users to choose between high level strategic data and detailed practical information the test subjects proposed an interactive zoom. One Officer said:

*The 2D maps are already quite crowded, I wouldn't add any more symbols to it. The essentials are already there except the emergency switches for electricity and gas. Instead I would like to see an interactive zoom; on higher zoom levels you could show room numbers and functions.*

Another Officer mentioned that doors should also be displayed on higher zoom levels. The test subjects also stated that dynamic data is very useful. The Knowledge Director / Officer said the following about this:

*Currently we need to ask the attack teams which rooms have been explored, after which we mark these rooms on the map. It would be great to collect live information about the rooms during the deployments, so everyone can see exactly what is going on. Dynamic data such as accessibility and personalized escape routes would also be nice, but it is important to assist firefighters in their thought process instead of making choices for them.*

A method for communicating building sections was proposed to the firefighters during the interviews. This method divided the building based on building level and main fire compartment. However the test subjects stated that it is important that the information on the visualizations matches the signage in the building. The GIS drafter / Officer mentioned the following about this:

*In the alert phase we often receive information about the fire source location from the emergency room. They mention the third floor for example, but the local emergency response officers mention something like 'Grand Café', which is the name of this floor in the building. We need unambiguous information that matches reality as closely as possible. Labels for rooms and building levels in the maps should be the same as the signage in the building.*

Furthermore some separate points of improvement were mentioned. Different test subjects said they want to see more information on the 3D main mapping pane. For example they want to see entrances and the position of the fire control panel. One Officer mentioned that he would also like to see vertical fire compartmentation in 3D, and ventilation shafts on higher zoom levels in 3D. In 2D they want to see room functions that require extra attention, such as elevator machine rooms or technical rooms. They also want to know if there are lowered ceilings in the building. They mentioned that they want the option to zoom, rotate and pan.

The reference maps are an important characteristic of ToggleMaps. Test subjects stated that they appreciated having both 2D and 3D reference maps, but it is uncertain to what extent they were actually used. They 'toggled' a lot between pages so it is possible that they used both the main mapping panes as reference maps instead of consulting the small maps in the corner. Based on these user tests this is difficult to say, future research with eye tracking software could potentially point out how the ToggleMaps are read.

The Faculty of Applied Sciences is a complex building by fire brigade standards, but the test subjects mentioned that they come across buildings that are more challenging. For example they have more complex corridor structures or they are much larger in overall volume. Indoor navigation with the ToggleMaps went well, the test subjects consulted the 3D map for an overview of vertical movement options and the 2D maps for detailed directions towards them. However it is difficult to say whether they would have been less successful with simple 2D floor plans. The firefighters would be interested in seeing the ToggleMaps concept applied to a building like the Alexandrium shopping centre in Rotterdam.

## 9. applying feedback to create final ToggleMap designs

The test subjects proposed changes to both the 3D main mapping pane and the 2D mapping pane. About the 3D Main mapping pane they proposed the following:

- Visualize entrances and the fire control panel
- Vertical compartmentation
- Higher zoom level: ventilation shafts
- Show location of personnel
- Show building wings
- Location labels that match reality
- Interaction: zoom, rotate & pan

As discussed before, spaces are compartmented in order to slow down the expansion of smoke and fire. Walls and doors create horizontal compartmentations, and ceilings create vertical compartmentations. Objects like staircases and ventilation shafts can compromise this vertical compartmentation.

Visualizing vertical compartmentation elegantly is a challenge. Three possible solutions come to mind. The first would be to visualize the complete vertical compartmentation by showing the compartmentation rating of all ceilings. However there are some issues with this solution. To start, it would require showing the complete floors instead of just the corridors in 3D. As explained before this leads to occlusion problems. Moreover this solution highlights which spaces are vertically compartmented, while the firefighters are mainly interested in which spaces are connected.

The second possible solution is to show only the compartments that are *not* vertically compartmented by showing these rooms completely in 3D (Figure 29)

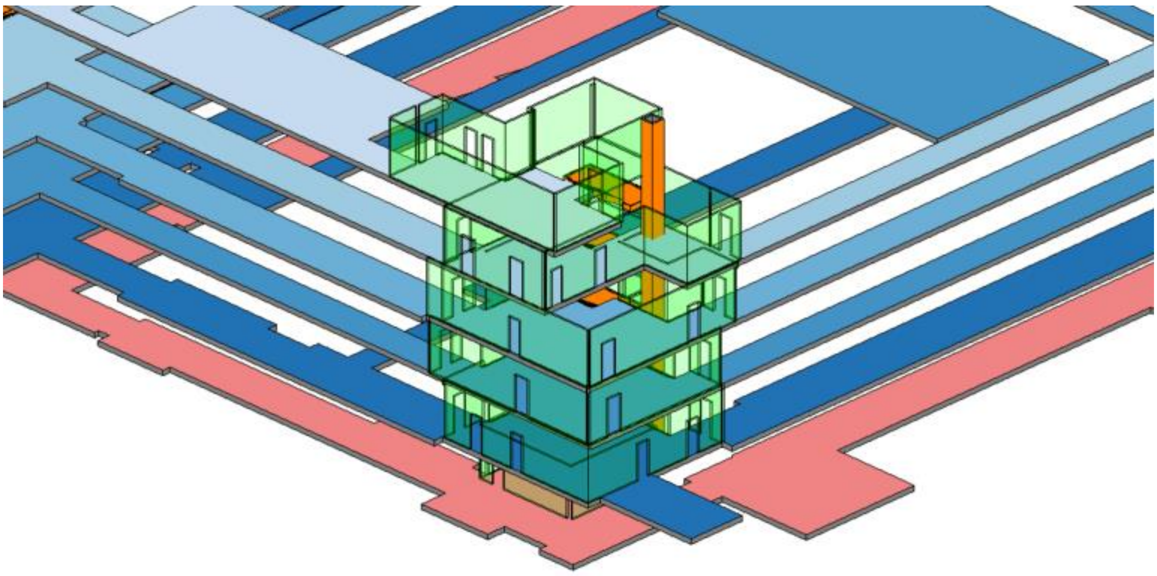


*Figure 29: Visualization of vertical compartmentation by highlighting the connected rooms*

The vertically connected spaces are highlighted in green to indicate that they form one compartment with 30 minutes fire protection. Transparency is added to allow the user to see the underlying objects. There are pros and cons to this solution. Visualizing the true shape of the spaces that are connected vertically gives the firefighters a good indication of the size of this compartment. However it creates visual clutter making it more difficult to derive other information, even at high zoom levels. Another weakness of this technique is that if fails to show which spaces are connected exactly. The spaces in figure 29 could all be connected, but it is also possible that there is a vertical compartmentation between floor 2 and 3 for example. The third solution is to create an 3D symbol to show vertical connections. Figure 30 shows such an example where a column represents this connection. It is placed inside the staircase because this is the object that connects the spaces. It could also be placed in the middle of the vertical fire compartment. This solution creates a less cluttered image, making it suitable for both high and low zoom levels. However it is a very abstract solution. An untrained user might expect to find a physical column in the real environment, so it is important to explain the meaning of symbols like these thoroughly.

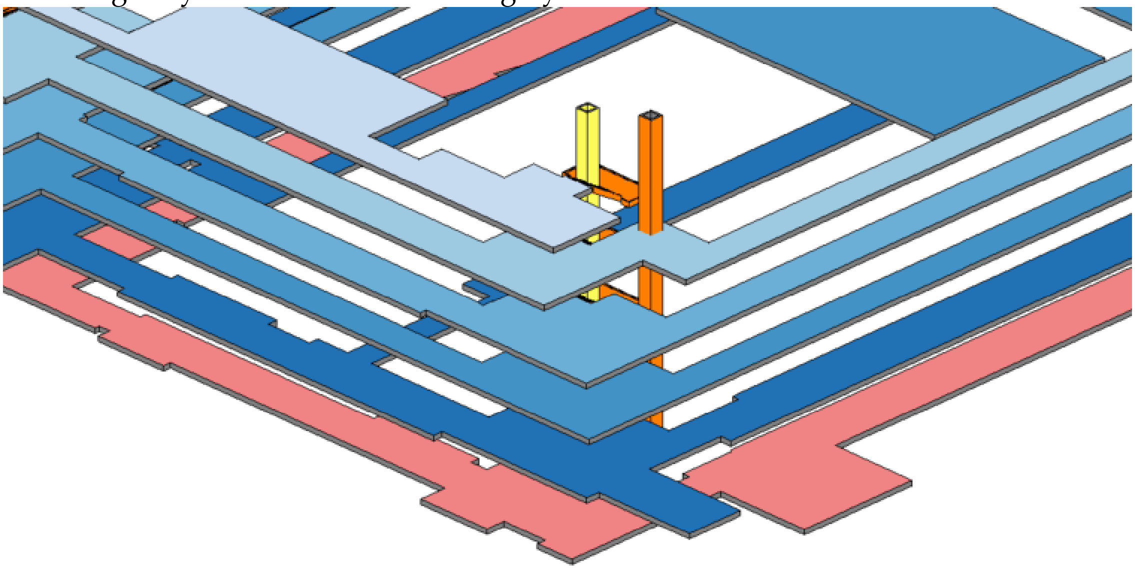


*Figure 30: Visualization of vertical compartmentation by placing a symbol inside the connecting object*

Neither of the solutions is perfect. They are compromises between precision and ease of reading. It is up to the user which visualization method is the best, or perhaps neither of these methods fulfil their needs. Further research with more user testing is needed to make this choice. For now the choice is made to use a yellow vertical column to represent vertical connections between spaces, because it is the least distracting method. Also labels were added for the building wings as they are named in reality, main entrances and side entrances are visualized an the location of the fire control panel is shown. The position of firefighters is shown by their unit (A-Z) and their number (1, 2, 3, 4 or 5). The resulting final Design for the 3D main mapping pane can be seen in figure 30.

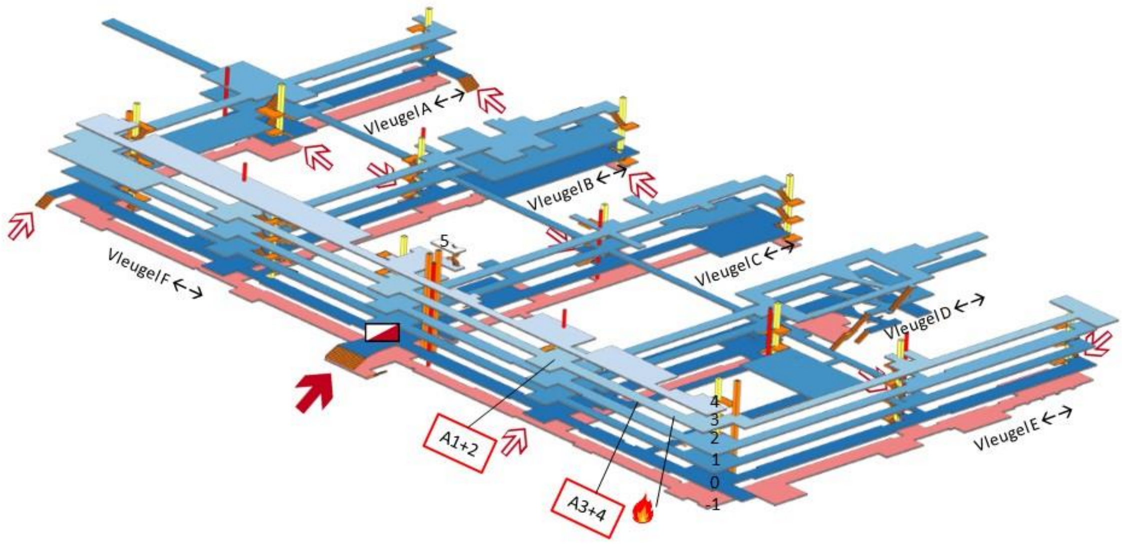



*Figure 30: Final design for the 3D Main Mapping Pane*

The firefighters also demanded interaction with the 3D model. They wanted to zoom, rotate and pan to certain locations. A future information system should have this possibility, but it is difficult to show in static visualizations. One officer stated that he would like to see ventilation shafts on higher zoom levels. Figure 31 shows a 3D Main mapping pane that is zoomed in on the fire location. Fictitious ventilation shafts are shown with their geometry instead of symbols.

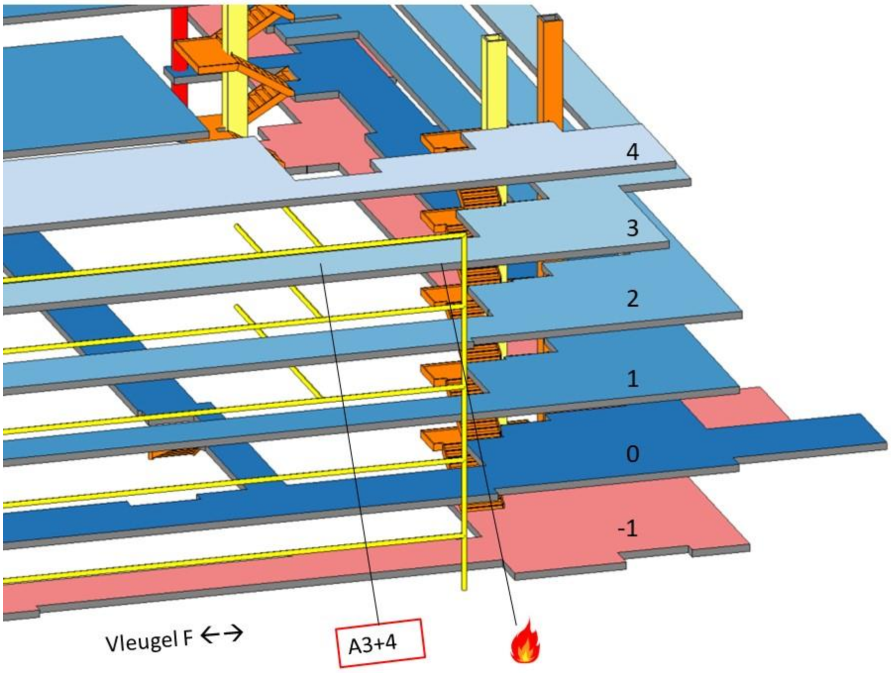



*Figure 21: ToggleMaps 3D main mapping pane showing additional information about ventilation shafts after zooming in*

The test subjects stated that they were missing the emergency switches for electricity and gas in the 2D Main Mapping Panes. These symbols are added in the final ToggleMaps designs on the ground floor (Appendix A). They also want to see location labels that match reality. The Faculty of Applied Sciences uses a room code that consists of the building wing, the building level and the room number. Room E 304 is in wing E on the third floor for example. Exact room numbers and their functions are not available in the dataset, so these are fictitious. The choice was made to label wings on every zoom level. The firefighters requested room numbers and function on higher zoom levels.

Test subjects also explained that they want to see the progress of the indoor exploration. They proposed a checkbox to verify if each room has been explored or not. Instead we propose to put a SAHF-triangle in each room that is explored, to allow the firefighters to share detailed information about the fire circumstances in each room. This would be a task for the navigator who operates the information system. With the SAHF triangle the navigator can describe the precise situation in each room with minimal user input. A zoomed in 2D main mapping pane of building floor 3 can be seen in figure 32.


*Figure 32: ToggleMaps 2D main mapping pane, zoomed in on incident site*

The rooms in the top row of wing F are all explored and 'clean'. On the bottom row there are three rooms left to explore. The exploration confirmed a fire in F 327, but the attack team also noticed that smoke has spread to F 325 and F 326.

The original design was a layout in landscape mode, with the main mapping pane in the bottom left corner and the reference pane in the top right corner. Finally the choice was made to use a layout in portrait mode with the main mapping pane on the top and the reference pane in the bottom right position of the layout. This proved to be a more effective division of space. Also the choice was made to add a notepad in the bottom left corner because interviewees stated that they use this a lot for communication. This notepad can also be used to display details about fire expansion. Appendix A shows the final ToggleMaps designs after applying the feedback of the test subjects. Appendices A1 and A2 show both states of the ground floor of the Faculty of Applied Sciences, and A3 and A4 show the same of the third floor. A5 and A6 showcase what extra information can be extracted after zooming in on the incident site.

## 10. Discussion

This thesis project aimed to combine cartographic backgrounds with needs of the Dutch fire brigade to create effective indoor cartographic techniques. The interviews and fire brigade background research resulted in a clear overview of their methodology and their user demands. However the safety region Rotterdam-Rijnmond is strongly represented in these results. Most interviewees are from this region, and most literature originates in this safety region as well. Differences in methodology, organization and information supply among safety regions can affect the validity of these results. The aim was to develop visualization techniques for the Dutch fire brigade as a whole, but during this research the question arose whether this can be regarded as a single organization.

The background research in cartography resulted in some general rules in cartography and symbology. Some of these general rules proved to be difficult to apply to indoor environments, 3D models and maps with wide varieties of overlaid symbols. It became clear that indoor cartography in general is still in its infancy. Not many publications exist in this field, and there is a lack of consensus when it comes to 2D versus 3D representations and symbology. No publications were found that provided solutions to the demands of the fire brigade. These end users want to use indoor information systems for both indoor routing and object localization, other publications mainly focus on either of these. Moreover the firefighters stated that they need both 3D and 2D representations.

ToggleMaps were developed to fill in the gaps of indoor cartography literature and to help the Dutch fire brigade adopt a more information driven approach. Demands from the interviews were successfully translated into visualizations. When looking at the cartographic communication process, ToggleMaps proved to be largely effective at conveying the intended message. The users used the 3D maps for deriving building complexity, vertical and horizontal routing, water riser pipes and basic object localization. For more detailed information they referred to the 2D maps. After a short introduction about the ToggleMaps concept and the meaning of some colour codes and symbols they could use the visualizations independently. Also they came to the same conclusions based on the ToggleMaps, minor differences in strategy resulted from personal preferences and different interpretations of protocols. Tests were executed with a small group of experts from the safety region Rotterdam-Rijnmond. They provided useful feedback that was implemented in the final designs. However the small number of test subjects could affect the validity of the results, as well as the fact that other safety regions were not represented. This research contributes to the Dutch fire brigade by translating the needs of the firefighters into tangible designs. It also proposes a significant change significant change in their unit composition: the deployment of a navigator.

They contribute to the field of cartography with a number of innovations. The first one is the combination of 2D and 3D maps in a single interface, with the option for the user to toggle between 2D floor plans and 3D models of the whole building. Second is the combination of a main mapping pane and a reference pane, to give the user the ability to bring 2D data into 3D perspective and vice versa. Lastly there is a number of designs that could be used in other indoor maps. For example there are colour coded columns representing elevators and vertical connectedness. Moreover there are the different colour values to help the user tell building levels apart, and the different hue to differentiate underground levels. Lastly there is the introduction of a staircase symbol. Current practice is to show the stair geometry in 2D. Clear symbols were introduced in the 2D maps, and users can still refer to the 3D map for the staircase geometry.

## 11. Conclusion

This thesis research was aimed at finding effective indoor cartographic methods to aid the Dutch fire brigade during indoor deployments. The research question was as follows:
*What are effective cartographic methods for presenting building information for assisting the Dutch fire brigade in tactics choice and choice of indoor firefighting methods and navigation?*

To answer this question a number of subquestions was composed.The first subquestion was:

- What are the demands of the Dutch fire brigade for operational indoor information to be an effective addition to their deployments?

Indoor operational information needs to serve two main purposes: assistance during on-site and indoor exploration and tracking fire expansion and personnel movement during the deployment. Interviewees stated that information should be dosed to the right person at the right time, and minimal user interaction should be necessary. The hardware should not impede movements of the firefighters. Interviewees stated that both 2D and 3D representations are of added value: 2D maps show detail per building level and 3D give a good overview of the building shape and complexity. Finally an indoor information system should assist the fire brigade in making choices instead of providing doctrines. No two incidents are the same, and personal judgement will always be necessary.

- Which user groups can be identified that could benefit from an indoor spatial information system?

Two user groups were identified: (head) officers and navigators. Officers and head officers are mainly interested in tactical information. They want to know the shape and complexity of the building and they generally focus on a large incident area. Officers and head officers are concerned with the location of different units and their progress during the incident. Navigators currently don't exist within the fire brigade, they were proposed during the interviews. They accompany the attack teams and help them finding attack- and escape routes. They provide the attack team with the operational information that they need to complete their tasks, such as the location of fire hoses inside the building. By deploying a navigator we give the attack team access to operational information while keeping their hands free to perform their tasks.

- What static and dynamic indoor building factors are suitable for displaying in an operational information system in order to assist the specific user groups and prevent information overload?

Choice of methods and tactics depend on many factors. The renewed view on firefighting dictates that firefighters should spend more time exploring the incident and gathering information. This is safer and more effective than jumping into action as quickly as possible. An effective indoor operational information system can help the firefighters with this exploration. Human characteristics and fire characteristics are best perceived on-site, but many building factors are suitable for display in an indoor information system. First of all the fire brigade is interested in the shape and complexity of the building, both in 2D and in 3D. 3D maps are suitable for showing objects that extend over several building levels such as water riser pipes, staircases and elevators. More detailed building information can be shown in the 2D floor maps. These maps should show rooms, corridors, entrances, hazmat information, repressive and preventive resources, fire compartmentation and special room functions. There are two types of dynamic data that were of interest to the interviewees: fire expansion and personnel location. These should be displayed in both the 2D and the 3D representations.

- What are effective cartographic methods for presenting the static and dynamic building factors in indoor environments to the user groups?

The answer of this last subquestion is also the solution to the main research question. A novel cartographic method was developed in this thesis research called ToggleMaps. These are interfaces with two mapping panes and a notebook area. The user can toggle between two states: a detailed 3D main mapping pane with a basic 2D reference map or vice versa. ToggleMaps allow the user to bring information into context. For example they can view a hazmat area in the 2D main mapping pane and consult the 3D reference map to see where this area is inside the building as a whole. Moreover a user can view tactical information in the 3D main mapping pane and consult the 2D reference map to see occluded areas of a building level. Test subjects stated that the combination of 2D and 3D in a single interface was very helpful. The prototypes proved to be effective for planning deployments and for indoor routing. Moreover the ToggleMaps provide information dosage: the 3D view is mainly helpful for the officers and their tactical tasks, and the 2D floor maps aid the separate units and their navigators with their operational tasks. Users are warned about fire expansion with three mechanisms: a sound alarm, blinking symbols and a message in the notebook. Both user groups demand a wide variety of building information with no clear intellectual hierarchy. To still present the information clearly to the user three strategies were used. First of all ToggleMaps divide different pieces of information over their four mapping panes. Secondly colour coding and convention were used to help user identify the symbols. Last of all an interactive zoom was proposed during the user tests, displaying additional detail after zooming in on both 3D and 2D maps.

## 12. Recommendations

The Renewed View on Firefighting states all firefighters should invest more time in on-site exploration and that firefighters should adopt a more information driven approach. It is expected that old school firefighters will have more trouble adapting to deployments where they have to spend more time exploring the incident site before jumping into action. They have every right to be sceptical about changes like these; they are the ones operating in dangerous environments. Effectivity is quality times acceptance, as one knowledge director worded it nicely during the interviews. When the visualization techniques of this research have been used to create a working spatial information system that meets the quality standards of the fire brigade, we cannot assume that it will be incorporated into their workflows flawlessly. Besides training to use the system the firefighters should be explained why they should use it and how it can improve safety and effectivity.

Furthermore it is recommended that the Dutch fire brigade adopts more nationally standardized approaches. Currently operational information strategies are developed separately for each safety region, and differences exist in methodology and deployment protocols. This made it difficult to create visualization techniques that can be applied to the Dutch fire brigade as a whole. Making agreements on building data standards and developing software systems nationally can prevent having to reinvent the wheel. Also a more centralized approach can improve knowledge sharing and communication between safety regions.

## 13. Further research

More research needs to be done to further prove the validity of the results. Additional testing should be done with commanders and officers from different safety regions to see whether they share the opinions of the current test subjects. Also the visualization techniques should be subjected to a variety of scenario's in different buildings. For example it would be interesting to see whether ToggleMaps are still effective with particularly complex buildings such as the Alexandrium shopping mall in Rotterdam or in buildings with many split levels. Future tests should be performed with working digital prototypes with interaction possibilities like panning, toggling, rotating and interactive zoom.

While test subjects stated that they found it useful to have two mapping panes in each interview, the effectivity of the reference map could not be proven during the tests. Future research with eye tracking software could point out whether these reference maps are actually used by the firefighters. Should it be the case that they only use the two main mapping panes then there is no use in adding a reference map. It would only be wasted space.

During this research the choice was made to have a linked zoom between the main mapping pane and the reference pane. A static zoom level in the reference maps would allow the user to see the whole building at all times. Future research could point out which is most useful to the fire brigade: the current practise with linked zoom or Togglemaps with static zoom in the reference map.

Kraak (2015) mentioned that map interaction stimulates thinking and decision making. The literature also pointed out that orientation is particularly challenging in indoor environments. Besides zooming, rotating and panning these visualizations offer a new kind of interaction: toggling between map states. Future research with working prototypes could point out whether toggling has an effect on indoor orientation.

Finally it would be interesting to see whether ToggleMaps are also applicable in other contexts. Data used for ToggleMaps could be overlaid with different data to make it useful for other purposes. For example they could be used to create evacuation maps for the emergency response workers or to create digital maps of complex shopping malls for public use. Having several purposes for building data can be cost effective; responsibilities of production and maintenance can be delegated among the users.

## Glossary – translation of English terms

| English term | Dutch term |
|---|---|
| Beachhead | Bruggenhoofd |
| Control room | Meldkamer |
| Fire control panel | Brandmeldpaneel |
| Head officer | Hoofdofficier van Dienst |
| Officer | Officier van Dienst |
| Penetration Depth | Aanvalsdiepte |
| SAHF / BE-SAHF | RSTV / G-RSTV |
| SCBA / Self Contained Breathing Apparatus | Ademluchtmasker |
| Water riser pipe | Stijgleiding |
| Water tender | Tankautospuit |

## Interviewees

| Date | Name | Function |
|---|---|---|
| 18-05-2018 | Rogier Piek | Officer, VRR |
| 23-05-2018 | Maurice de Beer | Knowledge director / Officer, VRR |
| 23-05-2018 | Ricardo Weewer | Lector in firefighting science, IFV |
| 24-05-2018 | Morgan Bremer | Operational Information officer, VRR |
| 24-05-2018 | Susila Haspel | Preparation specialist, Schiphol |
| 24-05-2018 | Jeffrey Tolboom | Preparation advisor, Schiphol |
| 06-06-2018 | Ben de Wilt | Commander, VRR |
| 06-06-2018 | Gert Wesdijk | Commander, VRR |
| 13-06-2018 | Marcel Henderson | Head of operational information, VRR |
| 20-06-2018 | Dennis Hassfeld | Operational information officer, VRR |

## Test subjects

| Date | Name | Function |
|---|---|---|
| 09-10-2018 | Rogier Piek | Officer, VRR |
| 10-10-2018 | Maurice de Beer | Knowledge director / Officer, VRR |
| 10-10-2018 | Huib Franssen | Head officer, VRR |
| 10-10-2018 | Fred van der Have | Officer / GIS drafter from Operational Information, VRR |

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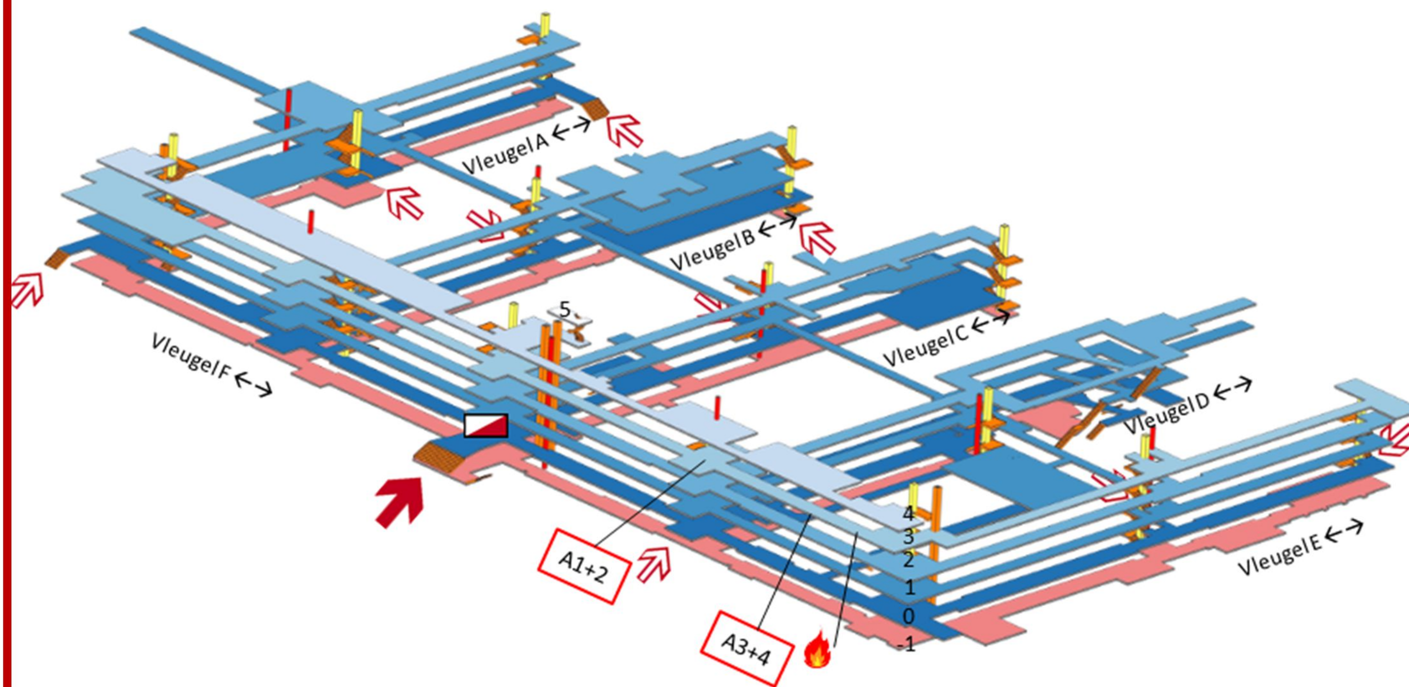
# Appendices

A: ToggleMaps Final Designs
B: The Renewed View on Firefighting Poster (Brandweeracademie, 2018)
C: ToggleMaps Test visualizations

A1

# 3D Hoofdkaart



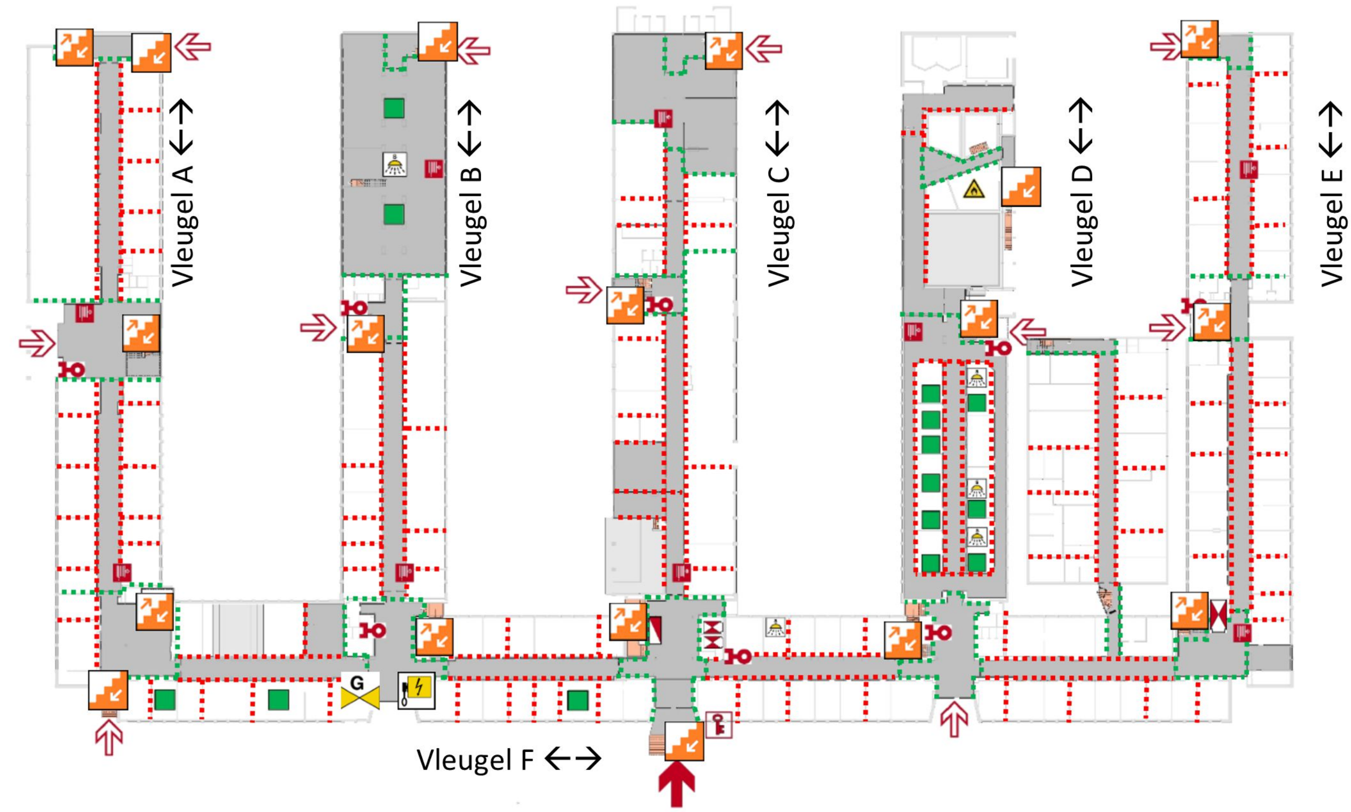

## Kladblok

14:40: OMS in F 327
14:48: Eenheid A aanwezig. Bruggenhoofd in centrale trappenhuis vleugel F, verdieping 3
14:52: OMS F 326
14:53: OvD aanwezig
14:54: Eenheid B aanwezig. Ondersteuning watervoorziening van eenheid A

## 2D Referentiekaart – verdieping 0

A2

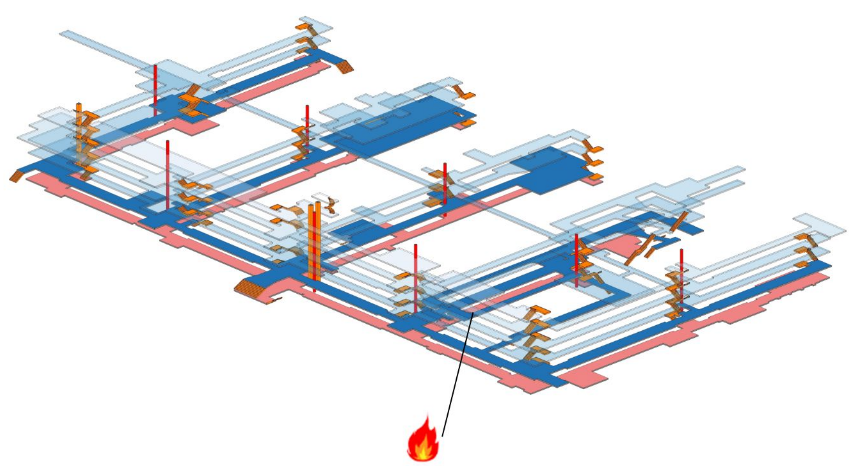
# 2D Hoofdkaart – verdieping 0




## Kladblok

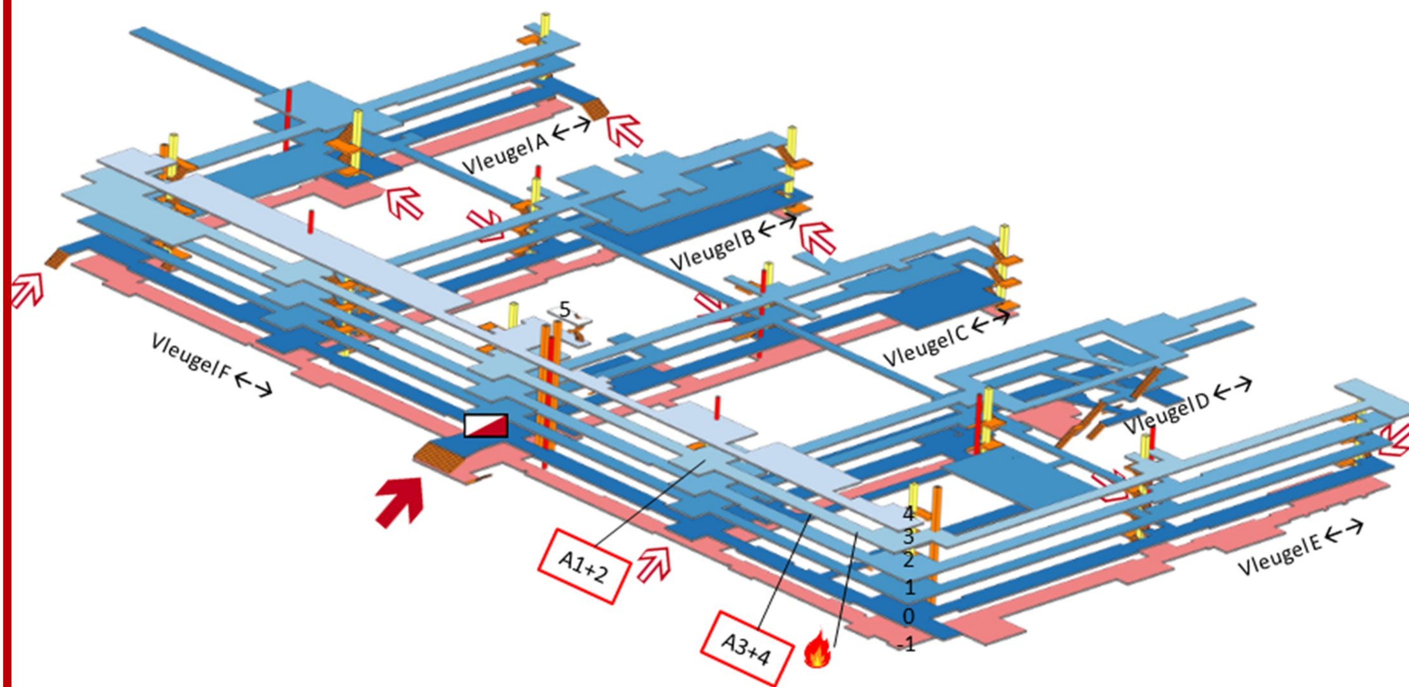
14:40: OMS in F 327
14:48: Eenheid A aanwezig. Bruggenhoofd in centrale trappenhuis vleugel F, verdieping 3
14:52: OMS F 326
14:53: OvD aanwezig
14:54: Eenheid B aanwezig. Ondersteuning watervoorziening van eenheid A

## 3D Referentiekaart – verdieping 0



A3

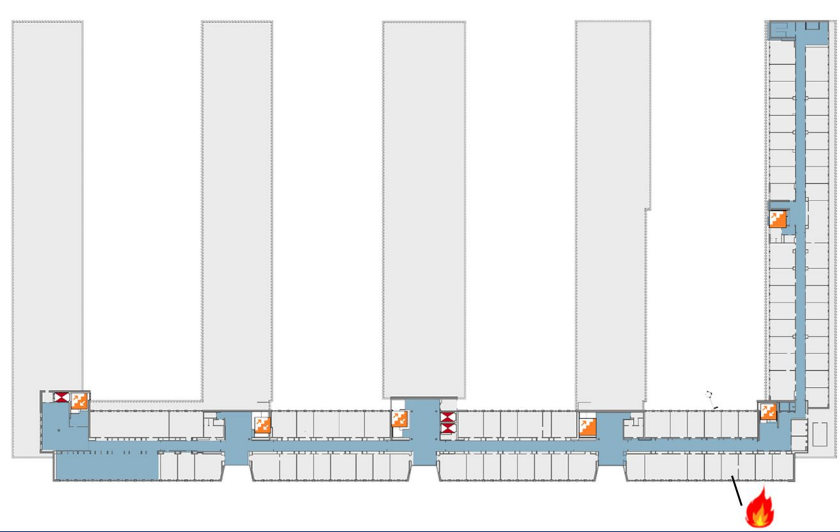
# 3D Hoofdkaart




## Kladblok

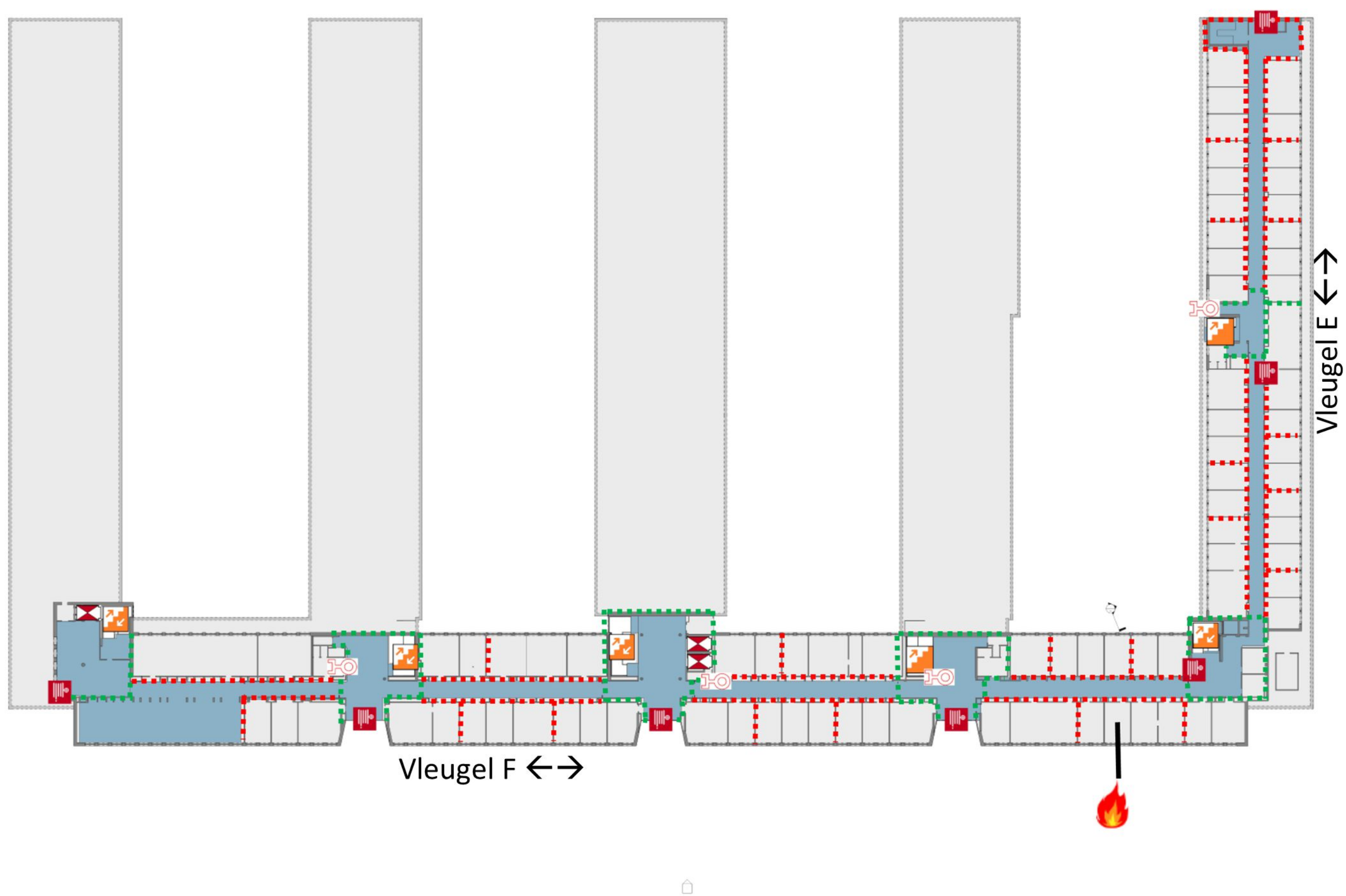
14:40: OMS in F 327
14:48: Eenheid A aanwezig. Bruggenhoofd in centrale trappenhuis vleugel F, verdieping 3
14:52: OMS F 326
14:53: OvD aanwezig
14:54: Eenheid B aanwezig. Ondersteuning watervoorziening van eenheid A

## 3D Referentiekaart – verdieping 3



A4

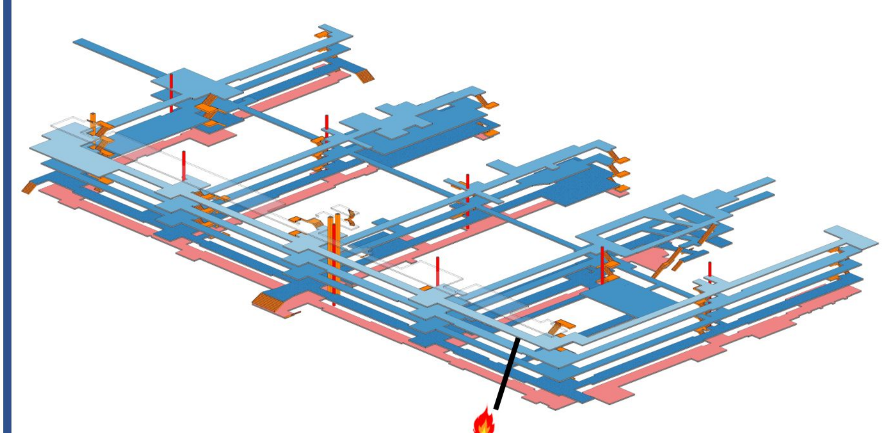
# 2D Hoofdkaart – verdieping 3




## Kladblok

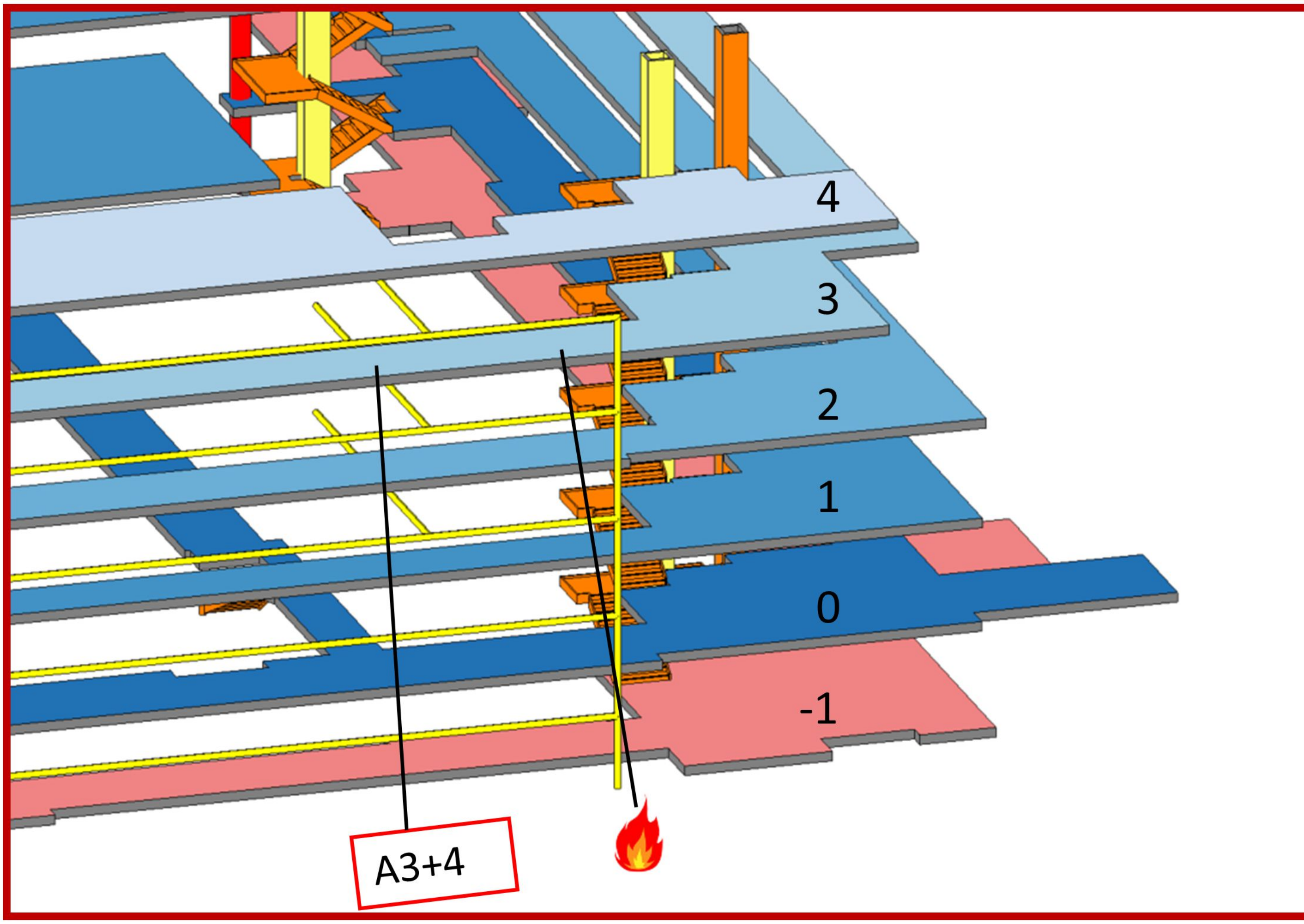
14:40: OMS in F 327
14:48: Eenheid A aanwezig. Bruggenhoofd in centrale trappenhuis vleugel F, verdieping 3
14:52: OMS F 326
14:53: OvD aanwezig
14:54: Eenheid B aanwezig. Ondersteuning watervoorziening van eenheid A

## 3D Referentiekaart – verdieping 3



A5

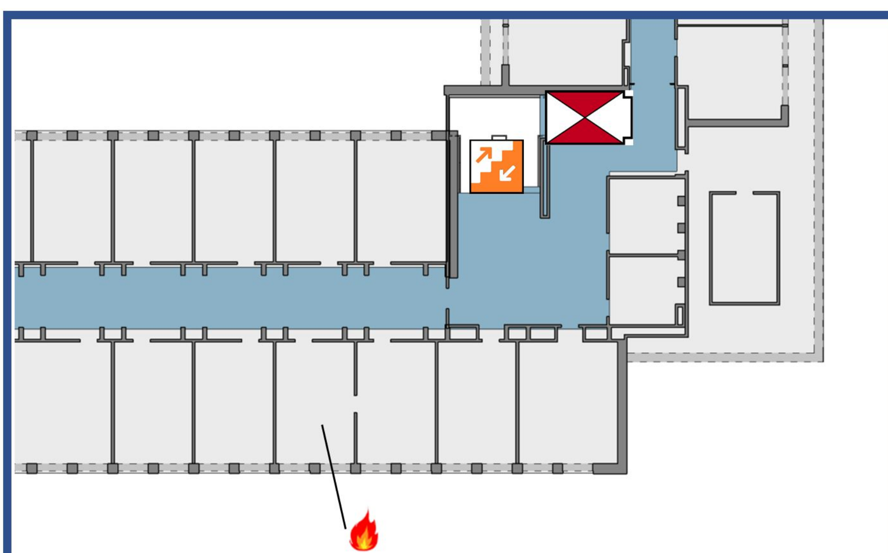
# 3D Hoofdkaart



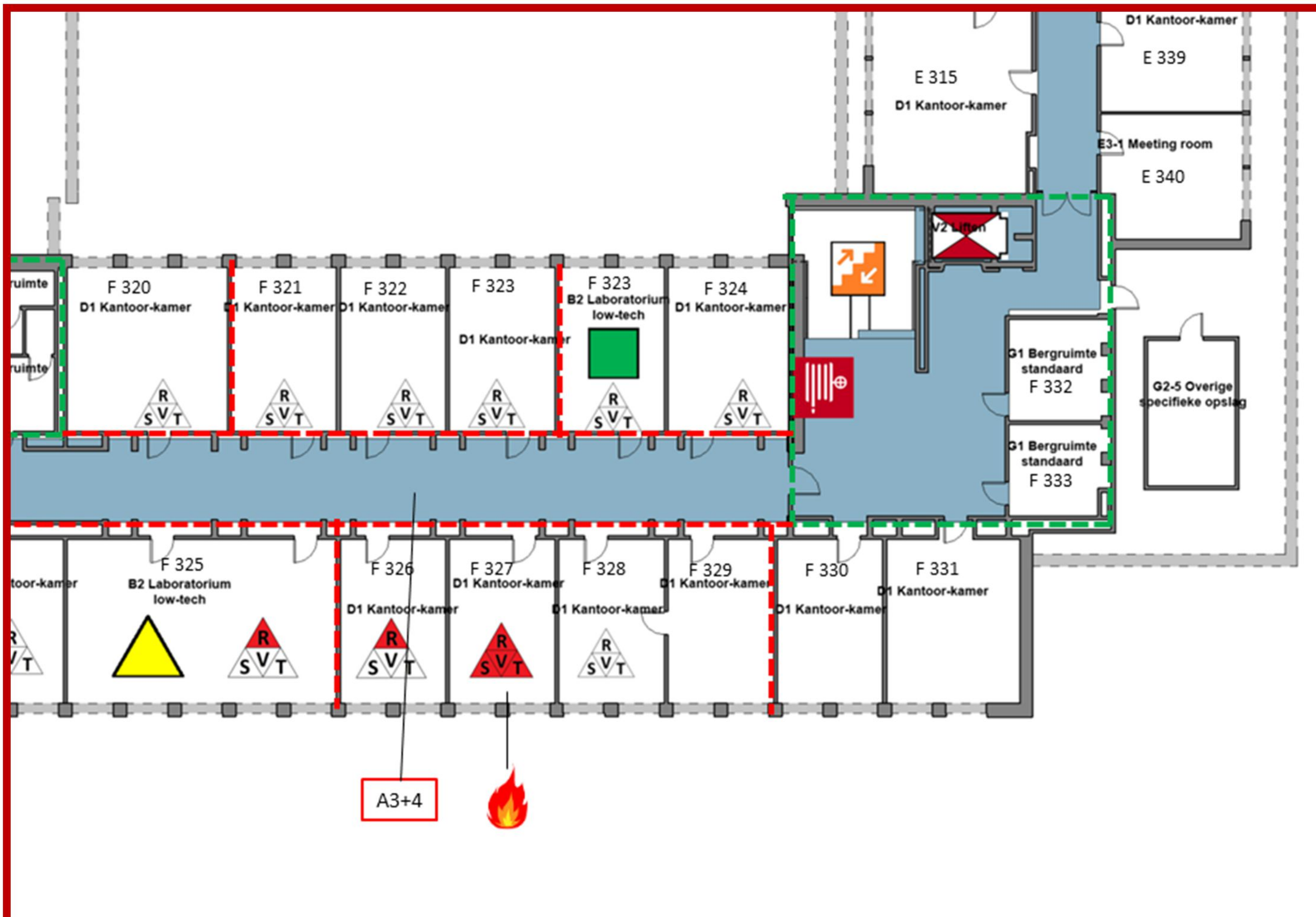

## Kladblok

14:40: OMS in F 327
14:48: Eenheid A aanwezig. Bruggenhoofd in centrale trappenhuis vleugel F, verdieping 3
14:52: OMS F 326
14:53: OvD aanwezig
14:54: Eenheid B aanwezig. Ondersteuning watervoorziening van eenheid A

## 3D Referentiekaart – verdieping 3



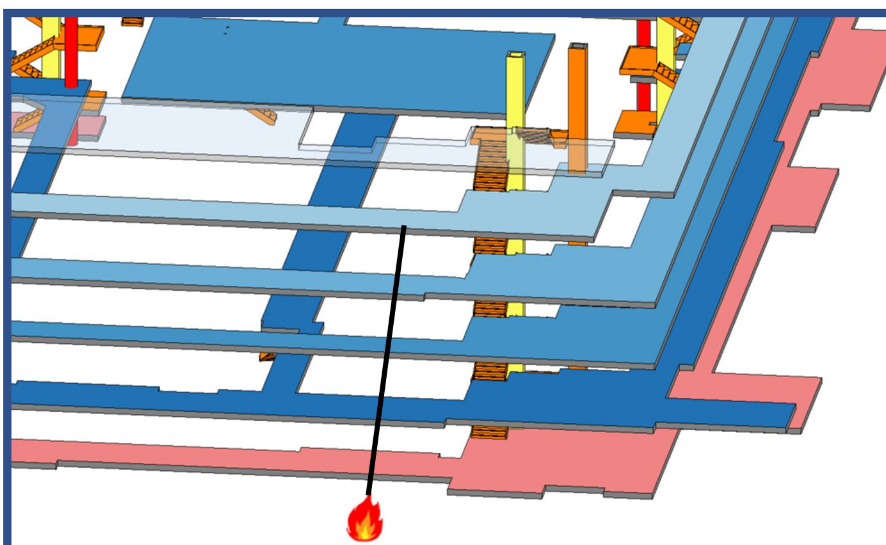
A6 # 2D Hoofdkaart – verdieping 3



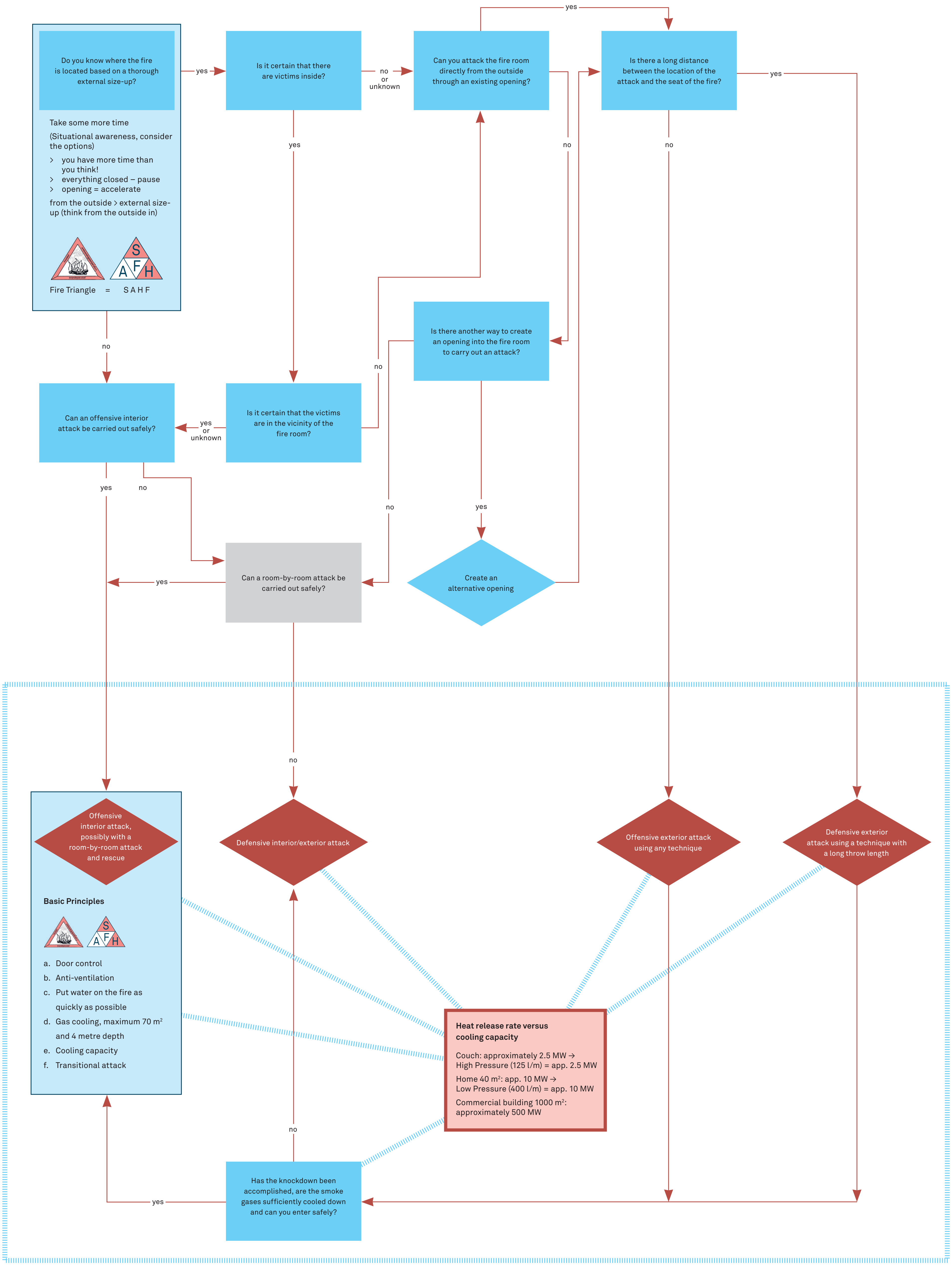

## Kladblok

14:40: OMS in F 327
14:48: Eenheid A aanwezig. Bruggenhoofd in centrale trappenhuis vleugel F, verdieping 3
14:52: OMS F 326
14:53: OvD aanwezig
14:54: Eenheid B aanwezig. Ondersteuning watervoorziening van eenheid A

## 3D Referentiekaart – verdieping 3



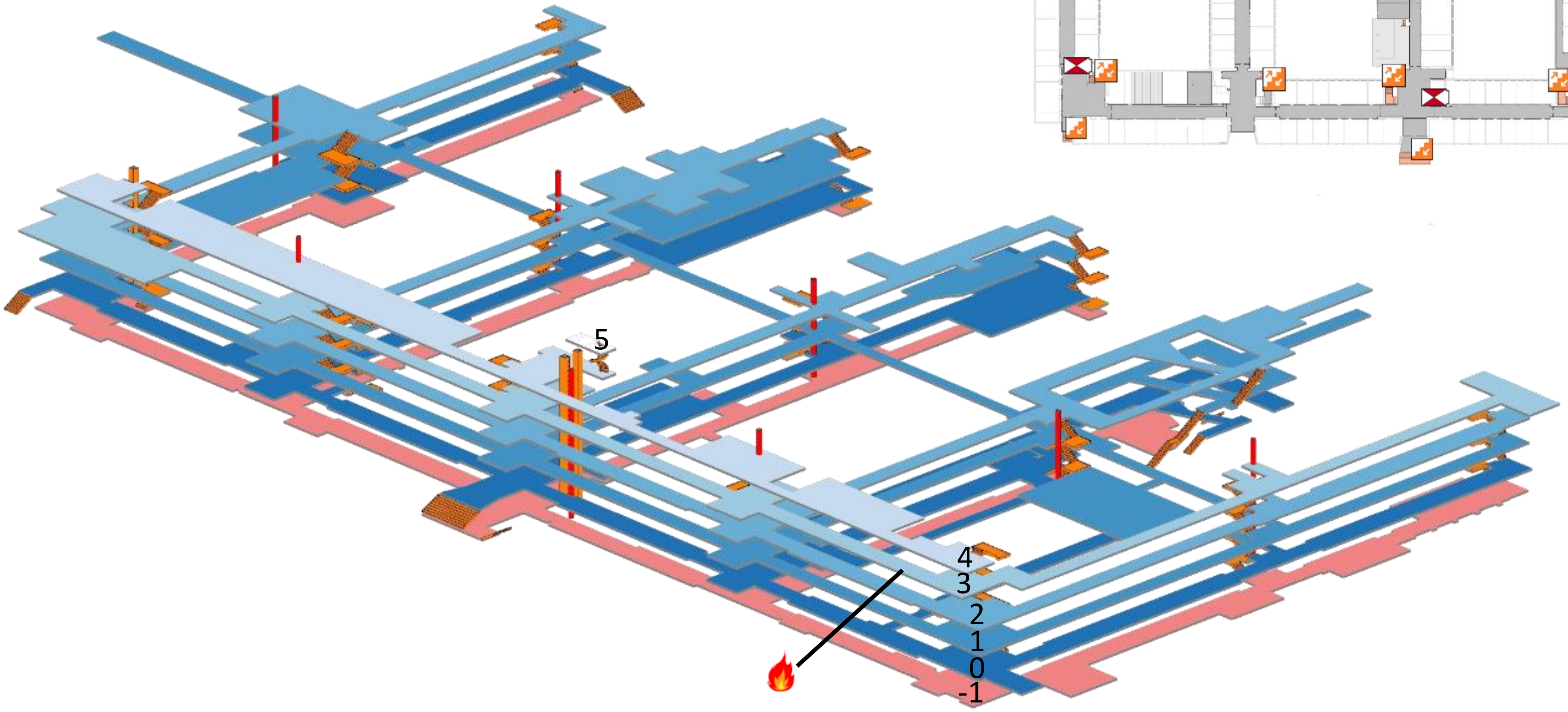
# The renewed view on firefighting




**BRANDWEER**
**Brandweeracademie**

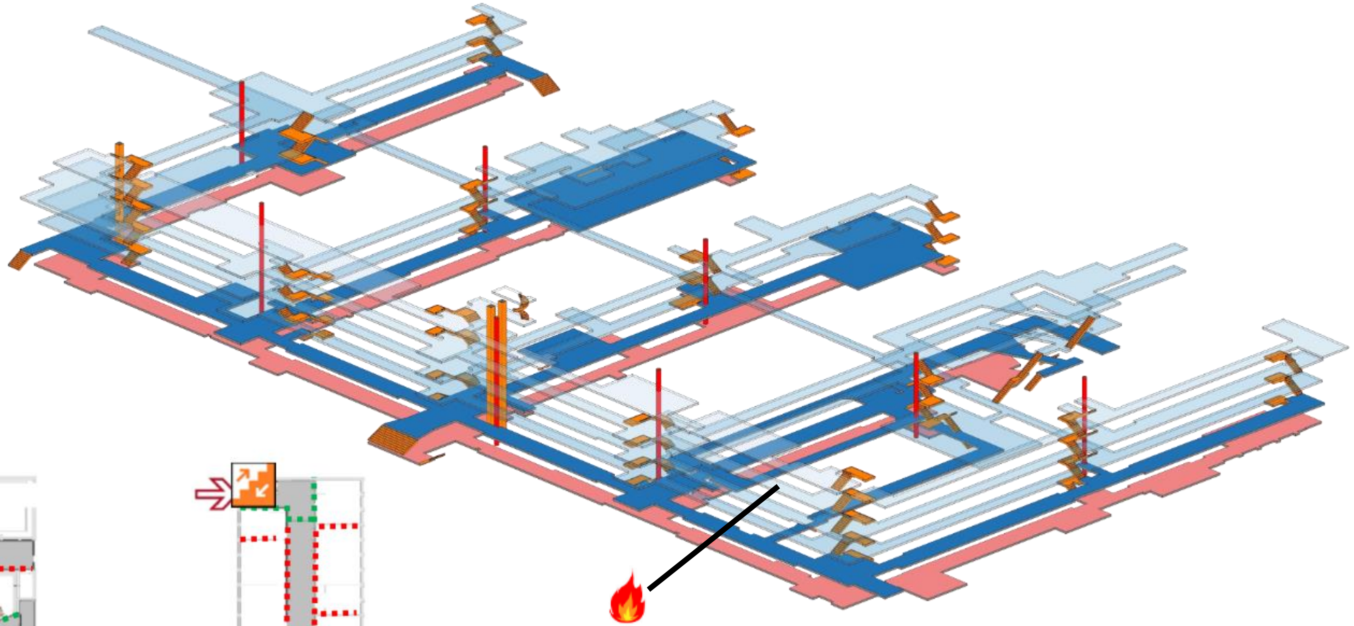
The Brandweeracademie is part of the Instituut Fysieke Veiligheid.

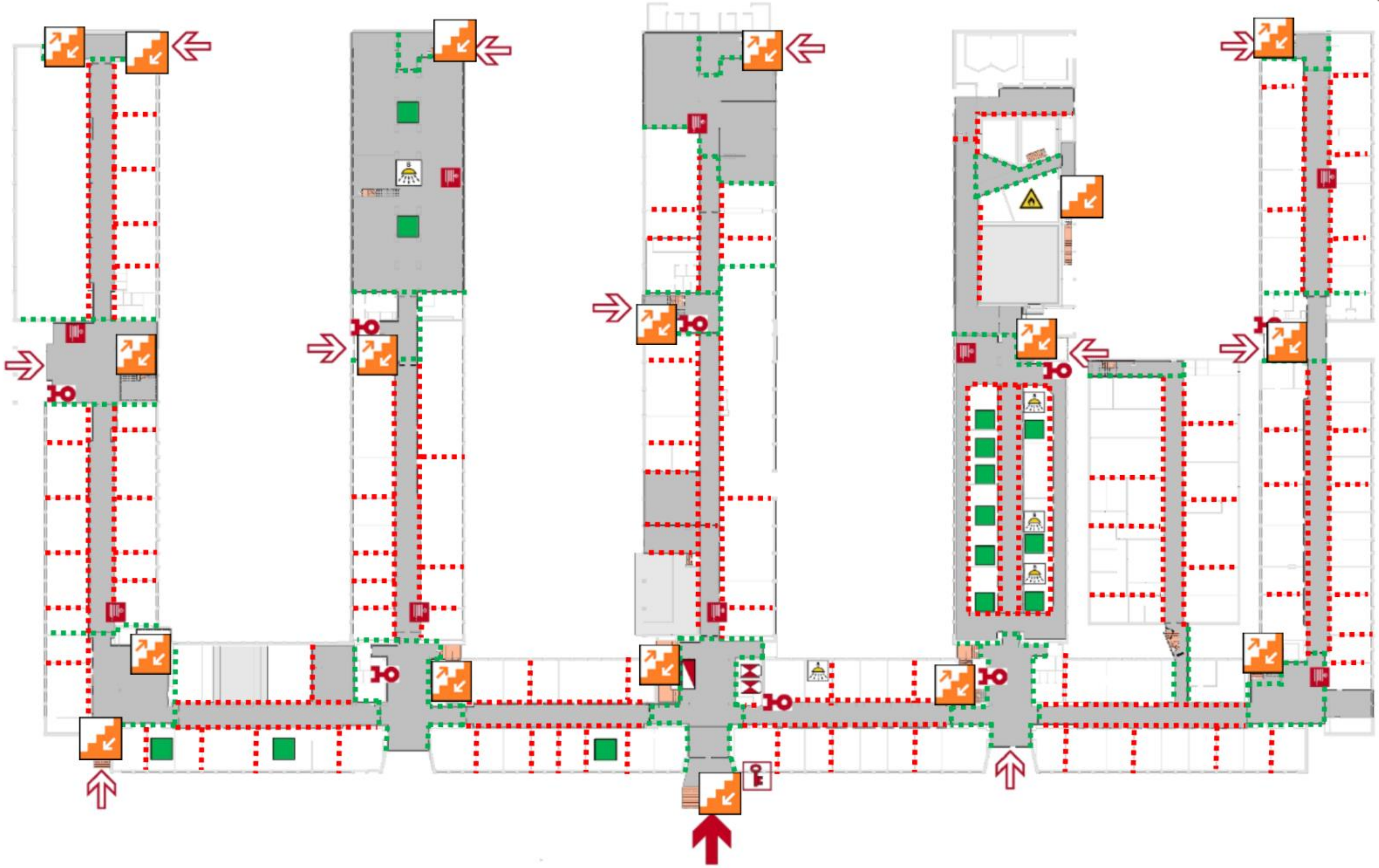
# ToggleMap 3D Ground Floor




**Current floor:**
0
**Units indoor:**
none
**Smoke detected:**
3-8

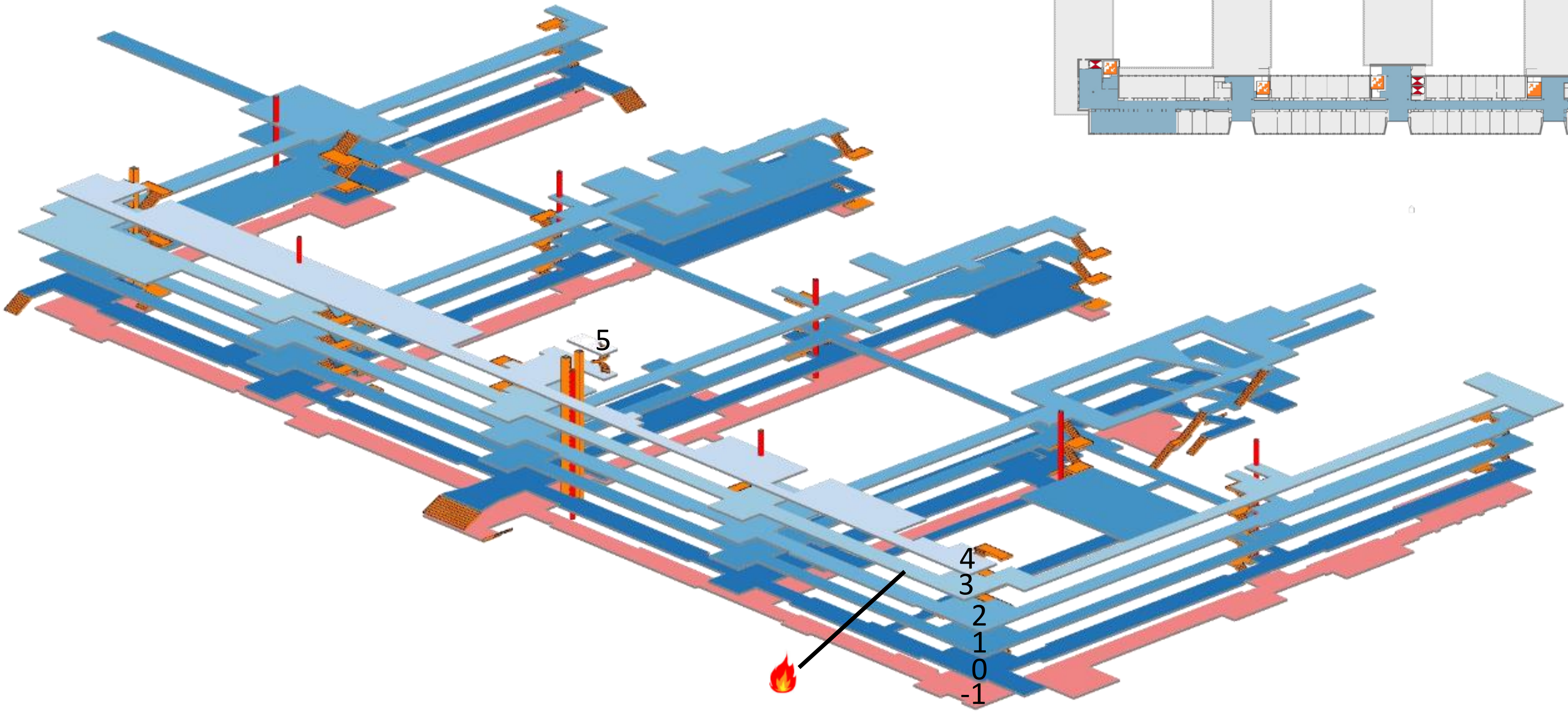
# ToggleMap 2D Ground Floor

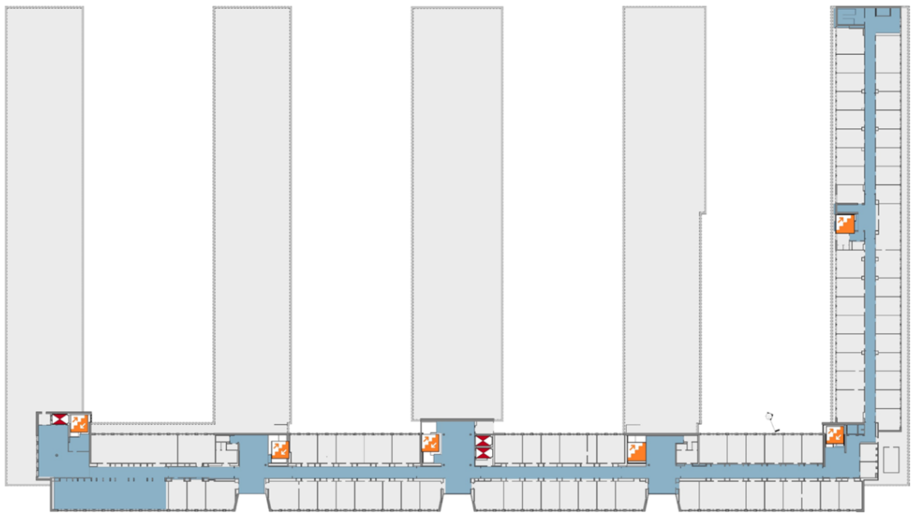




**Current floor:**
0
**Units indoor:**
none
**Smoke detected:**
3-8

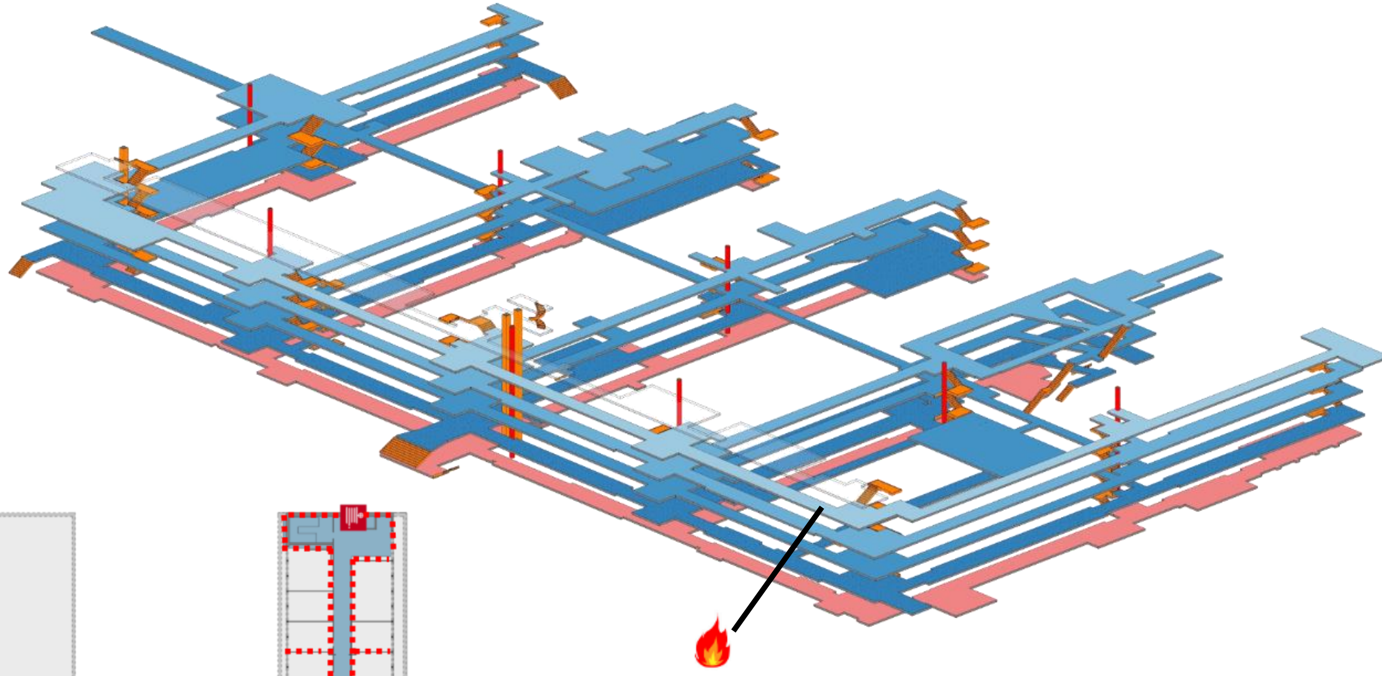
# ToggleMap 3D
# Third Floor

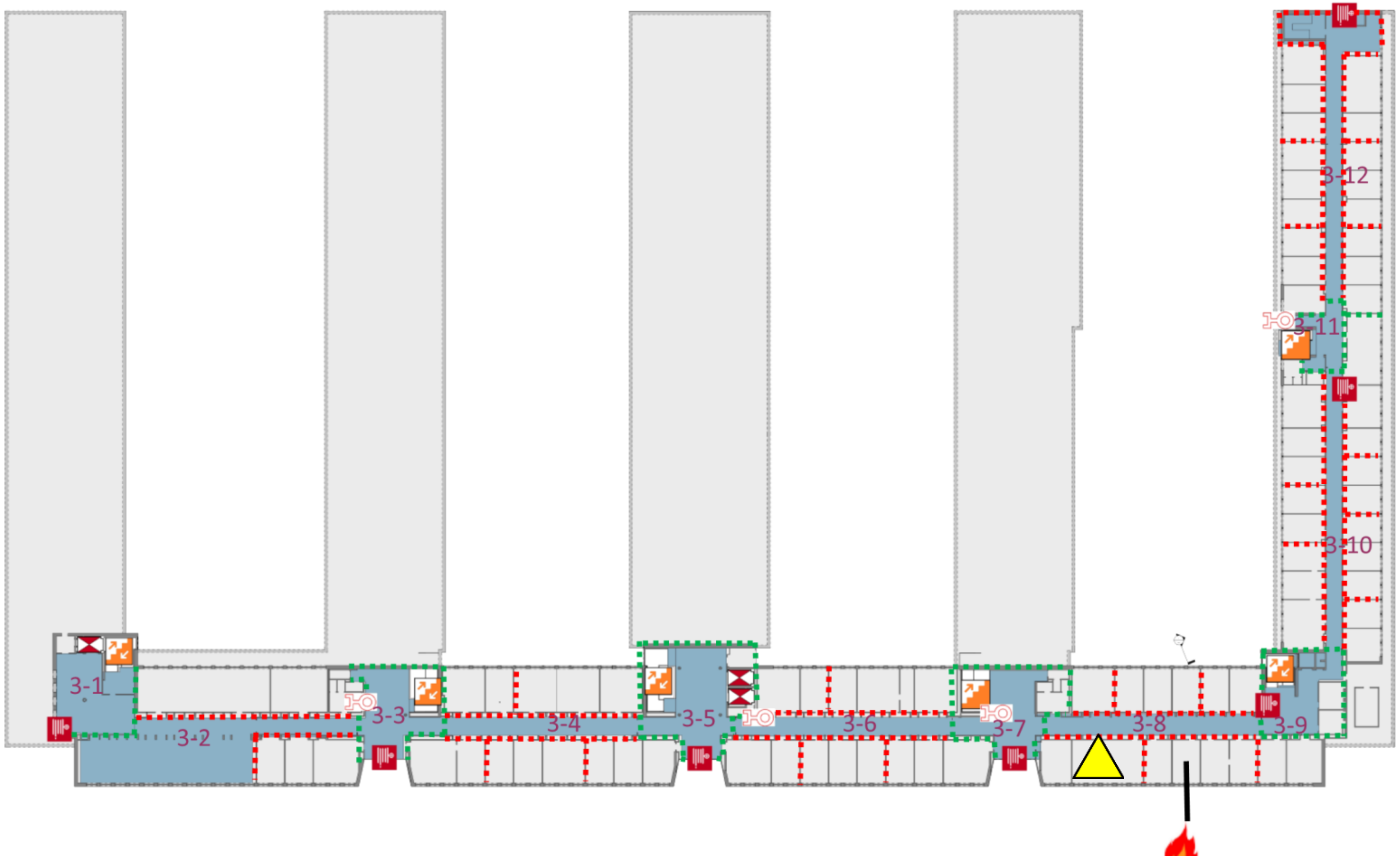


**Current floor:**
3
**Units indoor:**
none
**Smoke detected:**
3-8

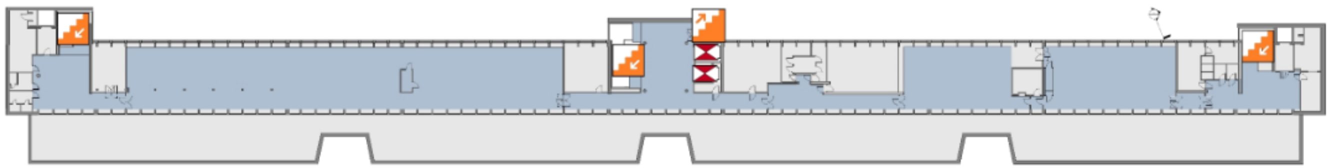
# ToggleMap 2D
# Third Floor

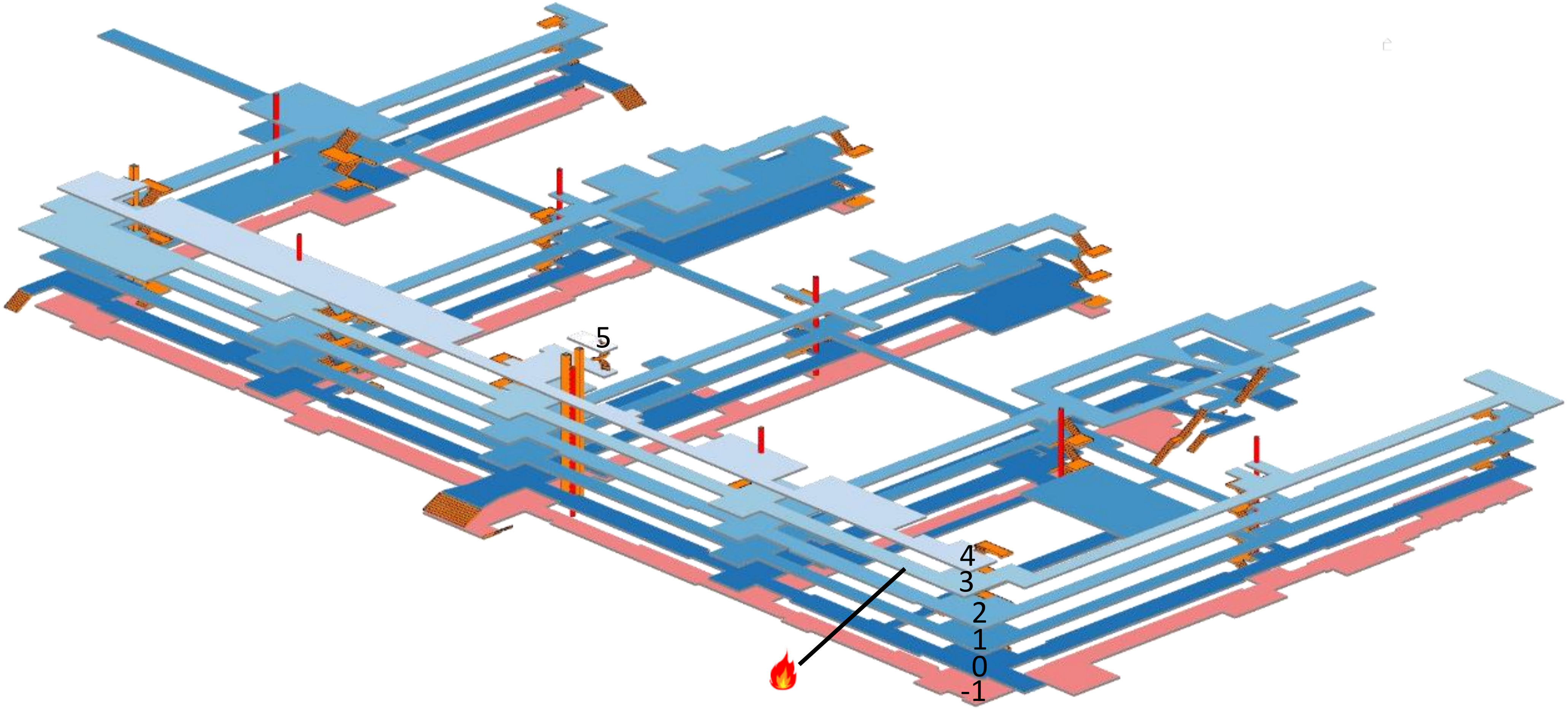





**Current floor:**
3
**Units indoor:**
none
**Smoke detected:**
3-8

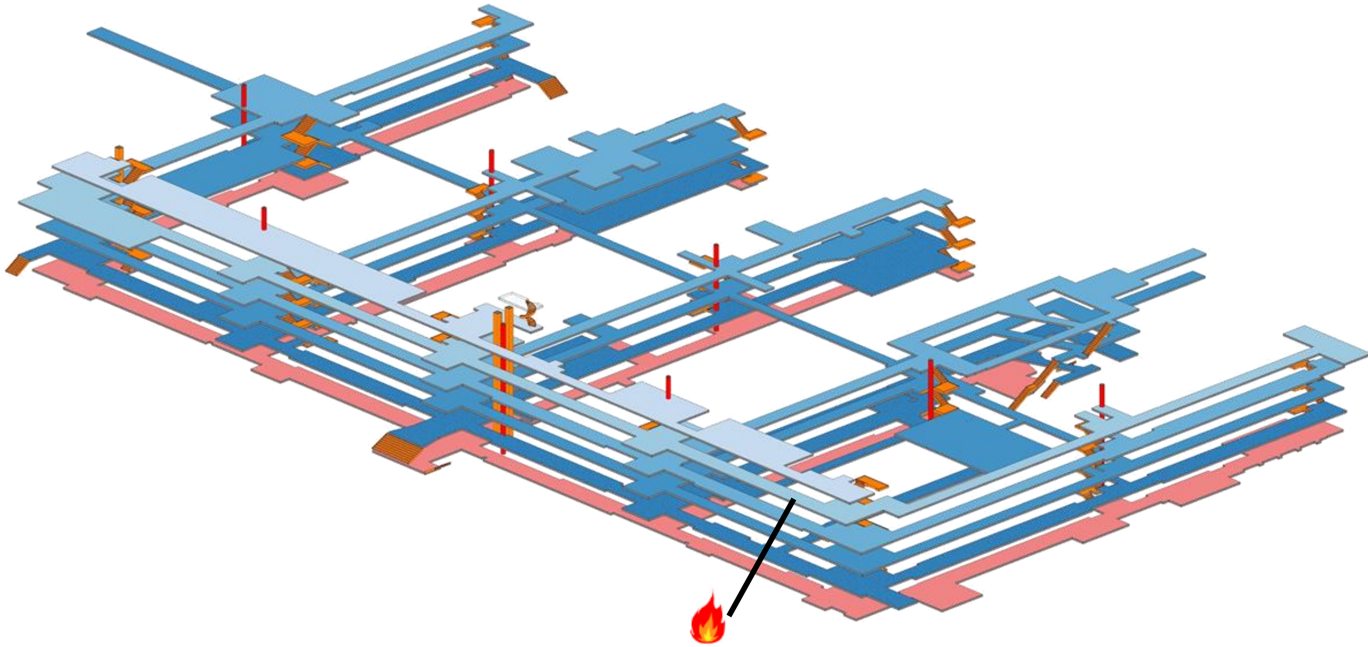
# ToggleMap 3D
# Fourth Floor

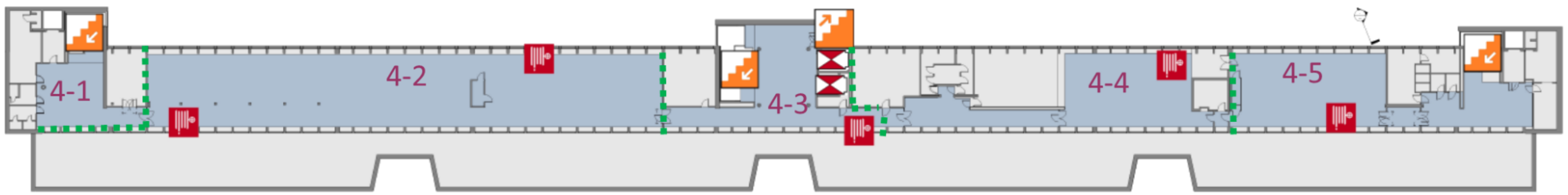





**Current floor:**
4
**Units indoor:**
none
**Smoke detected:**
3-8

# ToggleMap 2D
# Fourth Floor






**Current floor:**
4
**Units indoor:**
none
**Smoke detected:**
3-8

# Incident

- Brand in faculteit Technische Natuurwetenschappen
- Rookmelder afgegaan in kantoor op verdieping 3
- Er zijn geen sprinklers aanwezig in de betreffende ruimte
- Pand met gemengde gebruiksfunctie: kantoren, studieruimtes, opslagruimtes en laboratoria
- Waarschijnlijke oorzaak: kortsluiting
- BHV heeft bluspoging afgebroken. Ruimte was onbegaanbaar wegens hitte.
- Ontruiming is in gang gesteld. Onbekend of het hele pand leeg is.
- Rook waargenomen op verdieping vier, locatie onbekend
- Brand is nabij medium risico laboratorium