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Full Length Article

# Experience gained from 15 years of fire protection plans for Nordic wooden towns in Norway

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ABSTRACT

There is a genuine will to protect Nordic wooden towns in Norway, as they are considered national heritage and an important part of the urban identity. The fire protection of wooden heritage towns is an ongoing cooperation between private owners, who are required to keep their property up to codes, and the authorities who works to limit the residual conflagration risk. The present study systemizes national fire protection initiatives and present successes and challenges. Research literature, legal framework, and municipality fire safety site plans were analyzed. Personnel from involved municipalities, fire services and national directorates were interviewed. Compared to other countries, Norway has indeed come a long way regarding practical fire mitigating measures. In year 2000, the first fire safety plans dedicated to protecting wooden towns were developed. In 2014, 25% of the wooden towns had fire safety plans, and in 2020, 60%. Status as national heritage and thus, financial support from the Directorate of Cultural Heritage, was the most important success factor. Measures were often not evaluated prior to implementation, partly due to lack of horizontal knowledge sharing between the municipalities involved. Important lessons have thus been gained separately, and not shared. Smoke detection alarming the fire brigades directly is documented to have prevented major heritage losses. The most common firefighting challenges were related to locating and accessing fires in cavities. Through clearer wording in regulations, and better knowledge sharing, fire protection could be improved with limited additional costs.

## 1. Introduction

The Nordic wooden towns could be considered an anachronism already in the 19th century, as the rest of Europe had introduced mandatory brick buildings in city centers. However, after the 1904 Ålesund fire, i.e. the most severe fire disaster in Norwegian history (Losnegård, 2013), new wooden buildings were prohibited in the towns. Later town fires, as well as bombing and intentionally set fires during World War II, resulted in massive destruction of wooden towns in Norway. Furthermore, modernist urban planning in the 50s and 60s sought to demolish and redevelop wooden structure areas in several towns, often contributing to neglect and decay of the affected areas. However, during the 70s, especially the young population along with the heritage authorities, gradually started valuing the wooden town areas. Most redevelopments were prevented, and many restoration projects took place. Today, small wooden settlements and town centers are associated with the Scandinavian "hygge" concept, meaning they are perceived as cozy and indeed trendy. Thus, few countries have as high proportion of old wooden towns as Norway.

The sites focused on in the present study are in Norway termed "tette trehusmiljø" (literally, dense wooden house environments), in this study translated to dense wooden heritage sites (DWH sites). The Norwegian Directorate of Cultural Heritage (NDCH) has defined DWH sites as:

- the site mostly consists of wooden buildings.
- the site is considered to have heritage value.
- the buildings are largely constructed before 1900, however newer sites of significant heritage value may be included.
- there are normally more than 20 houses in the site.
- the distance between houses are less than 8 m.

The location of the most significant Norwegian DWH sites is shown in Fig. 1. These range from small fishing villages in rural areas via white painted homes in small coastal towns to the remaining narrow streets in

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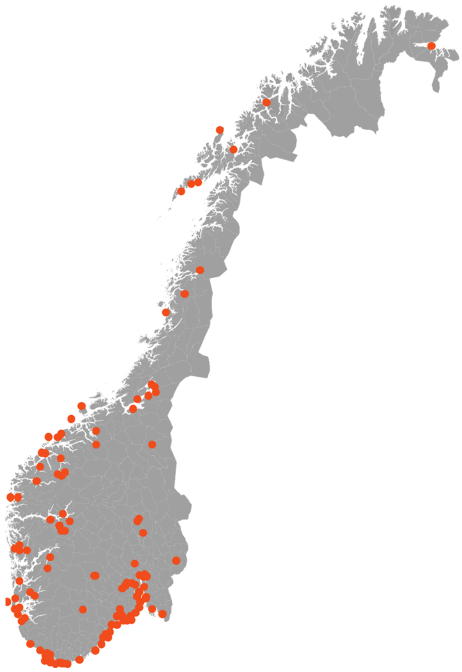

**Fig. 1.** The remaining dense wooden heritage sites in Norway.

larger cities, as seen in Fig. 2. The reason for the extremely few remaining sites in the northern part of Norway is due to the mentioned bombings and scorched-earth military strategy by the end of World War II.

Today, these DWH sites are part of the national identity and represent attractions highly valued both by locals and tourists. These sites are best preserved as "living sites", i.e. private owners and inhabitants use and take care of the buildings. Bryggen in Bergen, and Røros mountain mining village are listed UNESCO World Heritage sites. It is of national importance to protect all these sites from disastrous fires.

January 18th, 2014, a fire in Lærdalsøyri caught national, as well as international, attention (DSB, 2014; Steen-Hansen et al., 2015), see Fig. 3. After a period of adiabatically heated sub-zero temperature air from surrounding mountains resulting in very dry indoor conditions (Log, 2016), in storm strength winds, a fire raged through a residential area. It quickly approached the Old Lærdalsøyri heritage site, i.e. a major tourist destination. The blaze was controlled just as it entered the heritage site and fortunately destroyed only two heritage buildings, one of which were listed. The fire destroyed 40 structures, making it, to that date, the most severe town fire to occur during peace time in Norway since 1923 (Losnegård, 2013).

Despite the efforts undertaken worldwide to reduce the fire risk, fires continue to result in losses in heritage sites, and the authorities are concerned about measures to be implemented (Granda and Ferreira, 2019; Ferreiraa et al., 2016; Okubo, 2016; Yuan et al., 2016; Challands, 2010; Lee et al., 2021). Even fires limited to 1–3 houses may over time result in homogeneous heritage sites becoming fragmented by new buildings or vacant spaces. Loss of historic wooden buildings in fires represents a challenge in all countries, where still present. These kinds of fires also leave deep impressions in the general population and a sense of common loss that is not usually seen after a fire. Some fires even reach international headlines, e.g. the Notre Dame Cathedral (Paris, 15 April 2019), Shirakawa Village (Japan, 4 November 2019), Shurijo Castle (Japan, 31 October 2019) and Wengding Village (China, 14 February 2021). In Norway, following a period of very low indoor relative humidity (Strand et al., in press), similar to that experienced prior to the 2014 Lærdalsøyri fire (Log, 2016), a fire threatened the Risør DWH site 24 February 2021.

In line with the UN Sustainable Development Goals, 11.4, Norway has gradually strengthened its effort of protecting and preserving the remaining heritage sites. From early 2000, development of dedicated fire safety plans for DWH sites became common in Norway. These plans analyze possible risk factors and mitigation measures for a specific area, that cannot be left to the individual owners. The aim of the fire safety plans is to strengthen safety barriers often above the normal regulatory level. This effort comes after the acknowledgement that a) the risk of fire spread in wooden towns is substantial even when all buildings are up to code and the individual owners comply with all responsibilities, and b) conventional fire mitigation measures such as fire walls etc. could be implemented by individual owners but is often not desirable from an antiquarian stance. The 2014 Lærdal fire serves as a reminder that further fire protection is necessary (Log, 2016; DSB, 2014; Steen-Hansen et al., 2015). Indeed, from 2016 to 2021, about 80 fire incidents were reported annually in wooden heritage sites in Norway. Most of these were small incidents, although some caused major loss of heritage. Fire

(a) (b)

**Fig. 2.** Henningsvær fishing village at 68.2° N **(a)** and narrow streets in Trondheim **(b)**.

**Fig. 3.** Flames blown horizontal at the Lærdalsøyri fire January 18th, 2014. (Photo by Geir Trulssen. Reproduced with permission).

protection of the remaining sites are thus very important, and much work has been done in Norway, especially since the 90s. The municipalities have been working individually with limited knowledge sharing. In sum, this has resulted in fractionalized knowledge of what works and what does not work, and there is little research available regarding implemented or discarded DWH fire safety measures.

The main objectives of the present study were to systemize fire protection experience from the DWH sites in Norway, identify successes and challenges, and suggest future improvements. National laws, regulations, and guidelines, as well as municipal fire safety plans, and international research literature have been investigated. Personnel from local municipalities and national directorates were interviewed regarding fire safety measures as well as the fire protection process. Data from selected fires were analyzed regarding causes, detection, and challenges during firefighting. The results are expected to make it easier to select successful measures in future national and international fire protection initiatives and to develop improved fire safety plans for wooden heritage sites.

## 2. Methods

Three main methods have been used in the study: literature review, document analysis and empirical research. A review was carried out to map Norwegian literature specifically related to fire protection of wooden towns. Furthermore, international literature showing status and recent advances within research on large outdoor fires and the built environment were also analyzed. The literature search included research databases, e.g. Web of Science, Science Direct and Google Scholar, reports and guidelines, and MSc-theses at Norwegian educational institutions. The review of Norwegian literature summarizes relevant laws and regulations, research including master theses, and literature describing the historical context of the wooden towns. The purpose of this review was to accumulate experience with prevention or mitigation measures and analyze previous research studies.

The aim of the document analyses was to gather fire safety plans, and qualitatively and quantitatively describe the content of these documents. In part, checkpoints were used to quantitatively describe content and partly subjective observations were made. The analysis did not aim to evaluate the fire safety plans, but rather give an overview of their content. Furthermore, the study did not seek to evaluate any one person, company, or municipality. 60 fire safety plans from various municipalities hosting relevant historical sites according to the DWH definition were collected and analyzed, available (in Norwegian) as open access at the municipality's web pages or at einnsyn.no (on request). Given the authors' long experience with fire safety analysis, the evaluations may be recognized as quite valid.

The empirical part of the study had two goals. Firstly, to gather experience from a range of people working fire protection of wooden towns within municipalities and fire services and secondly, to gather firefighters experience form recent relevant fires. The results comprise data gathered from 70 municipalities covering 90% of recognized DWH heritage areas as well as firefighters experience from 20 fires within the last 5 years. Social science methods (Johannessen et al., 2016) were used for data collection and interpretation, and for establishing empirical relationships between measures and obtained results.

Questionaries formed partly as tick-boxes and free text fields were sent to selected resource personnel for each site to be studied. Semi-structured interviews (Gilham, 2005; Kvale, 2004) were used for data collection to give the interviewee flexibility to talk about the fire protection work, with occasional follow-up questions by email. Interviews were done by web-based platforms, e.g. Skype and Teams, or by phone. The informants were generally selected based on the municipality information desk and partly based on knowledge about professionally engaged persons via previous interactions. Since some groups involved in fire protection have direct economic interests in the work, e.g. equipment suppliers, and thus could be biased, this important group of informants unfortunately had to be omitted.

Tradeoffs had to be done regarding study width versus depth. The target group for the results was identified as personnel working with fire safety of densely built wooden heritage sites and decision makers defining relevant framing conditions, e.g. municipality directors, national directorates, etc. The study is limited to Norway, while the international research literature serves as sources for knowledge and ideas, not as an object of investigations as such. The study was limited to measures suggested or implemented by local municipalities, fire brigades and fire safety advisors. Work initiated by, e.g. county governors and national directorates was not included. Neither was experience from residents or owners included. The study does not seek to evaluate or analyze work related to individual buildings.

## 3. Selected international research studies

Compared to Norway, there has been less focus on fire safety in densely built wooden structures in the other Nordic countries. There are however some examples of fire safety projects. Eksjö in Sweden has a town center with many wooden heritage structures from the period 1500 – 1700. The fire safety challenges are similar to those in Norway, i.e. high fire spread risk and difficult access for fire trucks, etc. The materials use, evacuation possibilities, fire load, fire detection, heating methods and cultural value, etc. was mapped in 1999 (Räddningsverket, 1999) and are similar to what is found in Norway. It was highlighted that very few buildings in Eksjö had fire alarms directly notifying the fire station, in large due to owners considering such systems as a major expense (Räddningsverket, 1999). This issue appears unchanged in connection with news articles after a major fire in 2015. Recently, some measures have been taken, but there has also been resistance from the owners regarding the recommended measures (Swedish Television News, 2020a, 2020b; Smålands-Tidningen, 2020).

Two Swedish master theses on dense wooden house fire risk studies focused on quantifying or describing the risk of fire spread between buildings, however, with limited focus on preventive measures (Glenting, 2002; Jansson and Wikensten, 2014). One of the studies points to sprinkler systems as the most effective measure to prevent the spread of fire (Glenting, 2002).

Rauma, Finland, is a UNESCO World Heritage Site. After a severe fire in 1997, a fire protection project was initiated in which mapping of the building stock and inhabitants was central (Laurila, 2004). Sprinklers were considered too expensive, but some buildings were equipped with fire alarm systems. Other measures included information about fire preventive measures and building inspections to ensure a proper safety level.

The Guimara center, Portugal consists of 436 buildings and is a UNESCO World Heritage Site. Extensive work has been done to map fire safety in this area. In a recent study, Granda and Ferreira (Granda and Ferreira, 2019) mapped the buildings through an Index method and showed that 67% of the buildings had a moderate to high fire risk. This was caused by the buildings' design, lack of fire protection measures in individual buildings and characteristic features of the area's infrastructure. Each building finally got an overall rating based on several sub-grades within categories such as the building's general condition, internal fire load, internal fire protection measures, escape routes and potential ignition sources such as electrical installations or gas pipes. Buildings that typically had a high-risk index were characterized by, e.g. old electrical systems, unsafe load-bearing systems, a large indoor fire load, lacking fire alarm system and inadequate escape routes. Many buildings were also difficult to access for the fire brigade due to narrow streets. The results were visualized by a GIS tool. In contrast to similar surveys of the Norwegian wooden house environment, the index method takes greater account of the safety within each building and to a lesser extent the potential for the spread of fire. The grades were measured based on local building regulations, i.e. two identical buildings may receive different scores if the building regulations only require, e.g. fire alarm system in one of the buildings.

The same index method was also used for mapping Seixal, Portugal in 2016 (Ferreiraa et al., 2016). There, recommended measures also included monitoring abandoned buildings, preventive information work, fire drills, improving the water supply and fire trucks adapted to narrow streets. It should be noted that smaller fire trucks have also recently been purchased for similar sites in Norway, e.g. Skudeneshavn as seen in Fig. 4.

Japan also has a rich tradition of using timber for house building. The study of Okubo (Okubo, 2016) presents how traditional knowledge of construction and architecture has contributed to the continued existence of dense wooden buildings in Japan. Experience was gathered with a focus on traditional knowledge. Of the elements in the fire triangle (heat, oxygen and combustible material), traditionally combustible material was considered to be that which could be easily removed to limit fire. Japanese houses were therefore built so that roofs and walls could be easily demolished if a fire broke out. This is a similar approach to the "fire hook" concept in Norway, i.e. meant to be used to pull down timber or roofs in buildings on fire – a method not applicable in Norway today.

Also in China, we find dense cultural-historical buildings areas with large elements of timber. A study (Yuan et al., 2016) identified fire hazards in a typical historic building, Dangjia in Shaanxi Province, in order to better preserve them. A strong building tradition in this area is so-called siheyuan which consists of low houses in a square around an inner courtyard, i.e. similar to Norwegian "firkanttun" (square yards). The buildings consist of a mixture of timber and bricks. In the study (Yuan et al., 2016), the Siheyuan settlement was quantitatively mapped based on an index method, similar to that used in Guimara and Seixal. One of the focus areas was changes in the use of the buildings, which entails different requirements for fire safety than what they were designed for. Load-bearing timber structures were analyzed and found in poor condition. Furthermore, typical weaknesses were poor accessibility for the fire service and access to fire water as well as a lack of facilities enabling safe escape in case of fire.

**Fig. 4.** Søragatå street in Skudeneshavn. (Photo: Ørjan B. Iversen. Reproduced with permission).

Fire spread from wildland vegetation to buildings, i.e. Wildland-Urban Interface (WUI) fires, is an increasing challenge worldwide. In Norway, this is a known but generally a less severe challenge. The January 2014 sub-zero temperature WUI fire in Flatanger (Log et al., 2017), 10 days after the Lærdalsøyri fire (Log, 2016), resulted in loss of most wooden structures in a single fire in Norway since 1923. The WUI fires must be recognized as an increasing challenge also in Nordic climates.

In a recent study, Intini et al. (2020) reviewed standards and guidelines dealing with protection against natural fires, e.g. vegetation-free zones, classification of danger areas and requirements for the design of buildings. The article points out that existing standards have a high focus on, and are consistent in, assessing risk and measures related to vegetation. Requirements for buildings are less consistent both in terms of material use and execution. Several standards contained few or no recommendations regarding active measures and firefighting. This may indicate a lower level of maturity in the understanding of effective measures. The need for further research on concrete solutions was emphasized.

Other studies, e.g. (Bento-Gonçalves and Vieira, 2020; Caton et al., 2017) also points to the need for a better understanding of practical measures against fire spread in the WUI. The basic science is known, but buildings and society's response to the spread of fire in complex situations are not well known. The knowledge we have gained about WUI fires must be put to the test in laboratory experiments, scale tests and new data must be obtained from future fires. Several recommendations for measures against the spread of fire are not supported by scientific data.

Fire spread in informal settlements or slum areas is an increasing challenge for the poor populations in Africa, Asia, and South America, where tens of thousands of inhabitants may be left homeless after a single fire. Fire spread in these areas have parallels to fire spread in densely built wooden home heritage sites. In both situations, there are numerous owners and limited possibilities for measures in each structure, and the main focus is usually fire spread between the structures.

The study by Cicione et al. (Cicione et al., 2019) focuses on full scale fire spread between informal buildings, one with a steel plate construction and one with wood. The critical distance between buildings for preventing fire spread was 3 and 5 m. This is far less than what is normally allowed for new buildings in Norway. However, buildings in slum areas are small and emit far less radiant heat in fires than, e.g. a dry wooden home in Norway during a wintertime fire. The study also describes another parallel to DWH sites, i.e. the social peculiarities and uncontrollable conditions in the buildings that make fire protection difficult. In new buildings, fire safety responsibilities are clearly defined, and well-known measures may be enforced through the building codes. However, in a built environment where each building represents an individual owner, implementing any measures are challenging, especially when the legal basis is unclear. Some measures may not even be allowed due to heritage restrictions.

A study of fires in Cape Town informal settlements (Walls et al., 2017) also included full scale fire tests, which documented that flash-over could take place even within one minute. A well-known challenge with parallels to DWH sites is that combustible material often accumulates between buildings and establishes “fire bridges”, i.e. contributing to spread of fire between buildings. Reference is made to a hypothesis from (Moradi, 2016) that simulation of such fires will require a hybrid simulation of forest fire and house fire, which may be relevant for dense wooden house environments as well.

The ARUP framework for fire safety in informal settlements (Lane and da Silva, 2018) presents concrete measures that can be implemented at home, neighborhood and community level. Many of these are familiar measures for fire protection in Norway, such as limiting vegetation close to homes, increased local and area detection, improved water supply, fire drills for neighborhoods, fire trucks adapted for narrow passages and fire hydrants. Other measures are highly relevant, but not commonly focused in Norway, such as increased focus on safe cooking, notification of neighbors in the event of a fire, investigation and learning from incidents and sharing of knowledge.

For fires in calm weather, the risk of spreading can be assessed mathematically based on the heat radiation. However, almost all major town fires have occurred in strong winds. Under such conditions, it is primarily firebrands and glowing ember that spread fire. Research on embers and firebrands as mechanisms for fire spread is therefore very relevant, e.g. the study by Manzello et al. (Manzello et al., 2012). Their “fire-breathing dragon” helps understand how ember attacks thatched-roof buildings and learn to mitigate such attacks. Fire spread by glowing ember and firebrands over long distances was indeed the main mechanism in the Lærdalsøyri fire (Log, 2016) as well as the WUI fire spread to the buildings in Flatanger (Log et al., 2017). When renovating the roof of a heritage building in Old Lærdalsøyri in July 2016, severe burn marks were discovered, see Fig. 5. Of the 40 structures lost in this fire, fortunately only two detached heritage buildings in the outskirts of Old Lærdalsøyri, one of which was listed, were destroyed (Log, 2016). The burn marks in Fig. 5, i.e. under the shale roof tiles in a building 100 m away from the nearest building lost in fire, indicate that this fire was close to destroying the Old Lærdalsøyri heritage area and ruining one of the most important tourist attractions along an important tourist road of Western Norway (Gudvangen, Flåm, Nærøyfjorden World Heritage Monument, Lærdal tunnel (24.5 km), Old Lærdalsøyri and Borgund Stave Church).

## 4. The governing rules and regulations in Norway

In order to understand the Norwegian legal framework for fire protection of the wooden heritage sites, the associated rules and regulations were briefly analyzed.

According to the Norwegian Parliament Report no 35, Norwegian Ministry of Justice and Public Security, 2008–2009 (Brannsikkerhet. Forebygging og brannvesenets redningsoppgaver), the national goals for fire protection are:

- fewer fire related fatalities
- prevent loss of irreplaceable cultural-historical values
- prevent fires that paralyze critical societal functions
- strengthened preparedness and handling ability
- reduce the material losses due to fires.

The historic sites investigated in the present study are among the “irreplaceable cultural-historical values” covered in the 2nd bullet point, and as such, at risk regarding fires. The current regulations do not specifically mention requirements related to fire protection of old wooden towns or indeed heritage values but will be discussed in this respect.

The fire and explosion protection law (Lov om vern mot brann, eksplosjon og ulykker med farlig stoff og om brannvesenets redningsoppgaver) deals with the general obligations to prevent fire, and if a fire has started, to notify the fire service and to minimize the consequences, if possible. Chapter 3 deals with municipality duties. § 13, Special fire objects, is highly relevant to historical sites. Restrictions regarding upgrading of heritage structures are detailed in the fire prevention regulations (Forskrift om brannforebygging).

The Planning and Building Act (PBA) (Lov om planlegging og byggesaksbehandling) deals with planning and processing of

Fig. 5. Deep burn marks in the roof construction discovered when refurbishing a roof (on the pink house) in Old Lærdalsøyri, July 5th 2016. (Photo: Odd Helge Brugrand/NRK. Reproduced with permission.).

construction plans, construction activities and land management. Special provisions related to existing buildings are relevant for dense wooden buildings. Chapter 12 deals with zoning plans enabling the municipality to make regulations regarding consideration zones and the cultural environment. Quality requirements can be set to ensure heritage buildings worthy of protection. Performance based fire safety codes were introduced in Norway during the 90s. Thus, the regulations allow other measures than stated in prescribed codes when these measures can be documented to give as good, or better, fire safety. This introduced appreciated flexibility when dealing with heritage building fire safety.

The Cultural Heritage Act (Lov om kulturminner) deals with protection of individual buildings and built areas as part of Norway's cultural heritage. Very little is written regarding fire and fire protection, while degradation prevention is focused in, e.g. §17. Whole areas can be listed based on §20. Except for the two UNESCO World Heritage wooden building sites mentioned previously, five town areas are listed, including the fishing, and former shipping, village Skudeneshavn, see Fig. 4.

The fire prevention regulations (Forskrift om brannforebygging), chapter 4, i.e. § 14 to § 22, deals with the municipality regulations, including developing a risk and vulnerability analysis. The goal is to identify likely fire scenarios and corresponding risk management measures. In municipalities with densely built wooden heritage sites, conflagration is a likely worst-case scenario. The municipalities therefore are obliged to plan and implement preventive measures to mitigate this risk and develop a fire safety plan. Risk-based supervision of identified special fire objects is mandatory (§ 18). In the context of this study, typical risk objects can be determined based on cultural-historical value, e.g. DWH sites.

The regulations on the organization and dimensioning of the fire service (Forskrift om organisering og dimensjonering av brannvesen) shall ensure that each municipality has a fire brigade organized, equipped, and manned to satisfactorily handle tasks and incidents required by relevant laws and regulations. It must be dimensioned based on the existing risk and vulnerability. Cooperation with other municipalities and emergency organizations is required (§4), including the need for reserve forces. As an example, during the 2014 fire in Lærdalsøyri, forces from 14 neighboring fire brigades, the Civil Defense and the Armed Forces were engaged. Additionally, an airport fire truck, farmers with slurry tankers and civilians were also engaged fighting the fire (Log, 2016; DSB, 2014).

When the fire risk is much higher than normally, the municipality shall introduce higher emergency preparedness, e.g. increased manning, deploy equipment, etc. (§ 4–11). This may be relevant for predicted high fire danger weather conditions with low relative humidity, drought, and wind (Log, 2017; Log, 2019; Stokkenes et al., 2021; Log et al., 2017). The guideline states: "*Drought, often combined with careless handling of open flames, is a common fire risk in the forest. During periods of drought, the risk of fire can also increase elsewhere,* e.g. *in older wooden settlements*."

In areas with significant forest fire risk, a special reserve force must be organized and trained for wildfire response. This is relevant also where wooden heritage structures are at risk. Empirical evidence from municipal fire safety work shows that approx. 20% state that exercises have been carried out in connection with fire in densely built wooden home areas.

The technical building requirements regulations (Forskrift om tekniske krav til byggverk) shall ensure that construction measures are planned, projected, and carried out to meet the requirements, among other issues, for fire safety. Of relevance to heritage sites is that new buildings must be placed, designed, and constructed to reduce the probability of fire spread to other buildings (§ 11–1(3)).

### 4.1. *The individual owners' responsibilities*

In accordance with the regulations on fire prevention (Forskrift om brannforebygging), owners are required to ensure that buildings have satisfactory fire safety. This includes, among other things, that all homes should be equipped with smoke alarms and manual fire extinguishing equipment. Owners of old buildings are required to ensure that the fire safety level is upgraded to a level equivalent to that of the 1985 building regulations. Such upgrades can be achieved through implementing the concrete building regulations or through other compensatory measures, e.g. automatic fire alarms, sprinkler systems, etc. Compensatory measures must be subject to a risk analysis showing its applicable and provide sufficient safety. Upgrades are however only required if they are practical and economically justifiable. In the old wooden towns where separation distances are insufficient and fire barriers are scarce, there will be discrepancy between measures that can be imposed on the individual owner, to safeguard life and properties, and those measures that are recommended to secure intangible values such as cultural heritage.

### 4.2. *The municipality's responsibilities*

The Civil Protection Act (Lov om kommunal beredskapsplikt, sivile beskyttelsestiltak og Sivilforsvaret) and regulations on municipal emergency preparedness state that the municipalities are required to work holistically and systematically with emergency preparedness. As a basis for this, each municipality must prepare a risk and vulnerability analysis that identifies relevant scenarios. Furthermore, the analysis should form a basis for contingency plans to handle critical scenarios. For any municipality with recognized old wooden towns, urban conflagrations would be a relevant scenario to prepare for.

Through the Fire and Explosion Protection Act (Lov om vern mot brann, eksplosjon og ulykker med farlig stoff og om brannvesenets redningsoppgaver) and regulations on the organization of the fire service (Forskrift om organisering og dimensjonering av brannvesen), the municipality is required to ensure the establishment and operation of a fire service. The fire service must be organized and dimensioned based on the municipality's risks and vulnerability. For any municipality with recognized DWH sites, this should therefore be considered.

Through the Fire and Explosion Protection Act with regulations on fire prevention (Forskrift om brannforebygging), the municipality is required to identify and keep a list of areas where fire can cause major damage to material or cultural-historical values. For municipalities with dense wooden houses worthy of protection, it will be natural for these to be considered.

The municipality also has a duty to plan and implement measures to reduce the mapped risk, both through the Fire and Explosion Protection act (Lov om vern mot brann, eksplosjon og ulykker med farlig stoff og om brannvesenets redningsoppgaver) and the Civil Protection Act (Lov om kommunal beredskapsplikt, sivile beskyttelsestiltak og Sivilforsvaret). If urban conflagration and massive loss of heritage is identified as a risk, plans on how to reduce the risk must be implemented. This can be done by a dedicated fire protection plan for the urban area at risk.

### 4.3. *Guidelines on fire protection of Nordic wooden towns*

Based on fires in historic buildings in Norway during the 90s (Log and Cannon-Brookes, 1995), surveys and research projects were undertaken in the period 2000–2005 to present fire risk mitigating measures in DWH sites (Steen-Hansen et al., 2004; Nasjonal kartlegging av brannsikkerhet i verneverdig tett trehusbebyggelse, 2005; Veiledning for myndighetsutøvelse av tilsyn utført av brann- og feiervesenet, 2006). The Directorate of Civil Protection (DCP) and the Directorate of Cultural Heritage (DCH) developed guidelines on town fire protection in 2007 presenting how such sites could be fire protected (Bybrannsikring. Veileder, 2007). Risk parameters were elaborated. The guidelines state that no regulations specifically place the responsibility for the overall DWH site fire protection, only for single objects. This is still the case. Thus, fire safety in heritage areas requires that various actors cooperate, while owners are responsible for their own property and occupants are responsible for safe use and general caution. This contrasts paragraph (§

8) in the industry major accident regulations (Forskrift om tiltak for å forebygge og begrense konsekvensene av storulykker i virksomheter der farlige kjemikalier forekommer) and praxis elsewhere, e.g. regarding airports (Iervolino et al., 2019), where owners are responsible for preventing domino effects putting other facilities at risk.

The guidelines recommend fire safety plans to be developed for each heritage area, to ensure well-organized and documented measures (Bybrannsikring. Veileder, 2007). Further guidance is provided on what the fire safety plans should consider, how inspections and surveys can be authorized and general information on measures within prevention, detection, and fire damage limitation. The municipalities' fire safety plans therefore are important for developing plans and implementing measures to control the fire risk. The Directorate for Cultural Heritage has later formalized fire safety plans as a requirement for any municipality seeking funding for fire safety measures. Given a 10+ years period of developing and using such plans, it was due time to evaluate how this works in practice.

## 5. Results from fire safety work

### 5.1. Fire safety characteristics in DWH sites

Data from the Norwegian fire and emergency reporting system (No. brann- og redningstjenestens rapporteringssystem, BRIS) for fire service callouts was used to investigate characteristics of fires in wooden towns and compare them to general fire incidents. No previous studies have investigated statistical fire characteristics specifically related to fires in DWH sites.

The BRIS statistics revealed that over the 5-year period 2016–2020 buildings within these wooden town sites seem to be more susceptible to fire then buildings in general. Although there is a high amount of uncertainty related to this conclusion. 68% of fires occurred in housing buildings, and stove fires was by far the most common cause. Stove fires are registered when resulting in fire service turn-out but does not necessarily spread outside the stove. There is a clear tendency for severe fires to have been reported by phone rather than fire alarm systems, and opposingly for less severe fires to have been reported by fire alarm systems. The data also shows that the fires, in 3 out of 4 cases, were confined to the extent it had upon arrival of the fire brigades. Again, there was a tendency for fires reported by fire alarm systems to have a less severe extent, upon arrival of the fire service. While the risk of severe conflagrations and loss of cultural heritage is obviously higher, especially in dry and windy conditions (Log, 2016; Log, 2017; Log, 2019; Stokkenes et al., 2021; Log et al., 2017), the typical economical fire losses were not statistically higher than for regular building fires.

The number of buildings in Norway, the number of fires reported in these buildings and the fire frequency are given in Table 1. The number of fires reported has been increasing during the last years, as can be seen in Fig. 6. This may be related to an increasing number of automatic fire alarm systems reporting directly to fire stations. Dry cooking may be an example of an incident that will not necessarily be included in the statistics unless the building has such an automatic fire alarm system. Of

**Table 1**
The number of buildings in Norway, the number of fires reported in these buildings during 2016–2019 and the corresponding fire frequency.

| Explanation | Heritage sites | Buildings in general | Homes in general |
|---|---|---|---|
| Number of fires | 397 | 33,957 | 17,716 |
| Number of buildings | 23,896 | 4,176,665 | 1,573,580 |
| Fire frequency ($y^{-1}$) | 0.0166 | 0.0081 | 0.0113 |
| Fire fatalities [1] | 2 | 185 | 148 [2] |

[1] Data only for 2016 until May 2019.
[2] This number is based on 80% of the fire fatalities being related to home fires in Norway.

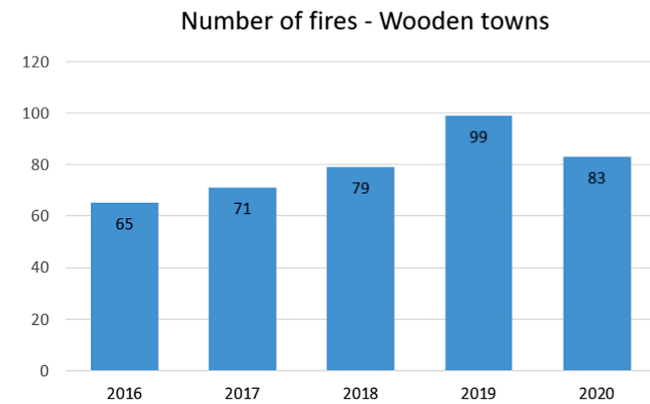


**Fig. 6.** The number of fires reported in the official Norwegian BRIS fire database labeled DWH sites.

these fires, 72% took place in homes while the rest 28% of the fires took place in various types of commercial buildings. In the commercial buildings, fires in shops and business buildings, restaurants and cafés, warehouses and office buildings dominated the numbers.

The fire start location is shown in Fig. 7, where it is quite clear that cooking and electrical equipment dominate as the fire start causes. Fires in trash bins are often associated with arson, and the statistic for the studied period shows 8 such fires, one of which spread from the bin to the room of origin. It is previously anticipated that 10% of the fires were due to arson (Steen-Hansen et al., 2004). The Directorate of Civil Protection fire statistics analysis records also indicate that the fire service units report that 10% of the fires in residential buildings were a result of intended actions. This may, however, not be the case DWH sites as there was no proof of this labeling within the studied period.

In this study, 20 fires over the last 5 years were chosen for a detailed review, and empirical data was gathered from the fire on-scene commanders. Fires of larger extent and consequently media coverage, were chosen to analyze usual firefighting challenges in DWH sites. The most common and predominant challenge in these sites was getting access to fires hidden in cavities or attics. In close to 50% of the fires, the firefighters therefore had trouble locating the fire, could not apply water, and did not know whether the fire was extinguished or not. An example fire is shown in Fig. 8, and examples of cavities in heritage buildings are shown in Fig. 9. The empirical study further verified that larger fires were more commonly reported by a neighbor or a passerby.

### 5.2. Fire safety plans main findings

The results include a detailed mapping of the protection state in all DWH sites in Norway and a review of 60 fire safety plans. Perhaps most valuable is experience gathered from the 70 selected persons engaged in

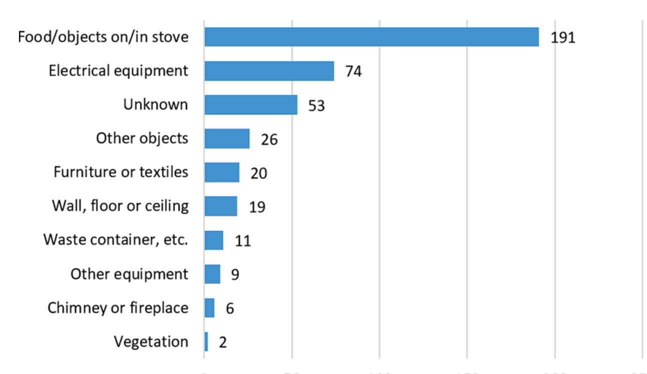


**Fig. 7.** The fire start object/cause.

**Fig. 8.** The fire service responding to a fire in the historic wooden town in Trondheim.

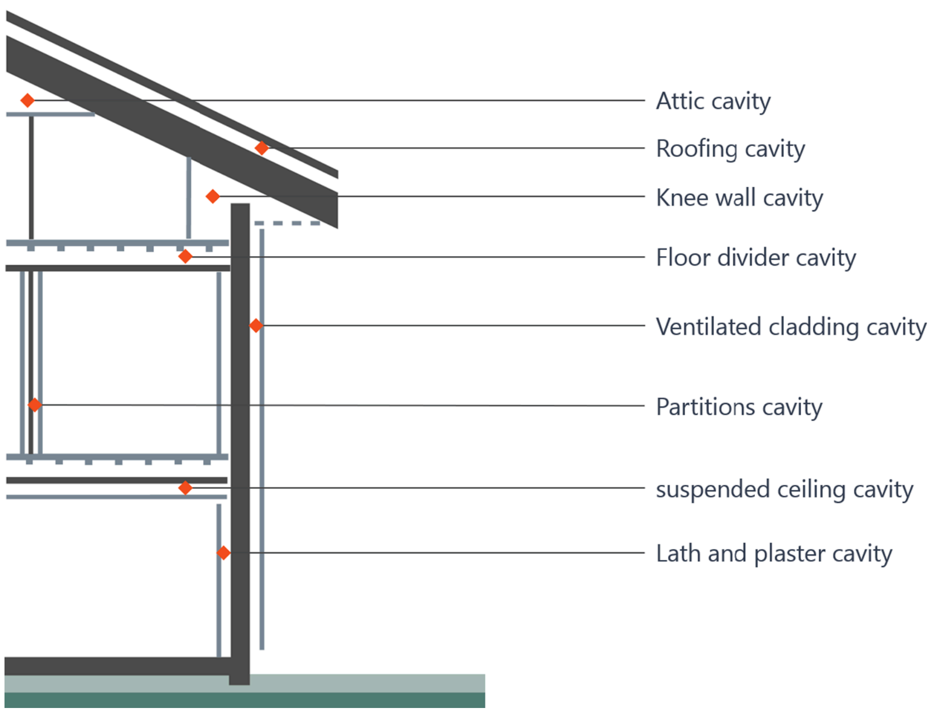


**Fig. 9.** Common cavities in Norwegian heritage buildings.

DWH fire protection. Most interviewees expressed a strong and sincere willingness and dedication to protect these heritage sites. This was evident on all levels, from local municipalities to relevant national directorates. Inhabitants that occasionally met the researchers also expressed proudness and dedication to protect their unique neighborhoods.

The sites included in this study are those recognized by the Directorate for Cultural Heritage as DWH sites, i.e. characterized by having at least 20 wooden buildings, build before the year 1900 and separation distances below 8 m. The sites range from small fishing communities without any urban planning, to large city centers with grid street plans. The buildings were designed to keep the weather out, and allowing plenty of ventilation for the construction, e.g. roof, attic, and cladding leaving the building envelope susceptible to fire. The vernacular architecture contains several construction cavities and later refurbishments often led to additional cavities.

Fire safety plans for wooden towns often emphasize early fire detection and fire service intervention. This is, however, dependent on the fire service response time. The response time for each wooden town was surveyed based on proximity to the nearest fire station and an approximation of turnout time based on the type of fire station, i.e. manned or unmanned, etc. The survey shows that the response time is about 10 min or less for 81% of the sites.

The municipalities' experience with fire safety projects highlighted several successes and challenges related to funding, staffing/capacity, cooperation, resident involvement as well as regulations and guidance. Funding was often mentioned, both as a limiting factor and as a success. The status as cultural heritage, and thereby focus and financial support from the National Directorate of Cultural Heritage, was the single most important reason for the improved fire safety today compared to, e.g. 20–30 years ago. Coping with the amount of work it takes to implement a fire safety plan into practice, especially when coordinating measures with residents, is a challenge. A common feature of the municipalities who succeeded with their fire safety plans and concrete fire safety measures, is that they had worked systematically over a long period, i.e. typically 10+ years. Another common feature is that they distributed the responsibility for the different fire protection sub-tasks within their organization.

Most municipalities worked independently on fire protection, generally with limited horizontal exchange of experiences and limited focus on the effect of established measures. Priorities and measures varied. A tendency to "copy paste", as opposed to assessing the effects of measures elsewhere and then evaluate whether these measures could be feasible in a local context, was observed. As an example, the vulnerability to wildland urban-interface (WUI) fires for many sites is often not discussed in the fire safety plans. This is strange since the Flatanger WUI fire in 2014 (Log et al., 2017), ten days after the Lærdalsøyri fire (Log, 2016), turned out to be the fire with most lost buildings in Norway since the Hemnesberget fire in 1923 (Losnegård, 2013). Fortunately, no heritage buildings were lost in the Flatanger WUI fire (Log et al., 2017).

Most fire safety plans do, however, provide useful information and, for the most part, recommend effective measures. They can sometimes be perceived as quite overwhelming, i.e. on average 35 pages and 14 measures, however, in some cases much more. Within the 60 fire safety plans, 159 different types of measures were proposed, often, without providing concrete and clear proposals. In absence of valid statistics and empirical data, the measures seem to be recommended based on risk perception, i.e. subjective judgement, rather than a more thorough risk analysis. An impression is that implementation of fire safety plans would be more manageable given tougher priorities. A possible mindset where "any and all measures are good measures" seems to complicate the process. This calls for better prioritizing of possible measures in a cost – benefit analysis. It should be noted that since such sites are very valuable as tourist destinations, the benefit should be evaluated in light of this, also with respect to income and employment. The high price of restoration, as experienced elsewhere, should also be a part of this picture (Kim et al., 2018).

The review of relevant international research (Granda and Ferreira, 2019; Ferreiraa et al., 2016; Okubo, 2016; Yuan et al., 2016; Challands, 2010; Lee et al., 2021) provided knowledge about risk factors and possible measures. The review does, however, leave the impression that Norway has a leading role when it comes to practical implementation. This could in part be due to an initially pragmatic approach to the fire protection and a sense of urgency to get protective measures in place. However, since different types of measures have been implemented in the communities, there is still a relatively small basis from which to gather experience.

Norwegian laws, regulations and guidelines state who is responsible for the fire safety of single objects. However, who is responsible for what regarding fire protection of heritage sites involving numerous privately owned buildings, is still unclear. It is indeed unclear to the extent that it has been considered uncertain whether anyone at all has an overall responsibility. This results in different approaches and needs to be clarified to better support future fire prevention work.

Despite maintenance issues and false alarms, automatic smoke detector alarm transmission, enabling early response, has prevented significant loss of cultural and historical values. This was confirmed by municipalities, national fire statistics and post fire investigations. The effects of fire prevention and passive measures could not be similarly documented. Further details regarding the results may be obtained in the study by Kristoffersen (Kristoffersen, 2020).

### 5.3. *Success of early warning remote IR cameras in a recent historical site fire*

About 20 years ago, IR cameras were introduced at the Røros UNESCO Heritage Town, Norway, for area surveillance identifying possible fire outbreaks outdoors. From the conspicuous Røros church tower, the cameras could monitor the whole area and warn about flames and possibly also hot smoke plumes. Within the present study period, 11 DWH sites in Norway had such cameras installed. None of these warned about serious fires in the period analyzed, i.e. 2015–2019. In the case of an outdoor fire, IR cameras will detect and alarm very effectively, given that there is a clear line of sight between the camera and the fire. In the case of fire starting inside a house the IR technology will likely not detect this fire until the fire breaks through a window or the roof. However, when alerted, the fire brigades may then use the closed-circuit television (CCTV) function to confirm a potential critical situation. This was the case in the Risør DWH town 24 February 2021. Two dedicated IR cameras were continuously monitoring the site. At 04:40:38 in the night, one IR camera gave alarm. It was confirmed that this was a real fire via CCTV, and the operators immediately realized that this could become a devastating fire, and thus, a full alarm was initiated. When the first firefighters arrived, the house of the fire origin was fully involved in fire, as seen in Fig. 10.

Recent research on wooden home fire risk has shown that this fire happened when the indoor wood materials were very dry, and thus, very susceptible for fast fire development and early flashover (Strand et al., in press). There was initially no wind when the fire spread to an adjacent building. After the firefighters had arrived, the wind picked up slightly. Even when present, and applying water to the fire, the fire fighters could not prevent fire spread to a third building (Brigades and Brann, 2021), as seen in Fig. 11.

About 5 min after the IR camera warning, residents that woke up observed the fire and called the emergency phone number. Thus, 5 min were gained by the remote IR camera system. The incident report (Brigades and Brann, 2021) considered the 5 min earlier response as very important regarding the loss of only three buildings. In Norway, this is the first known fire where remote IR cameras likely made a dramatic difference in the outcome of fire in a wooden heritage town. This incident thus represents a proof-of-concept of the IR technology and the interest of getting similar technology installed in other sites increased significantly after the fire.

## 6. Discussion

The main objectives of the present study were to systemize fire protection experience from the DWH sites in Norway, identify successes and challenges, and suggest future improvements. It is quite clear that there is a strong will and dedication, and much work is done, to protect these unique historic sites. The four research questions stated in Section 2 will be answered consecutively.

### 6.1. *The conditions affecting fire safety and the fire protection work*

Status as national heritage was identified as the single most important reason why 60% of the DWH sites have created fire safety plans, and many sound measures have been implemented. Municipalities succeeding with fire protection worked systematically over time and distributed responsibility for the sub-tasks. Fire safety plans presenting clear priorities and reasonable safety measures should in the future be used as examples of good practice for updating guidelines on fire safety plans. Doing this, it may also be valuable to look at analysis for, e.g. museum fire risk analysis. In areas with a rich wood construction

**Fig. 10.** Fully developed (post flashover) fire in the first building involved 24 February 2014, Risør historical village, Norway. (Photo by Hans Petter Bjerva. Reproduced with permission).

**Fig. 11.** Three buildings lost in fire 24 February 2014, Risør historic village, Norway. (Photo by Hans Petter Bjerva. Reproduced with permission).

heritage, museums are often wooden structures, and thus, susceptible to fires. Fire protection activities targeted to such buildings (Fafet and Mulolli Zajmi, 2021) are therefore of interest to wooden heritage sites.

When comparing vulnerability to the Swedish Eksjø (Räddningsverket, 1999), it was found that also in Norway, very few old buildings in wooden towns had fire alarms directly notifying the fire station. This was also the case for Rauma, Finland (Laurila, 2004) and for Guimara center and Seixal, Portugal (Granda and Ferreira, 2019; Ferreiraa et al., 2016). The Portuguese studies revealed that buildings with a high-risk index were also characterized by, e.g. old electrical systems, unsafe load-bearing systems, a large indoor fire load, inadequate escape routes, difficult access for the fire brigade due to narrow streets and abandoned buildings. Abandoned buildings are, however, generally not an important issue in Norway.

The concept of potential fire fuel removal in buildings, as designed for in Japan (Okubo, 2016), is not a concept in current Norwegian sites, neither is the changing use of building as experienced in China (Yuan et al., 2016). The focus on vegetation free zones, e.g. in Italy (Intini et al., 2020), has not been a major issue in Norway. This may partly be due to the situation where modern town buildings and villas with lawns and not fire prone garden bushes and trees often represent a large buffer zone between Norwegian historic sites and the fire prone wildland. However, in the present study, 20% of DWH sites were found to have a wildland-urban interface. In addition, decline in grazing, changing climate and controlled burns now being a rarity, the landscape has experienced encroachment by very fire prone vegetation, e.g. *Juniperus communis*, and experienced severe WUI fires (Log et al., 2017; Metallinou, 2020).

### 6.2. *Planning, implementation and follow-up of fire safety measures and experiences gained*

Fire protection gained traction in the early 2000s when fire safety plans dedicated to protecting whole town areas began taking shape. Initially these plans started out as pragmatic plans with emphasis on technical protection measures. The goal was to establish a line of defense against devastating fires, not to prevent all fires. Fire safety plans seem to have grown somewhat more complex, often building on one another.

They have without doubt proved useful in protection of national heritage but can sometimes be perceived as quite overwhelming. Fire protection efforts has been left to the individual municipality's priorities. It is, however, not a well incorporated task in most municipalities. Some places, wooden town centers are a vital part of local identity or a tourist attraction and has therefore been prioritized. Other places dedicated municipal employees have taken on the fire protection task. However, the amount of work it takes to implement a fire safety plan is a challenge. Those who succeeded have worked systematically over a long period, i.e. typically 10+ years. Most municipalities worked independently, and generally with limited horizontal exchange of experiences. Since the Norwegian concept of fire safety plans is unique, it is difficult to compare this initiative with similar initiatives elsewhere.

### 6.3. Successful fire protection measures and experiences gained from fires

Early smoke detection stands out as a very important measure, while maintenance of such systems represents a challenge. This is also the case elsewhere (Glenting, 2002; Jansson and Wikensten, 2014; Granda and Ferreira, 2019; Ferreiraa et al., 2016; Laurila, 2004). The positive effect of early warning was confirmed by the municipalities, fire statistics and investigation of fires in the period analyzed. IR camera alarm systems viewing whole sites are easier installed than internal smoke detectors, i.e. no intervention or maintenance inside private homes, and stands out as an attractive independent warning system. The experience with IR camera warning system in Risør, 24 February 2021 (Brigades and Brann, 2021), served as a proof-of-concept, in the near future likely to be copied in several of the other Norwegian sites. In such cases, the local municipality gets in charge of the DWH site protection measure, often partly or fully sponsored by local enterprise fund raising initiatives.

Similar effects to that of early smoke detection could not be documented for preventive and passive fire safety measures. It should however be noted that several municipalities have positive experience with fire safety inspections in private houses. This allows for direct contact between the fire service and the owners and often leads to concrete improvements in the inspected objects.

In the case of a fire, it should be noted that several characteristics of informal settlements, e.g. closely built combustible buildings and difficult fire brigade access (Walls et al., 2017; Lane and da Silva, 2018), are also experienced in the studied Norwegian sites. An important difference is, however, the very short time to flashover in informal settings which could be as low as one minute (Walls et al., 2017). It should, however, be noted that excessive current demand due to heating and cooking in the wintertime are among the most important factors resulting in the high fire frequency in Norway during the winter months, particularly during December and January. This is when wooden buildings are driest internally (Log, 2017) and thus, experience the fasted fire development towards flashover (Strand et al., in press). An increased focus on such risk peaks may indeed benefit from the approaches mentioned in the ARUP framework for informal settlements (Lane and da Silva, 2018).

### 6.4. Possible improvements based on new knowledge and future trends

New firefighting technologies and methods were successfully demonstrated in the studied period. With this knowledge, R&D should be further encouraged for continued technical innovation, modeling of future risk peaks for flexible manning (Log, 2019; Metallinou and Log, 2018; Strand et al., in press), risk level-based spatial fleet allocations (Log et al., 2020), etc. Initiatives to improve the wording in rules and regulations should be focused, and the responsible for the DWH sites as such should be defined. It could be an idea to make this a responsibility for, e.g. the county governor. This could be based on the national responsibility regarding historical sites and their existing crisis management lead position in possible major civil sector incidents. It would bring the regional governor in a quality control position regarding the local municipalities, and put more weight on the crisis issue than, e.g. the NDCH currently does. By better sharing of successes, municipalities with DWH sites may certainly improve their fire protection with limited additional costs. It is suggested that the responsibility for identifying measures for improved knowledge sharing be allocated to the NDCH, which has detailed knowledge of historic buildings, modifications allowed when implementing fire safety measures, etc.

Combustibility of wood varies with weather conditions, in particular with the air relative humidity, as does the fire spread risk which is also a function of wind strength. Thus, the conflagration risk is highly dynamic. New methods forecasting fire risk peaks may help focus attention to critical high-risk periods (Stokkenes et al., 2021; Strand et al., in press). When the risk is recognized, possible compensating measures for such periods can be considered, e.g. warnings to the public, increased manning (Metallinou and Log, 2018), risk-based fleet allocations (Pérez et al., 2016), etc.

Improvements in computer modelling may also be utilized to identify risk factors, as demonstrated by Huang (Huang, 2020) for the Shuri Castle World Heritage site, which suffered from a major fire in October 2019. Such modeling, combined with knowledge about the dry wood fire risk contribution (Strand et al., in press), may become very valuable for reducing the fire risk in the DWH sites analyzed in the present study.

The municipalities should work more closely together and share knowledge and experience regarding effective, as well as ineffective, fire protection measures. Heritage wooden sites should also be considered when dimensioning the emergency response system in the future. This may typically be evaluated when, e.g. new fire stations are built, often as part of organizing previous municipal fire brigades into consolidated intermunicipal fire and rescue services.

It is suggested that the guideline for developing fire safety plans (Bybrannsikring. Veileder, 2007) is updated based on the findings in the present study. This should not only be limited to technical measures, but also include suggestions for initiative for knowledge sharing, etc. Since NDCH owns the existing guideline for developing fire safety plans, it is suggested that they take the initiative to update it.

### 6.5. The methodological approach

When gathering experience from a limited number of interviewees, some valuable information may not have been caught during the process. However, as this study involved interviewing 70 persons in 60 municipalities with such sites and included analyzing 60 fire safety plans, it is assumed that a relatively good picture was established of the current situation in Norway. The study analyzed common features of the fire protection work for the sites, and the suggestions for improvements are general for urban wooden settlement fire protection in the Norwegian context. It may also have bearing to other countries considering similar fire safety plans.

### 6.6. Suggestions for improving the future fire safety

Due to long distances, environmental impacts of the travelling and adverse weather condition, travelling to meetings for knowledge sharing and discussions in Norway is a challenge. However, after most municipality employees for long periods were forced to work from home during the COVID-19 pandemic, it is now easier to mutually share challenges and successful solutions through virtual meetings. Formalizing horizontal cooperation and knowledge sharing regarding fire safety plans is thus suggested as a low-hanging fruit regarding improved fire safety plans and concrete solutions for the involved sites. Based on the analysis, findings and conclusions in the present study, it is suggested to update the existing guideline for fire safety plans. This could improve future fire safety plans. The Norwegian Directorate of Cultural Heritage is highly respected and has a general solid standing in the society. It is therefore suggested that it takes the responsibility to facilitate increased knowledge sharing and that it funds the necessary work regarding updating the existing fire safety plan guideline.

With respect to further research, it would be beneficial to identify characteristics and motivation for individuals who take responsibility and make successful initiatives regarding the fire safety work in DWH sites. Another important topic for future research could be related to identifying successful initiatives for improved horizontal knowledge sharing. Such research could reveal findings of importance for improving the work within this, and related fields.

Lastly, the fire protection of DWH sites should be incorporated as a continuous process in every municipality where present, and not seen as a time-limited project.

## 7. Conclusions

Fire safety plans dedicated to help protecting dense wooden heritage sites in Norway were first introduced in year 2000 and have since then resulted in increasing focus on heritage fire protection. In 2014, 25% of the wooden heritage town sites had fire safety plans, and in 2020, 60%. Status as national heritage and thus, financial support from the Norwegian Directorate of Cultural Heritage, was the most important success factor. Common features of the municipalities who succeeded with fire safety plans and concrete fire safety measures, are that they had worked systematically over a long period, i.e. typically 10+ years and distributed the responsibility for the different fire protection sub-tasks within their organization. Measures were, however, often not evaluated before being implemented, partly due to lack of horizontal knowledge sharing between the sites. Fires reported by smoke detection alarming the fire brigades directly has prevented major heritage fire losses. The most common firefighting challenges were related to locating and accessing fires in cavities. Through clearer wording in rules and regulations, and better knowledge sharing, involved municipalities could improve the fire protection with limited additional costs. It is suggested that the NDCH takes the responsibility to facilitate increased knowledge sharing and that it funds the necessary work regarding updating the existing fire safety plan guideline.

## CRediT authorship contribution statement

**Martin Kristoffersen:** Conceptualization, Methodology, Field work, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Torgrim Log:** Conceptualization, Validation, Resources, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A

Nordic Town Areas Investigated in the Present Study (arranged along the coast from the border to Sweden in the south east to the border to Russia in the north east)

| Area name | Municipality | Fire safety plan | | Number of buildnings | Fire service response time (minutes) |
|---|---|---|---|---|---|
| Damhaugen | Halden | Yes | 2009 | 256 | < 10 |
| Sørhalden | Halden | Yes | 2009 | 206 | < 10 |
| Banken | Halden | Yes | 2009 | 110 | < 10 |
| Værlesanden | Moss | Yes | 2017 | 40 | < 10 |
| Verket | Moss | No | | 30 | < 10 |
| Vestre Kanalgate | Moss | Yes | 2017 | 55 | < 10 |
| Vaterland | Fredrikstad | No | | 65 | < 10 |
| Gamlebyen | Fredrikstad | Yes | 2007 | 140 | < 10 |
| Drøbak | Frogn | Yes | 2017 | 750 | < 10 |
| Handelstedet Bærum Verk - Verksgata | Bærum | No | | 20 | < 10 |
| Telthusbakken | Oslo | Yes | 2009 | 21 | < 10 |
| Bergfjerdingen | Oslo | Yes | 2010 | 55 | < 10 |
| Rodeløkka | Oslo | No | | 155 | < 10 |
| Vålerenga | Oslo | No | | 254 | < 10 |
| kampen | Oslo | No | | 311 | < 10 |
| Øvrebyen Kongsvinger | Kongsvinger | Yes | 2017 | 200 | < 10 |
| Storgata Lillehammer | Lillehammer | Yes | 2018 | 143 | < 10 |
| Vingnes Lillehammer | Lillehammer | No | | 60 | < 10 |
| Gamlevegen Lillehammer | Lillehammer | No | | 36 | < 10 |
| Ved Søndre Park Lillehammer | Lillehammer | No | | 93 | < 10 |
| Gjøvik sentrum | Gjøvik | No | | 20 | < 10 |
| Øvre Storgate | Drammen | Yes | 2009 | 63 | < 10 |
| Sandsværveien/Spenningsgata | Kongsberg | Yes | 2017 | 281 | < 10 |
| Kirkegata/Hyttegata/Møllergata | Kongsberg | Yes | 2017 | 310 | < 10 |
| Nymoen/Stiksrudgata | Kongsberg | Yes | 2017 | 99 | < 10 |
| Nymoen/Stiksrudgata | Kongsberg | Yes | 2017 | 50 | < 10 |
| Eikerveien | Kongsberg | Yes | 2017 | 165 | < 10 |
| Nordre Torv | Ringerike | No | | 2 | < 10 |
| Nordre Torv | Ringerike | No | | 3 | < 10 |
| Nordre Torv | Ringerike | No | | 6 | < 10 |
| Nordre Torv | Ringerike | No | | 21 | < 10 |

(*continued on next page*)

(*continued*)

| Area name | Municipality | Fire safety plan | | Number of buildnings | Fire service response time (minutes) |
|---|---|---|---|---|---|
| Gamle Hokksund | Øvre Eiker | No | | 211 | < 10 |
| Smalgangen Vestfossen | Øvre Eiker | No | | 30 | 13 |
| Holmsbu sentrum | Hurum | Yes | 2016 | 175 | 22 |
| Gamle Åsgårdstrand | Horten | Yes | 2016 | 266 | 17 |
| Nordbyen Tønsberg | Tønsberg | Yes | 2009 | 41 | < 10 |
| Nordbyen Tønsberg | Tønsberg | Yes | 2007 | 26 | < 10 |
| Haugarlia Tønsberg | Tønsberg | Yes | 2009 | 166 | < 10 |
| Fjerdingen Tønsberg | Tønsberg | Yes | 2007 | 65 | < 10 |
| Grønli | Sandefjord | No | | 131 | < 10 |
| Nedre Bjerggata | Sandefjord | No | | 120 | < 10 |
| Nybyen Nord | Sandefjord | No | | 54 | < 10 |
| Nybyen Syd | Sandefjord | No | | 56 | < 10 |
| Stavern | Larvik | No | | 287 | 15 |
| Langestrand | Larvik | No | | 427 | < 10 |
| Nevlunghavn | Larvik | No | | 161 | 25 |
| Leira Holmestrand | Holmestrand | No | | 12 | < 10 |
| Kirkegaten Holmestrand | Holmestrand | No | | 14 | < 10 |
| Vestregate/Klyvegata/Smedgata | Porsgrunn | No | | 62 | < 10 |
| Osebro | Porsgrunn | No | | 30 | < 10 |
| Brevik | Porsgrunn | Yes | 2015 | 344 | < 10 |
| Kirkehaugen | Porsgrunn | No | | 92 | < 10 |
| Helleberget | Porsgrunn | No | | 91 | < 10 |
| Snipetorp | Skien | No | | 111 | < 10 |
| Langesund | Bamble | Yes | 2009 | 250 | 13 |
| Herre | Bamble | No | | 51 | 9 |
| Stathelle | Bamble | Yes | 2009 | 6 | < 10 |
| Stathelle | Bamble | Yes | 2009 | 114 | < 10 |
| Kragerø sentrum | Kragerø | Yes | 2019 | 57 | < 10 |
| Kragerø sentrum | Kragerø | Yes | 2019 | 36 | < 10 |
| Kragerø sentrum | Kragerø | Yes | 2019 | 102 | < 10 |
| Kragerø sentrum | Kragerø | Yes | | 165 | < 10 |
| Kil i Sannidal | Kragerø | No | | 89 | < 10 |
| Rjukan 1 | Tinn | Yes | 2017 | 76 | < 10 |
| Rjukan 2 | Tinn | Yes | 2017 | 10 | < 10 |
| Rjukan 2 | Tinn | Yes | 2017 | 1 | < 10 |
| Rjukan 2 | Tinn | Yes | 2017 | 6 | < 10 |
| Folkestadbyen | Fyresdal | No | | 77 | 8 |
| Risør sentrum | Risør | Yes | 2010 | 600 | 7 |
| Grimstad | Grimstad | Yes | 2009 | 510 | < 10 |
| Kolbjørnsvik | Arendal | Yes | 2014 | 366 | < 10 |
| Tyholmen | Arendal | Yes | 2014 | 90 | < 10 |
| Tvedestrand sentrum | Tvedestrand | Yes | 2016 | 335 | 8 |
| Lyngør | Tvedestrand | Yes | 2016 | 336 | 60 |
| Brekkestø | Lillesand | Yes | | 41 | 15 |
| Ågersøya | Lillesand | Yes | | 46 | 60 |
| Posebyen | Kristiansand | No | | 326 | 10 |
| Støkkan | Mandal | Yes | 2010 | 115 | 9 |
| Sanden | Mandal | Yes | 2010 | 76 | 9 |
| Øvrebyen | Mandal | Yes | 2010 | 136 | 9 |
| Tranggata | Mandal | Yes | 2010 | 13 | 9 |
| Vestersiden | Farsund | No | | 18 | 8 |
| Borhaug | Farsund | No | | 81 | 15 |
| Loshavn | Farsund | Yes | 2006 | 42 | 12 |
| Flekkefjord sentrum | Flekkefjord | Yes | 2015 | 136 | < 10 |
| Flekkefjord sentrum | Flekkefjord | Yes | 2015 | 111 | < 10 |
| Flekkefjord sentrum | Flekkefjord | Yes | 2015 | 3 | < 10 |
| Flekkefjord sentrum | Flekkefjord | Yes | 2015 | 7 | < 10 |
| Rasvåg | Flekkefjord | Yes | 2015 | 52 | 30 |
| Reme | Lindesnes | No | | 25 | 20 |
| Svinør | Lindesnes | No | | 61 | 30 |
| Gahre | Lindesnes | No | | 61 | 9 |
| Åvik | Lindesnes | No | | 52 | 20 |
| Sælør | Lyngdal | Yes | 2020 | 9 | 60 |
| Sælør | Lyngdal | Yes | 2020 | 2 | 60 |
| Sælør | Lyngdal | Yes | 2020 | 1 | 60 |
| Sælør | Lyngdal | Yes | 2020 | 35 | 60 |
| Korshamn | Lyngdal | Yes | 2020 | 29 | 40 |
| Korshamn | Lyngdal | Yes | 2020 | 32 | 40 |
| Feda | Kvinesdal | Yes | 2018 | 65 | 15 |
| Feda | Kvinesdal | Yes | 2018 | 161 | 15 |
| Egersund sentrum | Eigersund | Yes | 2010 | 375 | < 10 |
| Gamle Stavanger | Stavanger | Yes | 2007 | 195 | < 10 |
| Stavanger sentrum | Stavanger | Yes | 2003 | 350 | < 10 |
| Stavanger område 3 | Stavanger | Yes | 2003 | 70 | < 10 |
| Stavanger område 4 | Stavanger | Yes | 2003 | 49 | < 10 |
| Stavanger område 7 | Stavanger | Yes | 2003 | 85 | < 10 |

(*continued on next page*)

(*continued*)

| Area name | Municipality | Fire safety plan | | Number of buildnings | Fire service response time (minutes) |
|---|---|---|---|---|---|
| Stavanger område 8 | Stavanger | Yes | 2003 | | < 10 |
| Hasseløy | Haugesund | Yes | 2010 | 170 | < 10 |
| Haugesund sentrum | Haugesund | Yes | 2010 | 740 | < 10 |
| Risøy | Haugesund | Yes | 2010 | 235 | < 10 |
| Hauge | Haugesund | Yes | 2010 | 25 | < 10 |
| Sogndalstrand | Sokndal | Yes | 2009 | 43 | 13 |
| Smensundet Ystabøhamn | Kvitsøy | Yes | | 70 | 8 |
| Alvestadkroken | Bokn | No | | 13 | 8 |
| Skudeneshavn | Karmøy | Yes | 2017 | 206 | 8 |
| Skudeneshavn | Karmøy | Yes | 2017 | | 8 |
| Nordvikvågen, Utsira | Utsira | No | | 40 | < 10 |
| Nøstet | Bergen | Yes | 2015 | 2842 | < 10 |
| Marken | Bergen | Yes | 2009 | | < 10 |
| Sydnes | Bergen | Yes | 2009 | | < 10 |
| Laksevåg | Bergen | Yes | 2009 | | < 10 |
| Salhus | Bergen | Yes | 2009 | | < 10 |
| Nordnes | Bergen | Yes | 2009 | | < 10 |
| Sandviken | Bergen | Yes | 2009 | | < 10 |
| Skuteviken/Ladegården | Bergen | Yes | 2009 | | < 10 |
| Steinkjelleren | Bergen | Yes | 2009 | | < 10 |
| Bryggen | Bergen | Yes | 2009 | | < 10 |
| Vågsbunnen | Bergen | Yes | 2009 | | < 10 |
| Stranden | Bergen | Yes | 2009 | | < 10 |
| Leirvik, Stord | Stord | Yes | 2016 | 35 | 8 |
| Rymbilen | Odda | Yes | 2016 | 1 | 8 |
| Bråtateigen | Odda | Yes | 2016 | 28 | 8 |
| Bråtateigen | Odda | Yes | 2016 | 3 | 8 |
| Rymbilen | Odda | Yes | 2016 | 1 | 8 |
| Rymbilen | Odda | Yes | 2016 | 5 | 8 |
| Rymbilen | Odda | Yes | 2016 | 2 | 8 |
| Agatunet | Ullensvang | Yes | 2015 | 30 | 39 |
| Gamle Strusshamn | Askøy | No | | 15 | < 10 |
| Havråtunet | Osterøy | Yes | 2018 | 30 | 12 |
| Ytre Strandgata | Flora | No | | 22 | 6 |
| Rognaldsvåg | Flora | No | | 21 | 60 |
| Vikøyri | Vik | No | | 63 | 6 |
| Fjøra | Sogndal | No | | 85 | < 10 |
| Undredal sentrum | Aurland | Yes | 2010 | 35 | 15 |
| Otternæs bygdetun | Aurland | Yes | 2010 | 24 | 15 |
| Låvi | Aurland | Yes | 2010 | 37 | 15 |
| Lærdalsøyri | Lærdal | Yes | 2017 | 90 | 8 |
| Lærdalsøyri | Lærdal | Yes | 2017 | 57 | 8 |
| Eidsgata/Tverrgata Nordfjordeid | Eid | No | | 33 | 8 |
| Eidsgata/Tverrgata Nordfjordeid | Eid | No | | 20 | 8 |
| Eidsgata/Tverrgata Nordfjordeid | Eid | No | | 6 | 8 |
| Ålesund | Ålesund | Yes | 2020 | 515 | < 10 |
| Ålesund | Ålesund | Yes | 2020 | | < 10 |
| Ålesund | Ålesund | Yes | 2020 | | < 10 |
| Ålesund | Ålesund | Yes | 2020 | | < 10 |
| Ålesund | Ålesund | Yes | 2020 | | < 10 |
| Ålesund | Ålesund | Yes | 2020 | | < 10 |
| Grip | Kristiansund | Yes | 2011 | 103 | 60 |
| Kyrkjegata | Ørsta | No | | 50 | 6 |
| Hellesylt | Stranda | Yes | 2015 | 43 | 9 |
| Geiranger sentrum | Stranda | Yes | 2015 | 25 | 6 |
| Dyrkorn | Stordal | No | | 25 | < 10 |
| Alnes | Giske | No | | 100 | < 10 |
| Husøy | Sandøy | Yes | 2016 | 76 | 60 |
| Ona | Sandøy | Yes | 2016 | 35 | 60 |
| Søre Bjørnsund | Fræna | Yes | 2015 | 93 | 60 |
| Nordre Bjørnsund | Fræna | Yes | 2015 | 160 | 60 |
| Bud | Fræna | Yes | 2015 | 126 | 6 |
| Surnadalsøra | Surnadal | No | | 100 | < 10 |
| Todalsøra | Surnadal | No | | 25 | 8 |
| Veiholmen | Smøla | Yes | 2016 | 120 | 7 |
| Kystbyen 1900 Brønnøysund | Brønnøy | No | | 90 | 9 |
| Sjøgata Mosjøen | Vefsn | Yes | 2017 | 107 | < 10 |
| Moholmen | Rana | No | | 34 | < 10 |
| Nusfjord | Flakstad | No | | 40 | 21 |
| Henningsvær | Vågan | Work in progress | | 100 | 6 |
| Kabelvåg | Vågan | No | | 70 | 9 |
| Bleik | Andøy | Yes | 2016 | 198 | 16 |
| Område i Harstad sentrum | Harstad | No | | 13 | < 10 |
| Tromsø sentrum | Tromsø | No | | 550 | < 10 |
| Bugøynes | Sør-Varanger | No | | 133 | 75 |
| Østersunds gate | Trondheim | No | | 1500 | < 10 |

(*continued on next page*)

(*continued*)

| **Area name** | **Municipality** | **Fire safety plan** | | **Number of buildnings** | **Fire service response time** (minutes) |
|---|---|---|---|---|---|
| Kristianfeldgate-området | Trondheim | No | | | < 10 |
| Midtbyen | Trondheim | No | | | < 10 |
| Bakklandet | Trondheim | No | | | < 10 |
| Kristianstensletten | Trondheim | No | | | < 10 |
| Møllenberg - Kirkesletten - Rosenborg | Trondheim | Yes | 2009 | | < 10 |
| Svartlamoen | Trondheim | No | | | < 10 |
| Sverresborg Trøndelag folkemuseum | Trondheim | No | | | < 10 |
| Sannan | Trondheim | No | | | < 10 |
| Vollabakken | Trondheim | No | | | < 10 |
| Marinevold | Trondheim | No | | | < 10 |
| Ila | Trondheim | No | | | < 10 |
| Ilsvikøra | Trondheim | No | | | < 10 |
| Bergstaden sentrum | Røros | Yes | 2018 | 704 | < 10 |
| Bergstaden sentrum | Røros | Yes | 2018 | 26 | < 10 |
| Stjørdal | Stjørdal | No | | 25 | 6 |
| Levanger sentrum | Levanger | Yes | 2017 | 250 | 6 |
| Veita | Verdal | Yes | 2009 | 46 | 7 |
| Hylla | Inderøy | No | | 40 | 15 |
| Straumen | Inderøy | No | | 25 | 6 |
| Kroa | Indre Fosen | No | | 23 | 9 |
| Råkvåg | Indre Fosen | Yes | 2018 | 170 | 8 |

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