Statistical analysis of firefighting and damage caused by fire in mid-rise timber-framed residential buildings compared to other construction types

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Statistik analys av brandbekämpning och skada orsakad av brand i medelhöga träbostadshus jämförda med andra konstruktionstyper

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Abstract:
The contribution of greenhouse gas emissions in the production of construction materials has sparked a new interest and recent changes in building regulations regarding the use of renewables like wood as the main component in load-bearing elements. Recent regulation changes focus on allowing taller timber structures which bides the question of how to adequately maintain an acceptable level of fire protection considering the characteristically flammable properties of wood-based products. This thesis analysis data on recorded incidents of fires in residential buildings of at least three floors in two countries, Canada and Finland, to try to estimate the impact of building characteristics and firefighting operations in relation to damage caused by fire. Databases used are PRONTO (Finland) and NFID (Canada), the data is analysed using common statistical tools including summary statistics and linear regression. Preluding the statistical analysis is a comparison of building regulations in the two countries, a comparison of general fire statistics and a review of two previous studies on the same subject that utilizes the same databases. The results of the statistical analysis were consistent with what the two studies previously had shown; no clear (positive or negative) correlation between timber-framed buildings and recorded damage seem to be statistically significant, however, timber-framed buildings accounted for more large losses when compared to buildings with non-combustible framing. The linear regression models used predicted simple correlations that were easy to guess intuitively which gives the models some credibility. The results of the comparison were probably skewed by the building height restriction which gave rise to an unfair comparison due to differences in the populations compared.

The author is responsible for the content of the report.

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Summary

The results from this thesis suggest that there is no linear correlation that is statistically significant for the type of building material and damage caused by fire. Timber-framed residential buildings with at least three floors, in comparison to other buildings with non-combustible framing, have in data from two databases from two different countries, NFID - National Fire Information Database in Canada and PRONTO - Pelastustoimen resurssi- ja onnettomuustilasto in Finland, a larger share of more extensive economic loss, and a higher average, of the reported loss in Euro and Canadian Dollar. The author of this thesis believes that it is due to differences in the compared populations, for which there is some support in the summary statistics and frequency tables of the data from the databases, as well as in the literature review that has been carried out. Timber-framed buildings in the analysis generally appear to be smaller, detached and not as often located in an urban environment. This affects the size of any fire compartments, the general fire safety level such as the lack of active systems and the rescue service's capacity and possibility to intervene.

Limitations like subjective data, incomplete data, data cleaning and translation of data impacted the results. The study was approached in a more practical way rather than from a mathematical perspective. Results from mathematical analysis were interpreted subjectively, tools used for analysis was restricted to summary statistics of observations (standard deviations, means, medians and cumulative proportions), correlations (for single continuous variables) and ordinary least square regression analysis (for multiple variables).

As a complement to the statistical analysis, a comparison of current building regulations for the two countries was performed. The comparison showed small differences between the countries. A deviation regarding requirements for separating construction was identified, 45 minutes of fire separation is in some cases allowed in Canada, compared to 60 minutes in Finland. Any differences in building regulations could explain differences in the statistics regarding damage outcomes. Both countries allow performance-based and prescriptive designs and any impact on the statistics is difficult to estimate.

A review of general statistics on fires and costs for fire protection in Finland, Canada and neighbouring countries (due to lack of data) was also carried out within the framework of this thesis. The statistics consistently showed that the Nordic countries spend less on fire protection and suffer from greater losses caused by fire in comparison. The reason can be explained by the difference in willingness to invest in rescue services and fire protection in buildings but also by differences in building stock, Finland has a larger proportion of detached residential buildings compared to Canada.

The statistical analysis was based on three methods to address the objective of how building characteristics and firefighting impact damage caused by fire in timber-framed residential buildings compared to other construction types; summary statistics, Person’s correlation coefficient with two-tailed t- test and regression analysis using the method of least squares. The summary statistics showed, among other things, that timber-framed buildings are older in comparison to buildings with non-combustible framing and are more likely to have three floors, which was the lower limit for building height that was applied. Timber-framed buildings had a longer rescue service response time and fewer personnel present at the operation. Pearson’s correlation coefficients showed linear dependencies for numerical variables in many cases, most easy to guess intuitively but, differences between compared building types reinforced the suspicion of significant differences in the compared populations. The least squares regression models also reported linear relationships between certain (categorical and quantitative) variables and the recorded damage. A possible linear relationship between construction type and damage caused by fire existed only in two instances with the lowest probability of measured statistical significance and the values were conflicting.

Linear regression and correlation are affected by input values and the uncertainty associated with those values is large and unexplained. The method of linear estimation of a fundamentally exponential process can be misleading, but if the interpretation is limited to magnitude, direction and significance, certain conclusions can be correctly derived. Linear regression entails many conditions/assumptions that must be met for the result to be accurate, including independent variables, which is not the case in this analysis.

Sammanfattning

Resultaten från detta examensarbete antyder att ingen linjär korrelation som är statistisk signifikant finns för typ av byggnadsmaterial och skada orsakad av brand. Träbostadshus med minst tre våningar, i jämförelse med andra byggnader utförda i stomme med obrännbart material, har i data från två databaser från två olika länder, NFID – National Fire Information Database i Kanada och PRONTO - Pelastustoimen resurssi- ja onnettomuustilasto i Finland, en större andel i skador som rapporterats som mer omfattade med hänsyn till en ekonomisk förlust och ett högre medelvärde för den rapporterade förlusten i Euro och Kanadensiska Dollar. Författaren av detta arbete anser att det beror på skillnader i de jämförda populationerna vilket det finns visst stöd för i den sammanfattande statistiken och frekvenstabellerna över informationen från databaserna samt i den litteraturgenomgång som genomförts. Träbyggnader i analysen verkar generellt vara mindre, fristående och inte lika ofta vara beläget i stadsmiljö. Detta påverkar storleken på eventuella brandceller, den allmänna brandskyddsnivån som till exempel avsaknad av aktiva system och räddningstjänstens kapacitet och möjlighet till insats.

Begränsningar så som subjektiva data, ofullständiga data, datarengöring och översättning av data påverkade resultaten. Studien avhandlades på ett mer praktiskt sätt snarare än från ett matematiskt perspektiv. Resultat från matematisk analys tolkades subjektivt, verktyg som användes för analys var begränsade till sammanfattande statistik för observationer (standardavvikelser, medelvärden, medianer och kumulativa proportioner), korrelationer (för enstaka kontinuerliga variabler) och minstakvadratmetoden (för flera variabler).

Som komplement till den statistiska analysen genomfördes en jämförelse av aktuella byggregler för de två länderna. Jämförelsen visade på små skillnader länderna i mellan. En avvikelse gällande krav på avskiljande konstruktion identifierades, 45 minuter brandteknisk avskiljning är i vissa fall tillåtet i Kanada jämfört med 60 minuter i Finland. Eventuella skillnader i byggregler hade möjligtvis förklarat skillnader i statistiken gällande skadeutfall. Båda länderna tillåter analytisk dimensionering och förenklad dimensionering, någon påverkan på statistiken är svår att visa.

En genomgång av allmän statistik över bränder och kostnader för brandskydd i Finland, Kanada och grannländer (i brist på uppgifter) genomfördes också inom ramen för detta arbete. Statistiken visade genomgående att de nordiska länderna spenderar mindre på brandskydd och lider av större förluster orsakade av brand i jämförelse. Orsaken kan förklaras av skillnaden i vilja att investera i räddningstjänst och brandskydd i byggnader men också av skillnader i byggnadsbestånd, Finland har en större andel friliggande bostadshus i jämförelse med Kanada.

Den statistiska analysen grundade sig i tre metoder för att besvara frågeställningen om hur byggnadsegenskaper och brandbekämpning påverkar skada orsakade av brand i träbostadshus jämfört med andra typer av konstruktioner, sammanfattande statistik (sammanfattade mått, läges- och spridningsmått), Pearsons korrelationskoefficient med tvåsidigt t-test och linjär regressionsanalys med minstakvadratmetoden. Den sammanfattande statistiken visade bland annat att träbyggnader är äldre i jämförelse med byggnader med obrännbar stomme och med större sannolikhet har tre våningar, vilket var den undre avgränsningen för byggnadshöjd som applicerades. Träbyggnader hade längre framkörningstid för räddningstjänsten och mindre personal närvarande vid insatsen. Pearsons korrelationskoefficienter visade på linjära samband mellan kvantitativa variabler i många, de flesta enkla att gissa, men skillnader mellan jämförda byggnadstyperna förstärkte misstanken om väsentliga skillnader i de jämförda populationerna. Regressionsmodellerna med minstakvadratmetoden redovisade också linjärt beroenden mellan vissa (kategoriska och kvantitativa) variabler och den rapporterade skadan. Ett eventuellt linjärt samband mellan konstruktionstyp och skada orsakad av brand fanns endast i två fall med den lägsta sannolikheten för bedömd statistisk signifikans och då med värden som var motsägande.

Linjär regression och korrelation påverkas av ingående värden och osäkerheten förknippad med dem är stor och ej förklarad. Metoden med linjär uppskattning av ett i grunden exponentiellt förlopp kan vara missvisande men om tolkningen begränsas till magnitud, riktning och signifikans kan vissa slutsatser vara korrekt härledda. Linjär regression medför flertalet förutsättningar/antaganden som ska vara uppfyllda för att resultatet ska vara korrekt, bland annat oberoende variabler, vilket inte är fallet i denna analys.

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1. Introduction

Fires in buildings threatens life and property throughout the world. To mitigate the consequences, and in some cases also the likelihood, of fires national and/or regional building regulations are often implemented meant to ensure occupants safety in the building as well as protecting property. Building regulations differ between countries but generally tend to cover how safe evacuation is achieved given the intended building use, how to limit the risk of fire and smoke spread and rescue service intervention. In many countries systems such as fire alarm systems, sprinkler systems and fire-rated constructions, i.e. standardized performance tested construction materials, is prescribed in regulatory documents meant to define goals set by the society and to guide engineers in the design of a building. These documents often take on the form of a pre-approved solutions that are based on past experiences and historical precedents (Lundin, 1999).

Prescriptive building codes are not always comprehensive enough for innovative or unusual buildings and therefore a reason exists to complement prescriptive codes with codes based on performance. Performance-based codes allow building designers to use other solutions than the ones presented as pre-approved solution if the designer can show that regulations are complied with (Meacham, 1996). In performance-based design protection of occupants and property and compliance with regulations can be achieved through for example calculations to estimate required time to evacuate and /or fire modeling of different scenarios (Lundin, 1999). Canada and Finland both have prescriptive and performance-based codes (Commission on Building and Fire Codes, 2015) (Miljöministeriet, 2017), Australia on the other hand has a National Construction Code which is solely performance-based but contains Deemed to Satisfy solutions (Australian Building Codes Board, 2016).

Building codes are continuously evaluated and changes are made with respect to new practices, legislation and knowledge with the hope that it will constitute improvements for whatever reason one can think of. In recent years for example, timber as a construction material in multi-story buildings has experienced a renaissance after a long period of its use being restricted in higher or larger buildings. This conservative approach was due to citywide fires that destroyed entire cities where timber was widely used as a building material. Nowadays timber is considered a renewable material with the potential of building more sustainable buildings in comparison to other, for example, metal or stone (concrete/brickwork) materials (Östman, et al., 2017).

This renaissance is not limited to cladding on facades, interior decorations showcasing exposed timber details or light non-bearing walls, it comprehends timber as a structural material to an extent never seen before, see Figure 1. Architect Michael Green, a longstanding advocate for - and designer of - wooden buildings was quoted saying that there are "…a whole bunch of things converging right now." in a CNN-article (Holland, 2020). The article in relation to the quote further explains the converging factors as business and climate economics as well as a change in building regulations that brings on a shift in culture that transforms cultural attitudes to wood materials in architecture, materials like CLT - Cross-laminated timber in particular. Green goes further and mentions that since his Ted talk in 2013 on why we should be building tall wood structures, one especially significant shift has happened: “cost.”. Economies of scale and more competition is bringing costs down.

Figure 1. The 49 m high Treet (The Tree) apartment block in Bergen, Norway, was completed in 2015 and is one of the tallest cross-laminated timber structures in the world (WSP, 2017). Photo: David Valldeby, published with permission from the copyright holder.

The newfound interest of sustainable buildings and the following increased use of timber as a building material has sparked a scientific debate on how to build with wood in a way that warrant adequate fire safety. Studies have been published on fire statistics as well as construction methods, see (Department for Communities and Local Government, 2012) (RISCAuthority, 2011) (Brandon, et al., 2015) (Eriksson, et al., 2016), some consensus can be found in the opinion that sprinklers have a major impact in reducing fire losses in all buildings regardless of construction type (Rao, 2014) (Ocran, 2012).

One way to try to find out if timber construction is an acceptable alternative to more commonly used building materials in multi-story buildings regarding fire safety is to collect the fallout of recorded incidents and compare them. Statistics is a tool often used when comparing populations with different characteristics, but the accuracy of results is often limited by the available data. If several populations with slightly different characteristics are included to increase the available data, the results might be skewed due to difference within the selected populations and if the differences are not identified the interpretation of the results can become biased. As such, there is a balance between accuracy and understanding of differences within the populations to make accurate interpretation of any results of statistical analysis.

A classic example of this often appears in media outlets, claims of certain foods prolonging your life expectancy (see How to live longer - the amount of tomatoes you should be eating every week (Atherton, 2019)) can be cherrypicked results from statistical studies. No doubt tomatoes are probably healthy for you but there are a lot of other factors at play, characteristics of the population if you will, when it comes to life expectancy. Lifestyle in general for example. People who eat a lot of tomatoes are perhaps more prone to a healthy lifestyle and therefor live longer. A person confounding occurs when the two groups are analyzed together, this despite the conceivable differences between people who eat tomatoes and those who to a larger extent refrain. In statistics a confounder is a variable that influences the dependent and independent variable, being healthy in this case probably causes me to eat more tomatoes as well as making me live longer.

Building characteristics as decided by building codes is not the only factor impacting the outcome of a fire. Fire-fighting operations are often necessary and sometimes crucial in limiting the spread of fire and thusly directly affect the expected total loss. By intervening and stopping the spread of fire by firefighting it is undisputed that firefighters contribute to control losses, some which can be attributed to smoke and water damage (Jerome & Hodge, 2001). Given that, for example, the availability, funding and level of training differ among rescue services it can be assumed that firefighting is an important factor in the expected loss regardless of construction type and therefore should be considered when comparing expected losses between different populations.

Statistical studies on timber construction versus other types have been done before (Kelly, et al., 2017) (Tillander, 2004). The study by Kelly is based on statics gathered in Canada in the National Fire Information Database and the study by Tillander on Finnish statistics in the PRONTO-database. The studies have conflicting results about fire losses in different construction types. Tillander found that the total loss in timber-framed apartment buildings was larger when compared to other construction types and Kelly that timber-framed buildings were negatively correlated to total loss when compared to the entire population. Other results presented in the study by Kelly showed no statistically significant correlations between construction type and total loss, which goes to show that results of statistical analyzes are highly dependent on the input data and method used. The above-mentioned studies highlight a possible approach and additional need for more and closer examination of the statistical differences between timber-framed constructions and other construction types in relation to damage caused by fire and the impact of fire-fighting operations.

1.1 Purpose and objectives

The purpose of this thesis is to analyze statistical data obtained in fire-fighting operations in low- and mid-rise residential buildings that are timber framed and compare the results to other construction types in two countries, Canada and Finland. To address possible differences in the statistical observations an understanding of how the relevant building regulation compare is relevant. Furthermore, a literature review of previous studies on the subject is included. Taking the recent revival of timber as a construction material into account a study on the subject is deemed relevant.

Finland has collected data on rescue service incidents in PRONTO for a long time and Canada has recently made the National Fire Information Database available for research, two provinces in Canada, Alberta and British Columbia and Finland collect data on construction type which is crucial for this type of study. Sweden, for example lacks such a comprehensive database on fire incidents where data on the type of construction and other important factors, like loss, are recorded. The choice of countries is mainly based on the availability of data.

The objectives are as follows:

1. To estimate the impact on the damage caused by fire of the following factors: Firefighting and building characteristics.
2. To compare and examine the impact of the above-mentioned factors in timber-framed buildings versus other types of construction.

1.2 Methodology

This section contains descriptions of the applied methodology in this thesis.

1.2.1 Establishing the relevant regulatory requirements for mid-rise timber-framed residential buildings

To be able to understand building characteristics in residential buildings with more than two stories knowledge of regulatory requirements is relevant. Each country also has its own set of requirements and therefore an understanding of the differences is necessary when making comparisons.

1.2.2 Review of previously performed studies on the same subject

This is not the first study on the subject, a literature review is therefore appropriate.

1.2.3 Data analysis utilizing statistics

Data used in the analysis has been gathered from Finland (PRONTO) and Canada (NFID). Applied methods are:

1. Summary statistics – summarized sets of observations
2. Pearson's correlation coefficient with two-tailed t-test
3. Ordinary least squares regression analysis

Calculations and graphics are made using R (R is a programming language for statistical computing and graphics). Since the impact of firefighting and building characteristics is estimated utilizing data gathered in databases and analyzing it statistically, the choice of applied methods is based on common denominators utilized in statistical analysis. Summary statistics is an umbrella term for concepts like mean and median, generally summary statistics communicates information about distributions in a fast and simple way. Pearson Correlations is a common measurement of linear correlation between variables and Ordinary least square or OLS is a type of linear least squares method that estimates unknowns in a linear regression model, i.e. it can take several variables into account when measuring linear dependency. The main advantages of this approach are that it is relatively simple, easy to understand and can easily be reproduced. The main disadvantage is foremost that it does not take into account non-linear relationships, however, this does not have to mean that all such relationships are overlooked. It is quite coarse to estimate all dependencies as linear, but any interpretation is and also should be limited to mainly direction (positive or negative) and strength (weak or strong correlation). This especially given the many assumptions that entails for example OLS which are rarely met in full outside statistics. Also see Fire Data Analysis Handbook (U.S. Fire Administration, 2004) for more information on statistical analysis using data from fires.

1.2.4 Discussion and conclusions

Evaluation of results from the data analysis, statistical analyses always include uncertainties that need to be addressed. From this discussion, and acquired knowledge from research and literature review, conclusions are drawn to summarize results and to present suggestions for more research.

1.3 Limitations & Delimitations

This thesis is based on statistical data as recorded by incident responders in two countries and consequently how data is collected and presented differs. To use statistics to characterize a fire is a way to do it objectively, however, the statistics are a representation of historic conditions that change over time e.g. building regulations etcetera. Building regulations also differ between countries and building use. National differences are considered in an explanatory way and by limiting the scope to only residential buildings it is possible to eliminate some different building characteristics due to use.

Limitations

Sometimes the incident data is incomplete, i.e. only a few parameters were recorded, but these incidents have been included to make the most of the available data. In the end, the data is sometimes subjective, and a real value cannot be established.

During the processing gathered data is cleaned to make it more manageable, meaning it is not always verbatim from the source database. Data from PRONTO in Finnish and/or Swedish has also been translated.

Measurable quantities are defined by the available data.

In some sense, the research is approached in a practical way rather than a mathematical. Practical in this case means that the mathematical analysis results are interpreted subjectively, tools used for analysis is restricted to summary statistics of observations (standard deviations, means, medians and cumulative proportions), correlations (for single continuous variables) and ordinary least square regression analysis (for multiple variables).

Delimitations

The statistical analysis only involves residential buildings with more than two stories. Data was gathered from reported incidents in Finland (1996-1999, 2000-2018) and in Canada (2005-2014).

2. Regulatory requirements by country

This chapter covers regulatory requirements in countries that are included in this study. By giving a summary of relevant building codes, one can highlight any differences to be able to indicate if different regulatory requirements have an impact on recorded statistics. This is by no means a comprehensive guide on all regulations covering every specific situation, material classes and requirements on fire resistant structures very wildly in prescriptive design depending on many factors, not all included here. Factors included are mainly limited to building height, building area, surface linings, sprinkler requirements, separation requirements and test methods, all of which are deemed to effect value at risk and in some respects expected loss.

2.1 Canada

The following sections covers the National Fire Code of Canada and the other provisions of building codes in Canada, in short, for combustible construction.

2.1.1 National Fire Code of Canada

Provincial and territorial governments authorize building regulations in Canada, legislation may include The National Fire Code of Canada (NFC) without changes or with modifications to suit local needs. The NFC is used as a model code and is published by the Commission on Building and Fire Codes to promote consistency among the different jurisdictions. The NFC is objective-based and contains acceptable solutions, the objectives are as follows:

- Safety
- Health
- Fire protection of buildings and facilities

The requirements in the NFC can be considered as the minimum acceptable measures if above objectives are to be achieved. Technical provisions in the code are referred to as Acceptable solutions. In case of change of use or alterations to buildings, the NFC is not applicable retroactively, but it is up to the enforcement authority to decide on a case-by-case basis what is deemed practicable. Code compliance can also be shown via Alternative solutions when the design differs from Acceptable solutions. When that is the case the proponent must demonstrate that the alternative solution addresses the same issues as the applicable acceptable solution. An alternative solution must be documented (typically a technical analysis that demonstrates a proposed design will achieve a level of performance that meets the minimum level intended) and shall include, but not limited to:

1. A Code analysis outlining the analytical methods and rationales used to determine that the proposed alternative solution will achieve at least the level of performance required by Clause 1.2.1.1.(1)(b) of Division A, and
2. information concerning any special maintenance or operational requirements, including any component commissioning requirements, that are necessary for the alternative solution to achieve compliance with the Code after the building or facility is constructed.
   Source: (NFC, Division C, 2.3.1.1.2)

Objectives and functional statements in the Acceptable solutions are, however, qualitative, and compliance cannot be demonstrated in isolation, i.e. an effort must be made to show compliance, but it is not stated how, refer to Table 1 for an illustrative example. Acceptable solutions in Division B establishes the quantitative performance targets the Alternative solutions must achieve, but these targets are less precise than a true performance-based code. Clause 1.2.1.1.(1)(b) does specify that a clear effort must be shown to demonstrate that the Alternative solution perform as well as the applicable Acceptable solution. Any person who proposes an alternative solution needs to provide evidence to demonstrate that the alternative solution (proposed equivalent) will perform as required by the code, this can be in the form of, for example, specifications of building elements or an expert report. The term as well as is underlined to highlight its' importance and implication, a solution that differentiates a lot from the prescriptive Acceptable solution will required a very significant effort to demonstrate compliance "as well as".

The NFC 2015 complements the National Building Code of Canada 2015 (NBCC). Both must be considered when constructing, renovating or maintaining buildings. The NFC and local provincial fire codes contain references to the respective building code, the fire code also include requirements during construction and handling of flammable substances.

2.1.2 Combustible construction in Canadian building codes

Wood-frame and heavy timber construction[1] has long been the norm in Canada (Canadian Wood Council, 2019), city-wide fires came to limit the building height (Sereca Consulting Inc., 2015) but the use of timber construction in mid-rise buildings has seen a recent revival. Alberta and British Columbia are the provinces that has recorded statistics on type of construction (in the data used in this thesis), and therefore it seems appropriate to limit building regulations in Canada to those two provinces. Applicable method (alternative or acceptable solution) covering building height in timber buildings assuming a residential use are shown in Table 1:

Table 1. Height restrictions and expected complexity of analysis "Wood Use Matrix" as interpreted by the authors required for residential timber-framed buildings in accordance with the NBCC/British Columbia Building Code. The subjective "…values were provided by representatives from each area to the Procurement Working Group. The Ministries relied on a combination of internal expertise and their architectural, engineering and code consultants." (mgb ARCHITECTURE + DESIGN, Equilibrium Consulting, LMDG Ltd, BTY Group, 2012, p. 124).

Building Height (storeys/floors)	Complexity in rising order 1-4
1-6	1 - An acceptable solution in wood is permitted
7-9	2 - An alternative solution in wood is relatively easy to implement
10-12	3 - An alternative solution in wood will require advanced analysis
13+	4 - An alternative solution in wood will require extensive research

The British Columbia Building Code 2018 (BCBC) adopted the National Building Code of Canada 2015 (NBCC) provisions for mid-rise combustible buildings (timber-framed) with two variations, 10% of the building's perimeter must be adjacent to a street (NBCC 25%) and 100% of the exterior cladding to have increased fire protection (Province of British Columbia, 2019), these provisions may affect access for the rescue service and reduce the risk for rapid external fire spread. It should be noted that in the NBCC (and BCBC) provisions on exterior cladding are highly lenient on the proximity of other buildings and fire resistance ratings of other construction elements.

The Alberta Building Code 2015 conforms to the NBCC 2015.

Residential occupancies are classified as Group C in the NBCC, adjoining occupancies have an impact on fire protection features e.g. if the adjoining occupancies is Class E (mercantile) a two-hour fire separation between the occupancies is required. Canadian regulations differentiate between a *fire separation* and *fire-resistance rating*, a fire separation acts as a barrier but does not necessarily have to have a fire-resistance rating. A fire-resistance rating as prescribed in the Code means that the

[1]Heavy timber structures have similar member types as light-frame wood structures, but they use larger wood members - and fewer of them - to form the buildings structure.

construction element prescribed the rating must have structural stability and remain intact under fire conditions for the required fire-rated time.

The minimum NBCC-prescribed fire-resistance rating is 45 minutes and applies to residential buildings with a maximum of three floors, see Table 2. Heavy timber construction can be used, and the Acceptable solutions prescribe dimensions for columns etcetera. In case of four to six floors a 60-minute fire separation rating between suites (apartments) and an exitway is required as well as sprinklers throughout the building.

Combustible materials are allowed in buildings with timber frames when the flame-spread rating is less than 150 on any exposed surfaces when tested in accordance with CAN/ULC-S102. The purpose of the test is to determine the burning characteristics of the material, flame spread (distance) versus time and smoke development classification, results from the tests, including smoke density, are used to calculate a rating. The number is the relative rate at which flame spreads over the surface material when compared to red oak (100) and asbestos-cement board (0), generic lumber has for example a flame-spread rating of 150 (The Canadian Wood Council, 2014).

Fire-resistance rating can be based on two tests, ISO 834 and American Society for Testing and Materials (ASTM): ASTM E 119 Standard Test Methods for Fire Tests of Building Construction and Materials (Hamarthy, et al., 1987). The different test standards have essentially the same fire exposure (Forintek Canada Corporation, Canadian Mortgage and Housing Corporation, Quebec Housing Corporation, 2002); the corresponding Canadian test method is CAN/ULC-S101, which is similar to ASTM E 119. Both use the same time-temperature curve and the same performance criteria (Canadian Wood Council, 1996). The NBCC permits jurisdictions to accept tests using other standards (Sturgeon, 2013).

Table 2. Acceptable Solutions NBCC 2015 in Group C residential buildings up to 6 floors, any construction type.

Floors*	Building area[2] restriction [m^2]	Fire-resistance rating	Sprinklers
3	3000	45	Depends on configuration
4	2250	60	Required#
5	1800	60	Required
6	1500	60	Required

*Height not more than 18 m when measured from the first floor to the uppermost floor.
#In accordance with NFPA 13R, otherwise NFPA 13.

Provision of sprinklers, non-combustible construction and better street access allows for larger building area.

The prescribed fire-resistance rating for an assembly is the time which it can withstand the time-temperature curve while still abiding by these criteria:

- No passage of heat or flames hot enough to ignite cotton waste.
- Specimen to remain in place under design loads.
- Temperature increase on the unexposed surface of specimen limited to 140 K on average and 180 K maximum.
  Source: (Canadian Wood Council, 1996)

At the time of writing, national and provincial building codes in Canada were not freely available. Starting in spring 2019, the National Research Council will offer free access to the NBCC, NFC

[2] Building area is defined as the greatest horizontal area of a building above grade within the outside surface of exterior walls or within the outside surface of exterior walls and the centre line of firewalls.

etcetera and provincial codes published by the Council (Municipal Affairs, 2019). A new edition of the NBCC is planned to be published in December 2020 allowing for 12-storey wood structures (Sorensen, 2019).

2.2 Finland

The first section following this one covers Finnish building regulations focusing on residential mid-rise buildings, the second European standards for classification which has been implemented in all EU countries.

2.2.1 Building regulations in Finland

Markanvändning- och bygglagen (Land use- and building law, 132/1999 MBL) covers prerequisites for building in Finland. More detailed requirements and directions can be found in the national framework *Finlands byggbestämmelsesamling* (The Ministry of Environment's regulations on fire safety of buildings 848/2017 is part of the framework for example). The regulations within the framework apply to new buildings as well as renovations and changes but is flexible given the nature of the renovations and/or changes. The Finnish national framework states that a building complies with the regulations given that classes and numbers within the regulation are applied, or a scenario analysis can be performed on a case-basis, 848/2017 3 §:

> *"The essential technical requirements set for fire safety are met, if the building is designed and constructed in accordance with the classes and numerical values specified in this Regulation.*
>
> *Fire safety requirements are also met if the building is designed and constructed based on an estimated fire development, which covers the situations that are likely to occur in the building in question. Whether the requirement is met must be verified in each individual case, taking into account the building's properties and use. When designing based on an estimated fire development, such methods shall be used whose qualifications have been demonstrated.*
>
> *The bases for the design, applied models and results obtained must be reported in connection with the building permit procedure."*

There are prescribed specific "design fires" when dimensioning structural elements. The relevant authority for applications of building permits can require a safety investigation be prepared for construction works that are particularly demanding with regard to evacuation safety and Finnish building regulations do go more into detail what such a report should entail, this in contrast to other individual cases where it is up to the applicant to provide adequate verification of the design.

Buildings are divided into classes P0-P3, P1-P3 is used when a building is designed based on classes (building use, fire load density and type of building material) and number-specific values in the regulation (number of floors for example), see Table 3. P0 is used when the building is dimensioned according to fire scenarios that may arise in the building. The fire load density, number of floors, number of occupants, occupancy/use and the firecell area are factors that impact the building's class. Firecell in this instance is a direct translation, the implication is the same as fire compartment. The fire load density is divided into three categories (Joules per square meter floor area):

1. Below 600 MJ / m^2,
2. At least 600 MJ / m^2 but not more than 1200 MJ / m^2;
3. Over 1200 MJ / m^2.

The fire load density category is given by building use in the regulations for P2 buildings, residential buildings belong in the first category. The definition of fire load in the regulations does include building materials but no distinction is made between combustible and non-combustible construction. The mean fire load density based on fire load surveys in residential buildings is close to that number

(Buchanan & Abu, 2017). Fire load surveys do and should consider static loads like construction materials (Ocran, 2012).

Table 3. Summary of Finnish building regulations regarding building class P1 and P2 given residential use, P3 not relevant given limitations of building height (P3 only two floors).

Building Class	P1 (non-combustible construction required)	P2 (combustible construction allowed)
Number of floors	Max 4 (single apartment) and more than 2	Max 4 (single apartment) and max 8*
Structural stability, time and material class	R45, A2-s1, d0 and R60, A2-s1, d0	R45# and R60#*
Fire-resistance rating of each apartment and required material class in such construction	EI60, A2-s1, d0	EI60, D-s2, d2 or A2-s1, d0 depending on the configuration
External cladding	B-s1, d0 max 56 m	D-s2, d2* max 28 m
Material class, inner non-load-bearing walls and ceiling	D-s2, d2	D-s2, d2
Firecell area restriction	Each apartment/suite	Each apartment/suite
Floor area restriction	No limit	12 000 m^2

*Sprinklers required if more than four floors, #Filling and insulating materials need to be class A2-s1, d0

Fire-resistance rating, material classifications, test methods are defined and shown in Table 4, Table 5 and Table 6 below.

The above table includes two options relevant in this study, a single apartment/house with a maximum of four floors, or multiple apartments stacked on one another. In the case of multiple apartments, structural stability of 60 minutes instead of 45 is required. Combustible construction in prescriptive design is limited to 8 floors.

Table 4. Definition of classifications for building elements (European Committee for Standardization CEN, 2016).

Class/Element	Requirement/property/test method
R	Load-bearing capacity in minutes when exposed to fire. Specimen to remain in place under design loads, the requirement is set on deformation rate and maximum deflection.
E	Integrity (airtightness), the element needs to resist fire on one side without it spreading to the unexposed side through leakage of flames or hot gases.
I	Insulation time based on the temperature increase on the non-exposed side. 180 K max in a single point or 140 K average.

The time-temperature curve used in the classification of elements in Table 4 is ISO 834.

Table 5. A selection of surface classifications and test methods (European Committee for Standardization (CEN) , 2018).

Class	Test method	Classification criteria	Additional classification
A2 The structural element is extremely limited in its' contribution to fire development, e.g. gypsum boards, mineral wool.	EN ISO 1182 (1) or	ΔT < 50°C; and Δm < 50%; and Flame duration < 20s	
	EN ISO 1716 and	HHV $\leq$ 3.0 MJ.kg^{-1} (1) and HHV $\leq$ 4.0 MJ.m^{-2} (2) and HHV $\leq$ 4,0 MJ.m^{-2} (3) and HHV $\leq$3.0 MJ.kg^{-1} (4)	
	EN 13823 (SBI)	Fire Growth Rate $\leq$120 W.s^{-1}; and Horizontal flame spread < edge of specimen and Total heat release 600s $\leq$ 7.5 MJ	Smoke production, and flaming droplets/particles
B E.g. fire-retardant wood	EN 13823 (SBI) and	Fire Growth Rate $\leq$120 W.s^{-1}; and Horizontal flame spread < edge of specimen and Total heat release 600s $\leq$ 7.5 MJ	Smoke production, and flaming droplets/particles
	EN ISO 11925-2(5): Exposure = 30s	Flame spread $\leq$ 150 mm within 60s	
C E.g. paper covering on gypsum	EN 13823 (SBI) and	Fire Growth Rate $\leq$250 W.s^{-1}; and Horizontal flame spread < edge of specimen and Total heat release 600s $\leq$ 15 MJ	Smoke production, and flaming droplets/particles
	EN ISO 11925-2(5): Exposure = 30s	Flame spread $\leq$ 150 mm within 60s	
D The structural element is allowed to contribute to fire development e.g. wood, wood-based panels	EN 13823 (SBI) and	Fire Growth Rate $\leq$ 750 W.s^{-1}	Smoke production, and flaming droplets/particles
	EN ISO 11925-2(5): Exposure = 30s	Flame spread $\leq$ 150 mm within 60s	

(1) For homogeneous products and substantial components of non-homogeneous products.
(2) For any external non-substantial component of non-homogeneous products.
(3) For any internal non-substantial component of non-homogeneous products.
(4) For the product as a whole.
(5) Under conditions of surface flame attack and, if appropriate to end–use application of product, edge flame attack.

Table 6. Additional surface classifications (European Committee for Standardization (CEN) , 2018).

Additional classifications	Classification criteria
s1 **The structural element may only emit a very limited amount of smoke**	Smoke growth rate index $\leq 30m^2.s^{-2}$ Total smoke production$_{600s}$ $\leq 50m^2$
s2 **The structural element may emit a limited amount of smoke.**	Smoke growth rate index $\leq 180m^2.s^{-2}$ Total smoke production$_{600s}$ $\leq 200m^2$
s3	Not s1 or s2
d0	No flaming droplets/particles within 600s
d1	No flaming droplets/particles persisting longer than 10s within 600s
d2 **No requirement regarding restrictions on burning drops or particles.**	Ignition, not d0 or d1

There are key differences between P1 and P2 buildings with more than two stories in the regulations:

- P1: Load bearing structures cannot be combustible.
- P2: Only wood-based load-bearing structures in theory, if non-combustible construction is used it is beneficial to have the building in class P1 which allows for no limitations of total floor area/number of occupants, larger fire compartments and no requirements of sprinklers and non-combustible insulation.

2.3 Short comparative summary of building regulations in Canada versus Finland with respect to combustible construction and residential buildings

Fire performance tests of construction materials and classification methods in Europe are harmonized, but regulatory requirements are decided on a national level (Östman, et al., 2017). In Canada, building regulations differ by province, but is largely influenced by the National Building Code of Canada/National Fire Code of Canada and test methods conform to a standard used in North America (Commission on Building and Fire Codes, 2015). The standard test methods for resistance ratings and surface linings are comparable, ISO 834 "the standard fire curve" is much like the Canadian equivalent and classification D in the European system is achieved by (for example) untreated pine. Given that the "the standard fire curves" used are comparable it implicates a similarity between the test methods. Surface classification D and untreated pine also being a common denominator regarding requirements on surface linings indicates a likeness. That said, tests methods do differ between the countries.

One identified difference regarding building regulations of residential building in Canada and Finland is the applied fire-resistance rating, 45 minutes versus 60 minutes in Finland (up to three floors and depending on the configuration and use). In other respects, the countries codes are very much similar. Combustible surface linings are accepted, and four or more floors require sprinklers using an acceptable solution. Both countries allow for performance-based solutions that differ from a prescriptive design.

Chapter 2 is by no means a complete recollection of all the applicable building regulations but does provide an indication of the prescribed level of fire protection in what is assumed the most common situations. Regulations not being applied retroactively in full also means that many of the buildings included in the statistical analysis of this thesis has been constructed to a different standard, i.e. have no real connection to the classifications and test methods mentioned.

3. Literature review

This chapter summarizes several previous studies on the subject, utilizing statistics of fire incidents to try to explain consequences of fire in buildings. The chapter also contains reflections and opinions from the author of this thesis.

The goal of this literature review is to compare fire statistics between Canada, Finland and neighboring countries in some cases, to compensate for missing data. The review also includes previous studies that utilize statistics from the two databases used in this thesis.

Fire statistics reports referenced consists of publications from organizations that can be found for free online on the respective organization's website.

- The Geneve Association
  https://www.genevaassociation.org/
- CTIF - The International Association of Fire and Rescue Services
  ttps://www.ctif.org/
- Previously performed studies on the databases used in this thesis are freely available and can be found online on the database website or from the publisher respectively.
- NFID – National Fire Information Database
  http://nfidcanada.ca/
- PRONTO - The assignment register (database) of the rescue services (in Finland), report published by VTT Technical Research Centre of Finland Ltd
  https://cris.vtt.fi/en/
- VTT has published several reports using PRONTO, albeit in Finnish and all are not freely available.

Additional sources of general information on the subject:

- Mitigation of Fire Damages in Multi-storey Timber Buildings – Statistical Analysis and Guidelines for Design (Brandon, et al., 2018).
- Execution of Timber Structures and Fire (Just, et al., 2016)
- Fire Data Analysis Handbook (U.S. Fire Administration, 2004)

3.1 Fires and fire protection in numbers

This section will cover general fire statistics for each relevant nation to highlight any major differences in between nation's fire safety level. It will also show how statistics are reported have a major impact on values used in a statistical study even if the type of variable is common and easily defined and how prevalent missing values are.

The Geneva Association published a bulletin in 2014 that focused on fire statistics by country, the data includes information on costs of direct fire losses, human fire losses, cost of public fire brigades and estimated fire protection costs. The bulletin was based on statistics gathered by the World Fire Statistics Centre (WFSC, affiliated organization of The Geneva Association). It presents statistics on national fire costs from around 20 countries in an effort to persuade governments to adopt strategies aimed at reducing the cost of fire in buildings. The Geneva Association is, in their own words, the leading international insurance think tank for strategically important insurance and risk management issues (The Geneva Association, 2014).

Additional information is included from the from The International Association of Fire and Rescue Services World Fire Statistics Center (CTIF) yearly publication World Fire Statistics. CTIF (founded in 1900) develops fire statistics in reports published annually which offer data from 80 different countries and 90 capital cities. The organization has 39 member states, one million members worldwide and is on paper the largest firefighting organization in the world (CTIF, 2017).

3.1.1 Fire losses

Fire losses include explosion losses following fire, but exclude explosion losses where no fire occurs, e.g. some acts of terrorism. According to the bulletin, “Scandinavian countries continue to suffer above-average fire losses, perhaps due to the harsh climate and a higher percentage of buildings that contain wood.” (The Geneva Association, 2014, p. 5). Scandinavian countries together with Italy and France do indeed top the list, the United States, to compare with a North American country, has half the cost as average percentage of GDP compared to Scandinavia, see Table 7:

Table 7. Adjusted figures for direct fire losses and as average percentage of GDP, millions (The Geneva Association, 2014, p. 6).

Country	Currency	2008	2009	2010	Percentage of GDP 2008-2010
United States	$US	17 500	14 000	13 000	0.10
Canada	$CAN	-	-	-	0.11* [2007]
Finland	€	305	280	330	0.17
Sweden	SEK	5950	5550	5650	0.18
Norway	NOK	-	-	-	0.22 [2003-2005]

*Estimated direct fire loss sourced from (Wijayasinghe, 2011), calculation by author.

According to the Geneva Association, these statistics are always hard to calculate consistently and must be treated with care due to uncertainties. The variations in the submitted fire loss data has been reduced over the years (The Geneva Association, 2014).

The WFSC (World Fire Statistics Centre) believes that decreasing fire losses is correlated to declining GDP, austerity measure due to financial crisis in combination with improving loss results. The presented statistics are regarded as the most comprehensive on national fire costs (The Geneva Association, 2014). Differences between for example the United States/Canada and Finland is perhaps due to differences in building stock, Finland has a larger quantity of detached houses and fewer apartment buildings in comparison (Tillander, 2004) (C. Diamond, 2001). Detached houses are often a single fire compartment where fire can spread freely whereas apartment buildings consist of multiple compartments. The fire loss is strongly correlated to the area of the detached house (Tillander, 2004) and it would be safe to assume that most apartments are smaller than the average detached house. Cost of fire protection features (see Table 9) influences fire losses, an illustrative example would be sprinklers in apartment buildings. The value at risk is presumably larger due to higher building costs in harsher climates. Canada and Finland are climate-wise very similar and most likely face the same problems.

The mean rate of fire deaths per 100 000 inhabitants per year in 2012-2016 was 1.5 (CTIF, 2018). Human fire losses by country are displayed in Table 8:

Table 8. Published figures (deaths) and population comparisons (CTIF, 2018, p. 25).

Country	2012	2013	2014	2015	2016	Deaths Per 100 000/Pop 2012-2016
Canada	149	141	150	-	-	0.4 [2012-2014]
Finland	77	58	86	74	82	1.4

The comparably high number of deaths per 100 000 inhabitants for Finland is in part explained by the high rate of alcohol consumption, smoking habits and other factors (Östman, 2015). This relatively high figure is shared with other neighboring countries like Russia, Ukraine and Latvia (CTIF, 2018). Information on fire deaths presented here is not comprehensive and only included to make a relatively simple comparison and the source is used for consistency, fire deaths in general is not the topic of this thesis.

3.1.2 Fire protection costs in buildings

Spending on fire protection in buildings impact the level of protection and the associate risk of loss and is therefore relevant. Some of the variation in building fire protection costs is explained by differences in estimations, assumptions and methods. The temperature of the construction industry and the economy in general also affects building costs. For estimated fire protection costs see Table 9:

Table 9. Estimated fire protection cost, millions. Source: (The Geneva Association, 2014, pp. 12-13)

Country	Currency	2008	2009	2010	Fire Protection cost as percentage of GDP 2008-2010	Estimated percentage attributable to fire protection for the total national cost of building and construction
Canada*	$CAN	5200	-	-	0.32 [2006-2008]	3.9 [2006-2008]
Sweden	SEK	6900	6200	6600	0.20	2.5
Norway	NOK	-	-	-	0.36 [2003-2005]	-

*Reflecting the assessment of the fire protection costs of various types of buildings, ranging from 2% for single homes to 13.2% for high-rise apartments. Estimates are derived from preliminary statistics.

Variations among countries can be explained by different methods of calculation to some extent, in addition to this the rates of construction activity varies within the whole economy.

3.1.3 Fire brigades and public spending

Information on fire brigades is relevant when researching consequences of fire. The costs of public fire brigades are shown in Table 10:

Table 10. Adjusted figures for the costs of public fire brigades, millions (The Geneva Association, 2014, p. 11).

Country	Currency	2008	2009	2010	Percentage of GDP 2008-2010	Per 100 000/Pop 2008
Finland	€	325	345	355	0.19	6.1
United States	$US	40 000	40 500	43 000	0.29	13.2
Canada	$CAN	3 800	-	-	0.25* [2008]	11.5

*Public spending on firefighting services sourced from (Statistics Canada, 2020).

Properly managed resources to match risk, reduces risk, and therefore a well-funded fire and rescue service should decrease fire losses. An example of this is increased availability of fire trucks or fire and rescue service personnel. Fire and Rescue Service inspections performed by Her Majesty's Inspectorate of Constabulary and Fire & Rescue Services showed that by using a range of historical, current and predictive data fire and rescue services could allocate resources efficiently to match risk. By introducing two roaming fire engines they improved productivity, the services had the right resources to respond to major incidents and to do preventive works (HMICFRS, 2018). In many cases where a country does spend a higher percentage of GDP it also has lower fire losses, but this is not always the case (CTIF, 2018). In some instances, the availability of a fire brigades seems to have a positive impact on fire losses and in others there is not such an indication i.e. spending on and availability of fire and rescue services are still high but so are recorded losses. These cases are not presented here. Any difference is perhaps not significant and the impact on the outcome of a fire is negligible and/or very difficult to estimate. In conclusion, many aspects have an impact on fire losses, not just the availability of a fire brigade.

In addition to funding, the number of firefighters can have an impact on the outcome of a fire, see Table 11 for a comparison:

Table 11. Average number of inhabitants per 1 career firefighter, volunteer firefighter, fire engine and fire station. Source: (CTIF, 2018, p. 38)

	Average number of inhabitants per			
	Career firefighter	**Volunteer Firefighter**	**Fire engine**	**Fire station**
Country				
Finland	1478	471	3566	6109
Canada	1367	280	-	-
United States	876	479	4927	6415

3.1.4 Number of fires

The number of fires in each respective country is an indicator of the available data and information on how the data is gathered differs between countries. The mean rate of fires per 1000 inhabitants per year in 2012-2016 was 2.1 (CTIF, 2018). Number of fires by country are shown in Table 12:

Table 12. Number of fires 2012-2016. Source: (CTIF, 2018, p. 26)

Country	2012	2013	2014	2015	2016	Average	Per 1000 inhabitants per year
Canada	35 544	45 005	37 194	36 445	-	39 458	1.11
Finland	11 803	13 421	14 027	11 220	12 063	12 507	2.29
New Zealand	-	-	10 245	10 515	10 314	10 358	2.25

The number of fires per 1000 inhabitants vary greatly by country and once again, it is mostly likely due to how information is reported. According to CTIF reporting categories differ from year to year, for example, reported numbers for earlier years (not shown here) in New Zealand has twice the number of fires, and there is no reasonable explanation for this improvement other than that reporting categories have changed (Ahrens, 2018). For the years listed above Finland and New Zealand has very similar number of fires per 1000 inhabitants, while Canada has a substantially lower number. This is in part due to the selected observations only cover 72% of the Canadian population (six provinces report to NFID – National Fire Information Database) (Canadian Centre for Justice Statistics, 2018).

3.2 Canadian study using the NFID-database

The Canadian Association of Fire Chiefs, with the Canadian Council of Fire Marshalls and Fire Commissioners launched the national fire information database in September 2017. The National Fire Information Database (NFID) is a "*…national fire data pilot project that will gather and unify 10 years of fire information from across the country and create Canada's first national system for collecting fire statistics This project will link fire data with other relevant datasets, and will initiate the creation of new evidence-based research related to fire, public safety, and security."* (National Fire Information Database, 2016).

University of the Fraser Valley, Centre for Public Safety & Criminal Justice Research, published a review of the role of insurance in reducing the frequency and severity of fire losses in December 2017 (Kelly, et al., 2017) using data from NFID. It included a severity fire loss analysis limited to two provinces, Alberta and British Columbia. To estimate the severity of an incident of fire loss, two marginally different metrics were used, one for each respective province. The measure used for Alberta consisted of "*…a ratio of estimated dollar amount of damage to a building caused by fire relative to the estimated cash value of the building..."* (Kelly, et al., 2017, p. 33) abbreviated to Dollar loss/VAR (building). The measure used for British Columbia consisted of *"…a ratio of the estimated dollar amount of total damage caused by fire relative to the estimated cash value of the property including its contents…"* (Kelly, et al., 2017, p. 34) abbreviated to Dollar loss/VAR (total).

The severity fire loss analysis included ordinary least squares (OLS) regression models to evaluate the impact of building variables on the measured fire loss. For simplicity's sake OLS is comparable to the common linear equation written in the form y=kx+m, the difference being that often several k=vector coefficients, referred to as β in OLS, and x_i=independent variables are included. For more information on how OLS works, refer to section 4.2. An estimation/prediction of the severity of an incident of fire loss based on a set of variables in an OLS-model in itself is not very relevant for several reasons in this case, mostly due to the assumptions that are made when using OLS, for example independent variables are assumed. However, the model calculates vectors that indicate how a variable might impact, in this case, fire loss. Probability being the key word here, the interpretation of a vector can/should be limited to direction, magnitude and significance.

In the review, in an attempt to better understand how fire loss severity varied between structures, building characteristics (dollar value, occupancy, height, sprinkler protection etc.) and dollar loss values were extracted from the National Fire Information Database (NFID), for more information on NFID refer to section 4.1.1. Typical building related construction-type variables included in the analysis were:

- Combustible construction – open wood joist
- Protected combustible construction – wood protected by plaster
- Heavy timber construction
- Non-combustible construction – exposed steel
- Protected non–combustible construction – protected steel or concrete

Statistics for the severity fire loss analysis variables displayed above were based on 44 931 observations in Alberta and 35 695 observations in British Columbia spanning over years 2005-2015. Two different models were used, one for each province:

Dollar loss/VAR$_{ijt}$ =

$\alpha + \beta_1 \times \textit{First Nations}_{jt} + \beta_2 \times \textit{Urban}_{ijt} + \beta_3 \times \textit{Residential occupancy}_{it} + \beta_4 \times \textit{Residential property}_{it} + \boldsymbol{\beta}_5 \times \textit{Construction}_{it} + \beta_6 \times \textit{Height}_{it} + \boldsymbol{\beta}_7 \times \textit{Manual fire protection}_{it} + \boldsymbol{\beta}_8 \times \textit{Sprinkler protection}_{it} + \boldsymbol{\beta}_9 \times \textit{Fixed system}_{it} + \boldsymbol{\beta}_{10} \times \textit{Automatic fire detection system}_{it} + \boldsymbol{\beta}_{11} \times \textit{Fire detection device}_{it} + \boldsymbol{\beta}_{12} \times \textit{Outside fire protection}_{it} + \boldsymbol{\beta}_{13} \times \textit{Fire service}_{it} + \boldsymbol{\beta}_{14} \times \textit{Act or omission}_{it} + \boldsymbol{\beta}_{15} \times \textit{Initial detection}_{it} + \boldsymbol{\beta}_{16} \times \textit{Action taken}_{it} + \beta_{17} \times \textit{Median income}_{jt} + \beta_{18} \times \textit{Low education level}_{jt} + v_i$

Dollar value of loss/VAR$_{ijt}$ =

$\alpha + \beta_1 \times \textit{First Nations}_{jt} + \beta_2 \times \textit{Urban}_{ijt} + \beta_3 \times \textit{Residential occupancy}_{it} + \beta_4 \times \textit{Residential property}_{it} + \boldsymbol{\beta}_5 \times \textit{Construction}_{it} + \beta_6 \times \textit{Height}_{it} + \boldsymbol{\beta}_7 \times \textit{Manual fire protection}_{it} + \boldsymbol{\beta}_8 \times \textit{Sprinkler protection}_{it} + \boldsymbol{\beta}_{10} \times \textit{Automatic fire detection system}_{it} + \boldsymbol{\beta}_{11} \times \textit{Fire detection device}_{it} + \boldsymbol{\beta}_{12} \times \textit{Outside fire protection}_{it} + \boldsymbol{\beta}_{13} \times \textit{Fire service}_{it} + \boldsymbol{\beta}_{14} \times \textit{Act or omission}_{it} + \boldsymbol{\beta}_{15} \times \textit{Initial detection}_{it} + \boldsymbol{\beta}_{16} \times \textit{Action taken}_{it} + \beta_{17} \times \textit{Median income}_{jt} + \beta_{18} \times \textit{Low education level}_{jt} + v_i$

Where i, j, t denotes incident i, census subdivsions (CSD) j, and year t (Kelly, et al., 2017, pp. 40-41).

The categorical variable $\textit{Construction}_{it}$ has several (5) indicator variables as shown in the bullet list, β5 is the corresponding vector of five coefficients of the indicator variables. Results of the used models to calculate β5 are shown in Table 13:

Table 13. OLS regressions on value of loss/VAR for select variables (Kelly, et al., 2017, p. 41).

Independent Variable	Model Alberta Dollar loss/VAR	Model British Columbia Dollar value of loss/VAR
Wood construction	–0.01(0.07)	–0.17(0.06)**
Wood plaster construction	–0.15(0.07)*	–0.22(0.05)***
Heavy timber construction	–0.03(0.23)	–0.21(0.15)
Exposed steel construction	–0.13(0.14)	–0.35(0.10)***
Steel & concrete construction	–0.24(0.11)*	–0.34(0.09)***

All probabilities are two–tailed tests. * p≤0.05; ** p≤0.01; ***p≤0.001.
Standard errors are reported in parentheses.

The negative values of β5 indicate a negative association of the variables to the fire severity loss. Values of coefficients of variables shown are not very consistent between provinces, which would indicate that the variables are not correlated to the fire severity. Using these two models, the authors could show positive association between no manual fire protection and fire loss severity, as well as the low education variable and fire loss severity, but such results can hardly be seen as surprising. The author´s argue that this is due to lack of granularity in the data, and that the method at best, only shows what one can guess intuitively.

3.3 Finnish study using the PRONTO-database

Pelastustoimen resurssi- ja onnettomuustilasto (PRONTO) is the Ministry of the Interior's system to record, monitor and investigate accidents attended by the rescue services. The material is collected from the Register of Operations and Resources maintained by the regional rescue services. The Emergency Services Academy Finland is responsible for the technical maintenance and development of PRONTO (Pelastusopisto, n.d.).

Finnish VTT (Teknologian Tutkimuskeskus VTT Oy) and Helsinki University of Technology published Kati Tillanders dissertation for the degree of Doctor of Science in Technology in 2004 (Tillander, 2004). The dissertation utilized statistics to assess fire risks in buildings and was the first relatively broad statistical study using the national accident database PRONTO. The work concentrated on ignition frequency, economic losses of fires and the fire service´s response in the event of building fires.

The analysis showed that economic losses and ignition frequencies should be studied in relation to the fire compartment size and not total building area, which was the parameter recorded. To examine more closely the relation between losses and building area and other building characteristics, the material of the load-bearing structure was considered, data included 9697 fires reported during 1996-2001. Of the reported fires, 50% had registered the material of the load-bearing structure.

Wood-framed buildings consisted of 81% of the total building stock in numerical terms, however, wood-framed buildings only stood for 44% of the total area of the building stock, which was about equal to that of concrete. Given that concrete buildings tended to be much larger compared to wood-framed buildings, the average loss per floor area was deemed to be inappropriate to use when estimating the differences regarding fire losses between materials.

To be able to analyze more in detail the differences between materials, observations were divided into subgroups dependent on building type (apartment and detached houses) and material (concrete, wood and other). The cumulative distributions of fire loss in the subgroups showed differences between the materials that were statistically significant, e.g. the total loss in wood-framed apartment buildings was larger. The reason for this was partially explained according to Tillander by spread of fire beyond the ignition compartment which was more prevalent in wood-framed buildings as well as the contributing factor of the surface layer which more often boosted the fire in wood-framed buildings compared to other types of construction.

4. Data analysis

The objectives of this thesis states that the impact of building characteristics and firefighting on damage caused by fire is to be estimated, utilizing data gathered in databases and analyzing it statistically. In addition to this a comparison of the impact of the above-mentioned factors in timber-framed buildings versus other types of construction is to be included. So far, a comparison of building regulations has shown that buildings of prescriptive design constructed in somewhat recent years would have similar characteristics between Finland and Canada.

General statistics on spending and number of fires etcetera have shown differences exist between the two countries, but most importantly that statics vary a lot depending on how an incident is reported even if a variable has been deemed to belong in one and the same category, simply by how it is defined by the collecting entity.

Previously performed studies touching on the same subject, utilizing the same databases and making the same comparison as stated in the objectives have shown conflicting results regarding damages in timber-framed building in comparison to other materials.

Factors included in the analysis in this thesis are based on the available data which differs with the database used. All categorical variables are shown in Table 43 and Table 44 in the appendix, variables with multiple categories are simplified to be bivariate to increase the available data in ordinary least squares regression models. Continuous variables used are shown in Table 14 and Table 30. Data/variables extracted from the databases are all related to building characteristics like combustible or non-combustible construction, presence of active systems like sprinklers and/or manual fire protection facilities such as extinguishers. Furthermore, if data is available on the rescue service response such data is included. The variables relationship to recorded damage in the form of monetary loss or damage area is then analyzed.

The following chapter 5 will cover the data-analysis part of this thesis starting with a description of the datasets used, applied methodology for statistical analysis of the data with a summary of the data used, tables, graphics and statistical models with results.

As mentioned before, data used in the analysis has been gathered from Finland (PRONTO) and Canada (NFID). Applied methods are:

1. Summary statistics – summarized sets of observations
2. Pearson Correlations with two-tailed t-test
3. Ordinary least squares regression analysis

Summary statistics in descriptive statistics are used to summarize a set of observation. It is a way to communicate as much information as possible as simply as possible, commonly it can consist of:

- Central tendency like median
- Statistical dispersion like standard deviation
- Shape of the distribution like skewness

The information above can be relayed in for example box plots, probability density functions (density) of a continuous random variable and cumulative distribution function (distribution function) as shown in chapter 5.

If more than one variable is measured, statistical dependence like correlation is often included to accompaniment the summary statistics, in this thesis in the form of Pearson Correlations with two-tailed t-test.

When combining summary statistics and correlations it is possible to calculate the unknown parameters in a linear regression model, like ordinary least squares (OLS) which is applied in the last sections of chapter 5 for variables extracted from the NFID and PRONTO-databases. OLS extrapolates the unknown parameters of a linear function given different explanatory variables by minimizing the sum of the squares of the differences between the observed variable in the given dataset and those predicted by the line/linear function, see Figure 2.

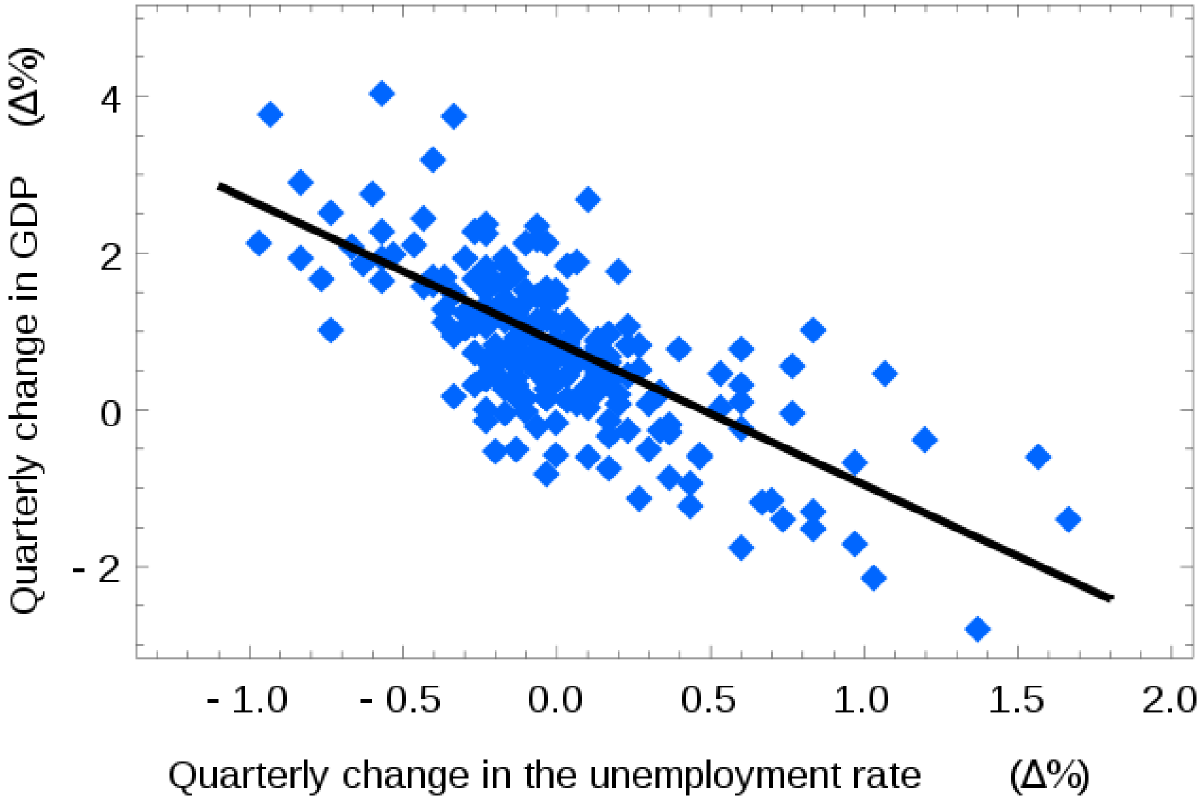
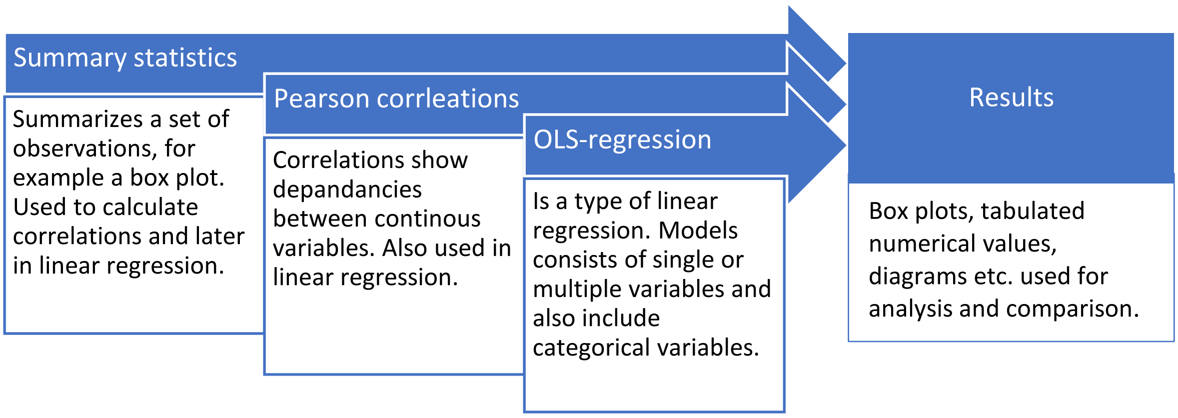


Figure 2. OLS regression using two variables. Okun's law in macroeconomics states that in an economy the GDP growth should depend linearly on the changes in the unemployment rate. Here the ordinary least squares method is used to construct the regression line describing this law. Source: (Stpasha, 2009) licensed under public domain.

The approach to the data-analysis part can be summarised in a flow chart as follows:



4.1 Notes on datasets used in analysis

Datasets used in this study is from databases in Canada (NFID) and Finland (PRONTO).

4.1.1 NFID

The author of this thesis requested access to the database and was granted permission on the condition that the dataset was cleaned as per the Data Sharing Agreement (Therrien, 2019). 'Cleaning' in this sense refers to the process of addressing invalid data points from datasets. The goal is to make the NFID freely accessible to all researchers (National Fire Information Database, 2018).

Additional cleaning was done by the author in the datasets used in this study due to what the thesis is trying to isolate, refer to the NFID Data Dictionary for information on all variables (National Fire Information Database, 2017). It is important to note that 'cleaning' involves human judgement and is therefore a factor in any results.

4.1.2 PRONTO

The data was cleaned and translated by the author. There is a similar document to the NFID Data Dictionary available for the PRONTO-database, which is referred to for information on all variables (Ketola, 2018).

4.2 Methodology in statistical analysis

The following section goes more in depth on OLS and how a model should be interpreted. It complements the information at the start of this chapter and information provided in the chapter following this one, which includes the actual statistical analysis.

Figure 3 is a stacked Venn diagram illustrating the different parts included in the analysis and the relationship between them, each part is necessary to perform for the next and with each step the utilization of the available data decreases due to, for example, missing values in the data.

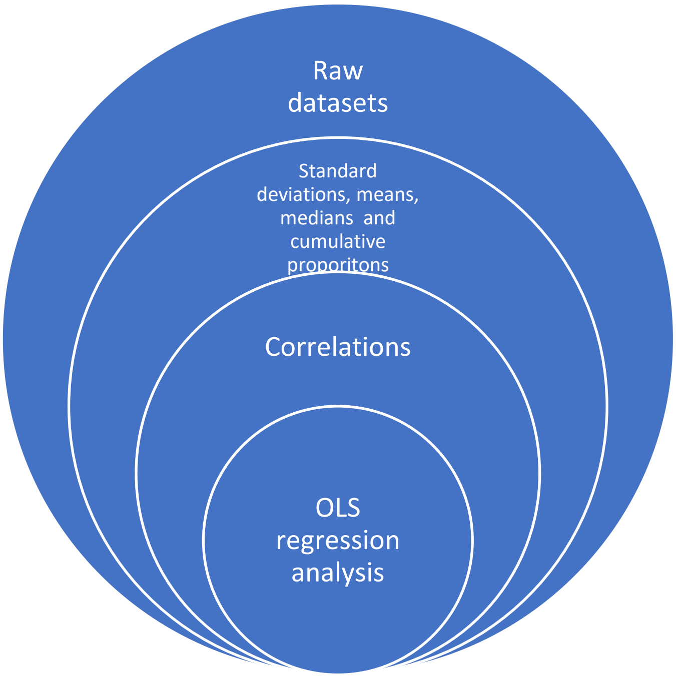


Figure 3. Stacked Venn diagram of parts included in the analysis.

Standard deviations, means, medians and cumulative proportions are typical statistical tools used to clarify the distribution of a variable. In the analysis the values are shown in tables, diagrams and as functions.

Correlation in statistics is a measurement of linear dependence between two variables, it is a value between -1 to +1. A positive correlation closer to 1 indicates an increase of the response (dependent) variable when the independent variable increases. For an inverse relationship the opposite applies, the correlation between the variables will be closer to -1.

A correlation of close to 0 suggests no dependence between the variables and low correlations ($-0.2 < x < 0.2$) indicates that the response variable (Y) is to a larger extent unexplained by the predictor (X).

Ordinary Least Squares (OLS) linear regression is one method used for the analysis and modelling of linear dependencies between a dependent variable and one or multiple independent variables. If such a dependency can be categorised as linear, the data can fit a straight line to model the relationship and can be written on this form:

Y_i= Intercept + $\beta_1 * X_1 + \beta_2 * X_2 + \beta_3 * X_3$ ….

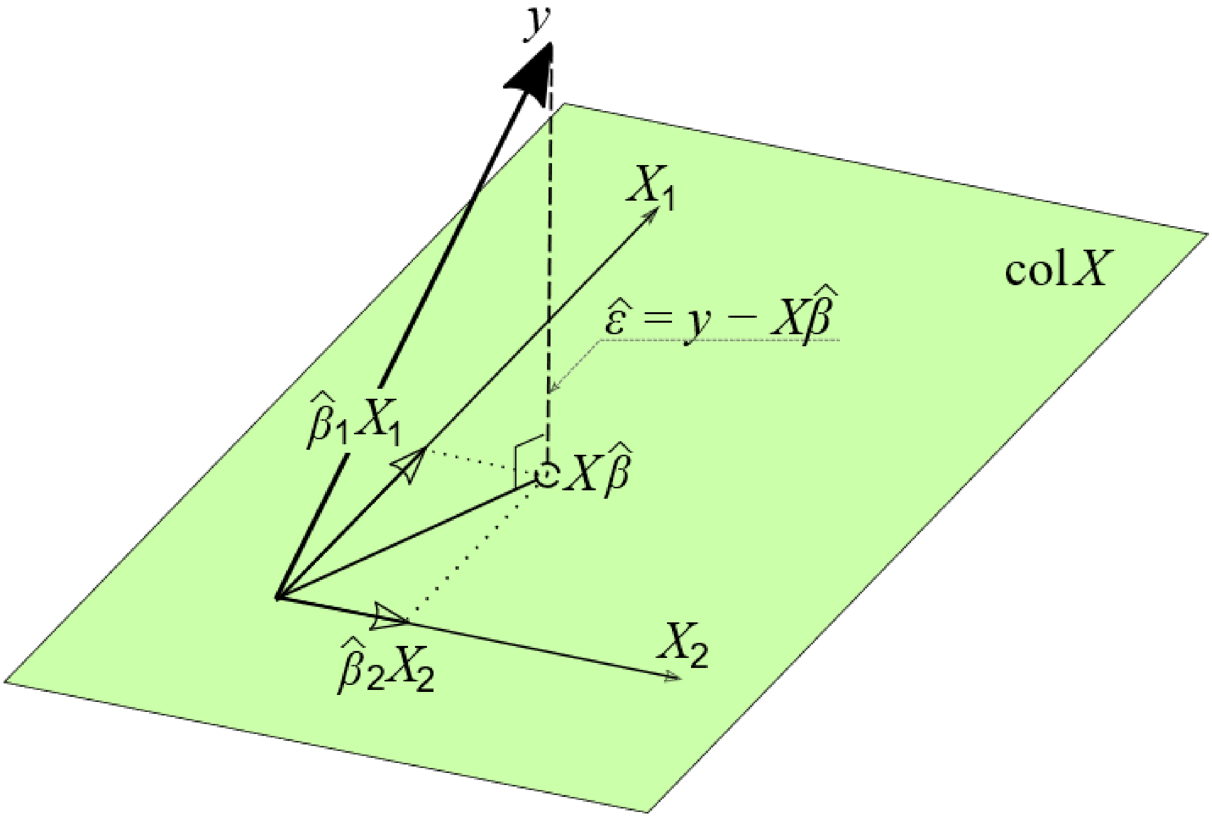


Figure 4. Linear regression can be viewed as an orthogonal projection of vector y on the linear subspace spanned by X with the OLS estimator being the coefficients of decomposition of the projected vector by the basis of X.
Source: (Stpasha, 2009) licensed under public domain.

Y_i is the response or dependent variable, β_i is the gradient or regression weight, X_i is the predictor or independent variable and the intercept is the expected Y of all X=0. The modelled OLS linear regression can be used to predict Y for varying inputs of X given the line fitted from observations. The regression weights measure the level of association and can be interpreted as the average increase in Y for one unit increase of X when all other predictors are fixed.

Five summary statistics can be used to calculate the slope and intercept: the standard deviations of X and Y, the means of X and Y, and the Pearson's correlation coefficient between X and Y variables.

To determine if the multiple regression analysis is relevant, an ANOVA (Analysis of Variance, a form of statistical hypothesis testing) is performed. Start by examining the F-statistic and the associated p-value, lower p-value of the F-statistics indicates high significance and a strong likelihood that at least one of the predictor variables is significantly related to the dependent variable. To see which predictor variables are significant, examine the estimate of regression weights and the associated t-statistic p-values. The t-statistic evaluates whether a regression weight of a given predictor associated with the outcome variable is significantly different from zero. In other words, a test result is deemed statistically significant if deemed unlikely that it happened by chance, and you can reject the null hypothesis that no relationship exists between the measured variables.

Model quality assessment can be done by examining the R-squared and the Residual Standard Deviation. In multiple linear regression, the value of R-squared represents the correlation coefficient between the values observed of the dependent variable and fitted or i.e. predicted values of the same. R-squared will range from 0 to 1 and describes the proportion of variance in the dependent variable that may be predicted by knowing the value of the independent variables. A value close to 1 means that the model explains much of the variance in the dependent variable.

By adding more independent variables to a model R-squared always increases, to take this into account, a second (adjusted) R-squared is calculated, that is corrected based on the number of variables in the model.

Residual Standard Deviation measures error of prediction. A low Residual Standard Error means a more accurate model given the available data.

5. Statistical analysis by country

This chapter applies what was explained in the precious chapter, a statistical analysis by country starting with Canada and the dataset extracted from NFID and concluding with Finland and the data from PRONTO. Calculations and graphics where made mainly using R.

5.1 Canada

The available fire loss data covered fires in residential buildings with at least three stories in Canada during 2005-2015 in a single dataset. Economic losses are estimated (in Canadian dollars) in two categories, building and property, loss of the building includes damages to building structures caused by fire, property loss indicates the damages to moveable belongings in the building.

Total recorded losses during the time period is in the range of 900 million $CAN, see Figure 5, in comparison that is less than half the yearly average of estimated total direct fire losses as reported by The Geneva Association.

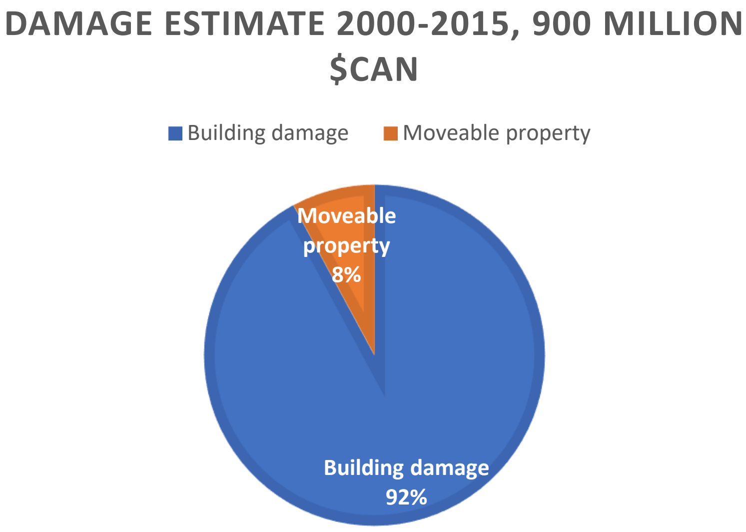


Figure 5. Estimated dollar loss in all incidents independent of type of construction.

The probability density function or density of recorded year of construction given construction type is shown in Figure 6. In probability theory, density of a continuous random variable is the data's possible values as a function (here represented by a line and under a filled in space) and is interpreted as the relative probability that the value of the random variable would be equal to that sample.

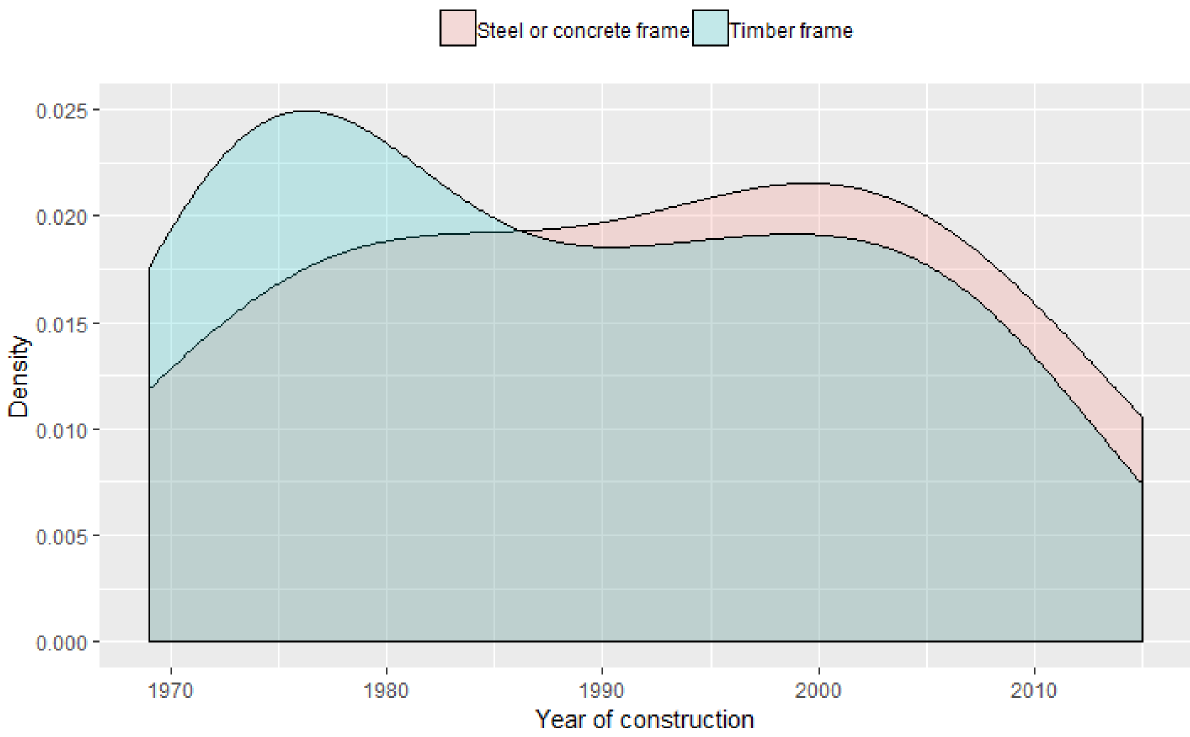


Figure 6. Density of year of construction in timber-framed and steel- or concrete-framed buildings. The variable for year of construction contain relatively few values, refer to section 5.2.

5.1.1 Summary statistics with references to figures and tables

In Table 14 and Table 15 (pages 39 and 40) summary statistics on continuous variables are shown by construction type. The variable (year of construction) shown in Figure 6 on this page as a density, is calculated as the difference of the recorded value in column two in Table 43 (see appendix) and the year of the incident. As shown in the tables 586 and 5500 values out of 613 and 5700 are missing.

Following Table 14 and Table 15 are box-and-whiskers plots, see Figure 7 on the next page. The plots illustrate some of the summary statistics in a graphical method commonly used with quantitative statistical evaluations. The box-and-whiskers plots are divided in type of construction and show more in depth the type of construction in comparison to Table 14 and Table 15. For each plot there are two versions, one showing the entire distribution (refer to the appendix, Figure 25, Figure 27, Figure 28) and one showing a smaller sample to visualize more clearly the nuances of the distributions, if all outliers are shown the boxes become very small. Refer to box-and-whiskers plots in Figure 8, Figure 9, Figure 10 and Figure 11 below (pages 41, 42, 43 and 44) and Table 14 and Table 15 respectively.

Lastly cumulative distribution functions by dollar loss and building type are shown in Figure 12 and Figure 13 (page 45).

The tabulated values and box-and-whiskers plots describing the distributions and cumulative distribution functions follow this short summary of observations. The summary statistics section covers a comparison of continuous variables response time, building age/height, value at risk and dollar loss in timber-framed versus buildings with non-combustible framing.

In general, the following tables and plots show that timber-framed buildings in the gathered statistics are or have when compared to other types of construction:

1. **Longer response time for the rescue service.**
   The mean, 3rd quantile and max for timber-framed buildings are higher compared to buildings with non-combustible framing, see Table 14 and Table 15 column 1. The difference is not very significant, and the variable is plagued by missing values.
2. **Older.**
   The difference is more significant than for longer response time but still not very significant, the variable is once again lacking due to missing values, see Table 14 and Table 15 column 2. This difference is clearly illustrated in Figure 6.
3. **Much more likely to have three floors.**
   This is probably the most reliable variable given that no missing values were reported, see Table 14 and Table 15 column 3.
4. **Considerably lower value at risk for the building but about the same for the contents.**
   Value at risk building/contents value have acceptable levels of missing data, value at risk total lacks data see Table 14 and Table 15 column 4, 5 and 6 as well as Figure 8 and Figure 9 for more details, outliers are also a factor that is relevant to note as shown in the box-and-whiskers plots. Given that most buildings of non-combustible construction have a greater building height this is not surprising. Contents value is probably based/estimated on a number per apartment and not the entire building, but there is no information to substantiate that claim.
5. **A higher average dollar loss value.**
   The mean, 3rd quantile and max for timber-framed buildings are clearly separated from non-combustible buildings but the median is the same, see Table 14 and Table 15 column 7, 8 and 9. For more details and a breakdown of the different construction variables refer to Figure 10 and Figure 11, outliers are also a factor that is relevant to note as shown in the box-and-whiskers plots.
6. **A larger portion of high dollar loss values.**
   Comparing the cumulative distributions functions shown in Figure 12 and Figure 13 a difference is noticeable. The logarithmic graphs (inverse exponential functions) for dollar loss in timber-framed buildings are not as steep which means that a larger portion of high dollar loss is recorded in timber-framed buildings.

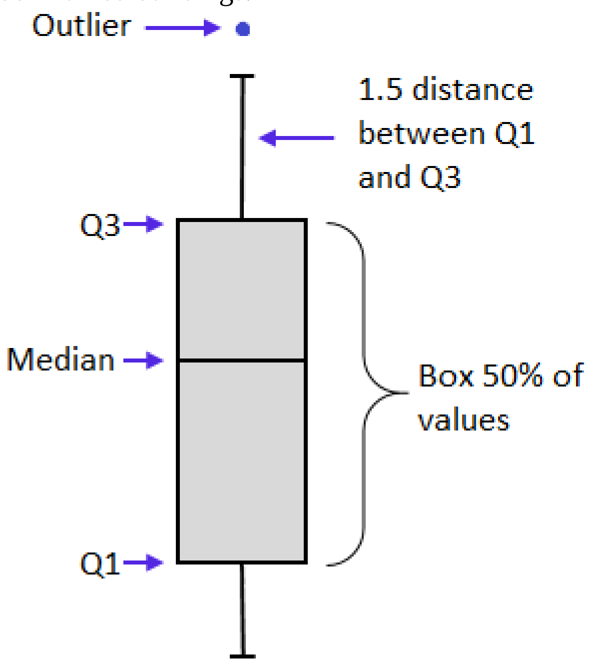


Figure 7. Box-and-whiskers plot, box contains 50% of values, "whiskers" illustrate the distance between quantiles and outliers are shown as dots.

Table 14. Summary statistics continuous variables in steel- or concrete-framed buildings 2000-2015, N=613.

	1. Response time of first vehicle [min]	**2. Years since construction ***	**3. Number of floors**	**4. Value at risk building [$CAN]**	**5. Value at risk contents value [$CAN]**	**6. Value at risk total [$CAN]**	**7. Dollar loss building vehicle# [$CAN]**	**8. Dollar loss contents [$CAN]**	**9. Dollar loss total [$CAN]**
1. Min.	0	0	3	1000	0	1000	2	10	10
2. 1st Qu.	4	7.5	4	1 000 000	0	712 500	513	262.5	500
3. Median	5	19	9	6 000 000	50 000	3 000 000	5000	900	1500
4. Mean	5.2	20.4	10.3	14 325 009	1 692 373	8 435 579	51 391	4805	19 008
5. 3rd Qu.	6	33	15	17 045 500	1 000 000	9 062 000	20 750	4750	10 000
6. Max	31	44	50	300 000 000	150 000 000	80 384 000	6 070 000	74 000	1 074 000
7. NA's	301	586	0	142	134	494	143	551	471

*Seldom reported, sometimes as a numerical value (year) or a bracket category (e.g. 1940-1950).
#No zero-dollar loss values recorded, blanks are NA's. No mobile homes (vehicles) are included in this analysis but the recorded variable in NFID contains such data.

Table 15. Summary statistics continuous variables in timber-framed buildings 2000-2015, N=5700.

	1. Response time of first vehicle [min]	2. Years since construction*	3. Number of floors	4. Value at risk building [$CAN]	5. Value at risk contents value [$CAN]	6. Value at risk total [$CAN]	7. Dollar loss building vehicle# [$CAN]	8. Dollar loss contents [$CAN]	9. Dollar loss total [$CAN]
1. Min.	0	0	3	1000	0	1000	2	2	2
2. 1st Qu.	4	10	3	498 500	0	550 000	1000	235	500
3. Median	5	24	3	1 752 000	50 000	2 000 000	5000	1000	2725
4. Mean	6.7	23.4	3.6	4 051 111	504 953	3 888 208	166 575	37 467	141 991
5. 3rd Qu.	7	35	4	4 013 000	400 000	5 000 000	31 966	10 000	25 000
6. Max	425	46	30	250 000 000	50 000 000	200 000 000	23 500 000	5 473 615	20 000 000
7. NA's	4115	5500	0	1261	671	2968	1410	3894	2810

*Seldom reported, sometimes as a numerical value (year) or a bracket category (e.g. 1940-1950).
#No zero-dollar loss values recorded, blanks are NA's. No mobile homes (vehicles) are included in this analysis but the recorded variable in NFID contains such data.

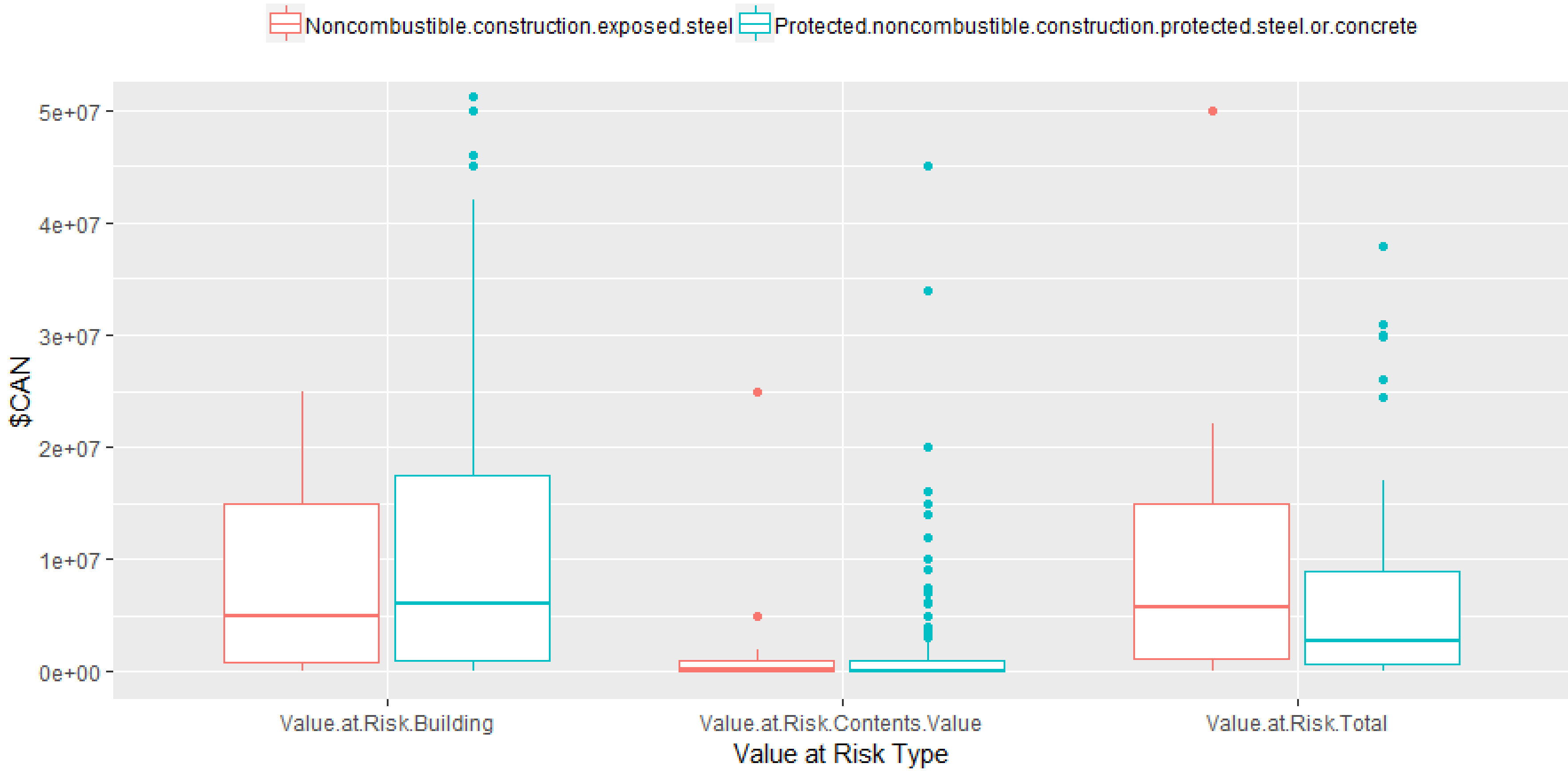


Figure 8. Box-and-whiskers plot by value at risk type in non-combustible constructions, selected values, for the full distributions refer to Figure 26 and additional information in the appendix.

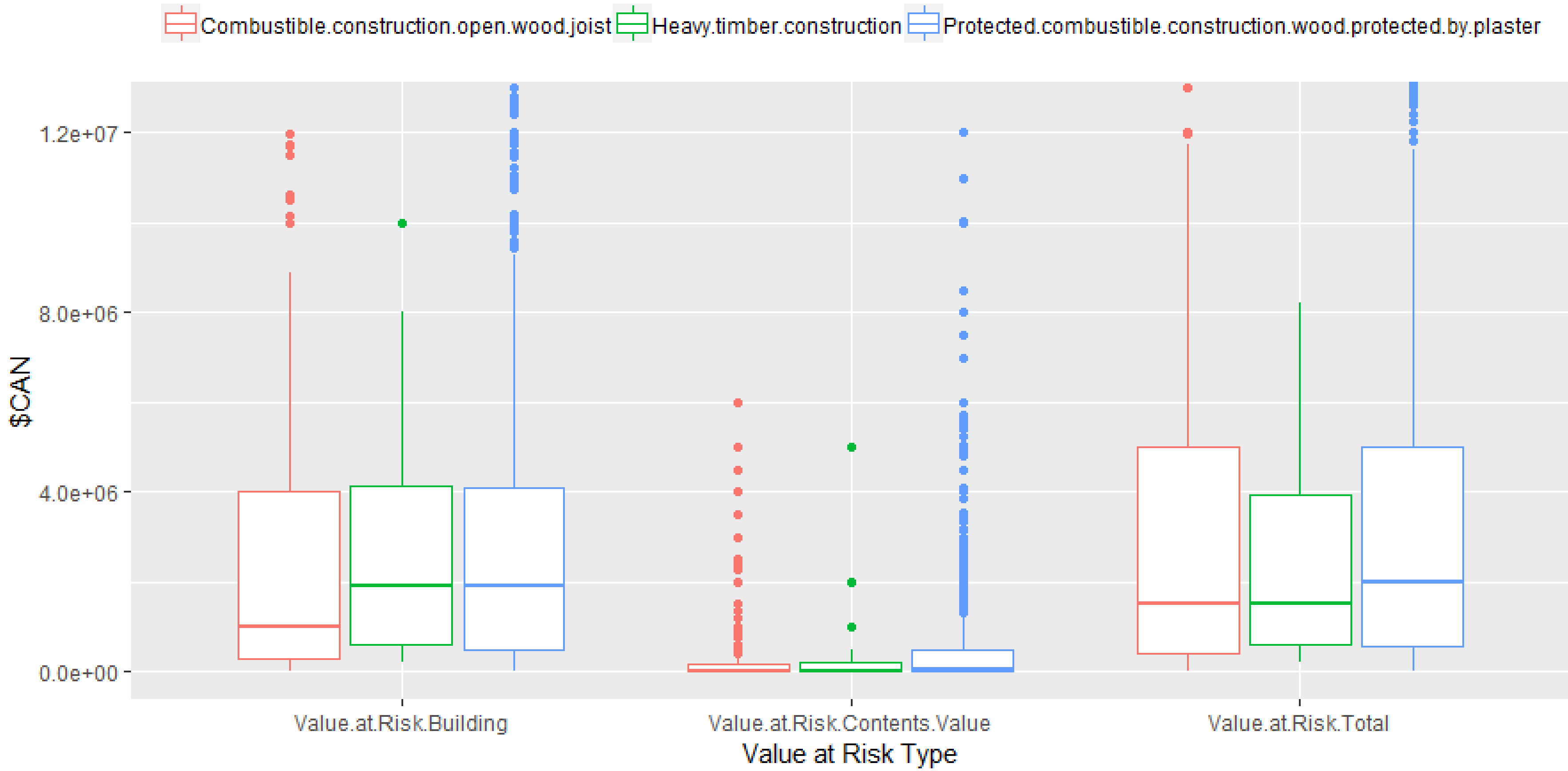


Figure 9. Box-and-whiskers plot by value at risk type combustible constructions, selected values, for the full distribution refer to Figure 26 in the appendix.

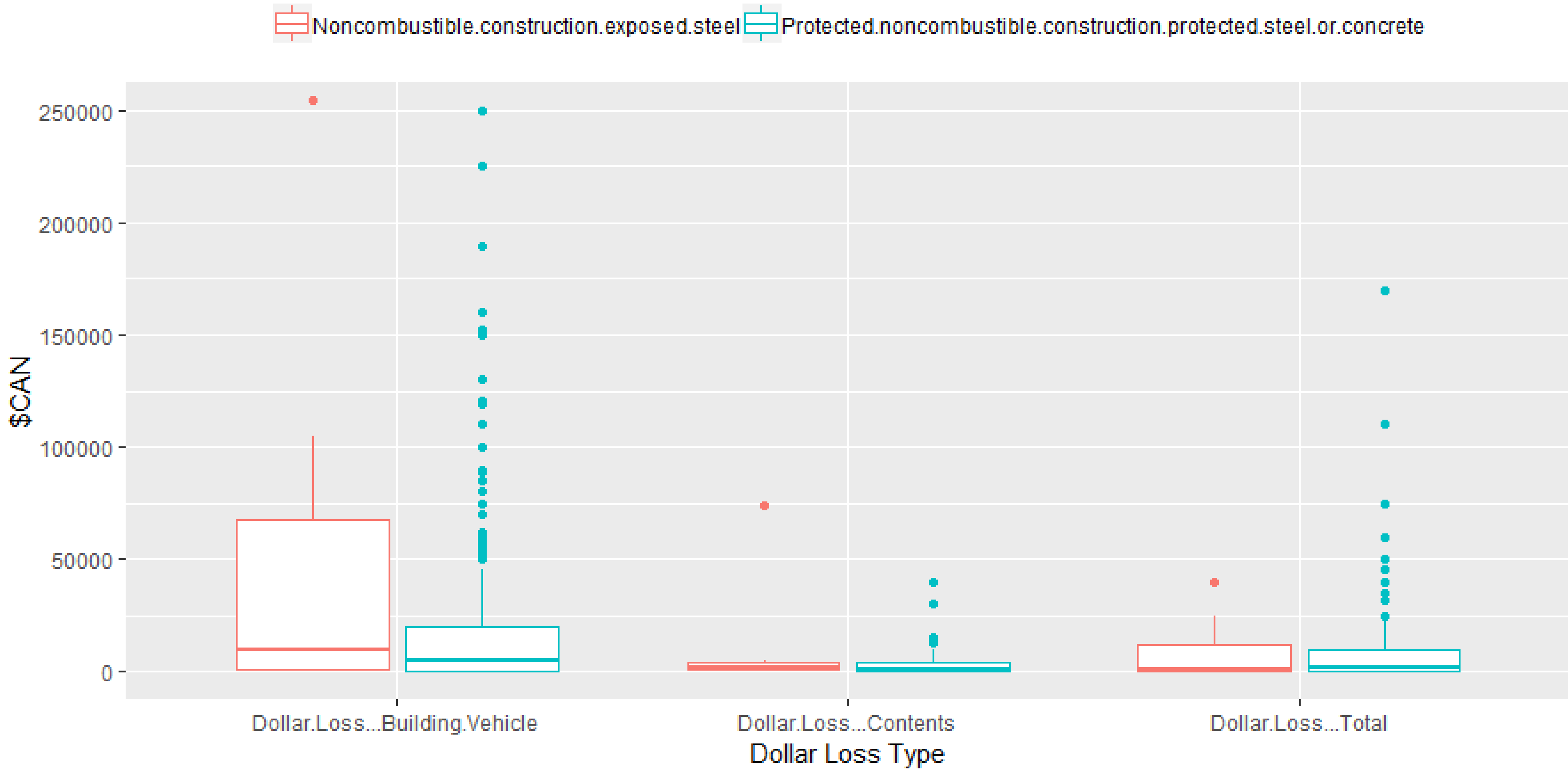


Figure 10. Box-and-whiskers plot by dollar loss type (in Canadian dollars) for non-combustible constructions, selected values, for the full distribution refer to Figure 27 in the appendix.

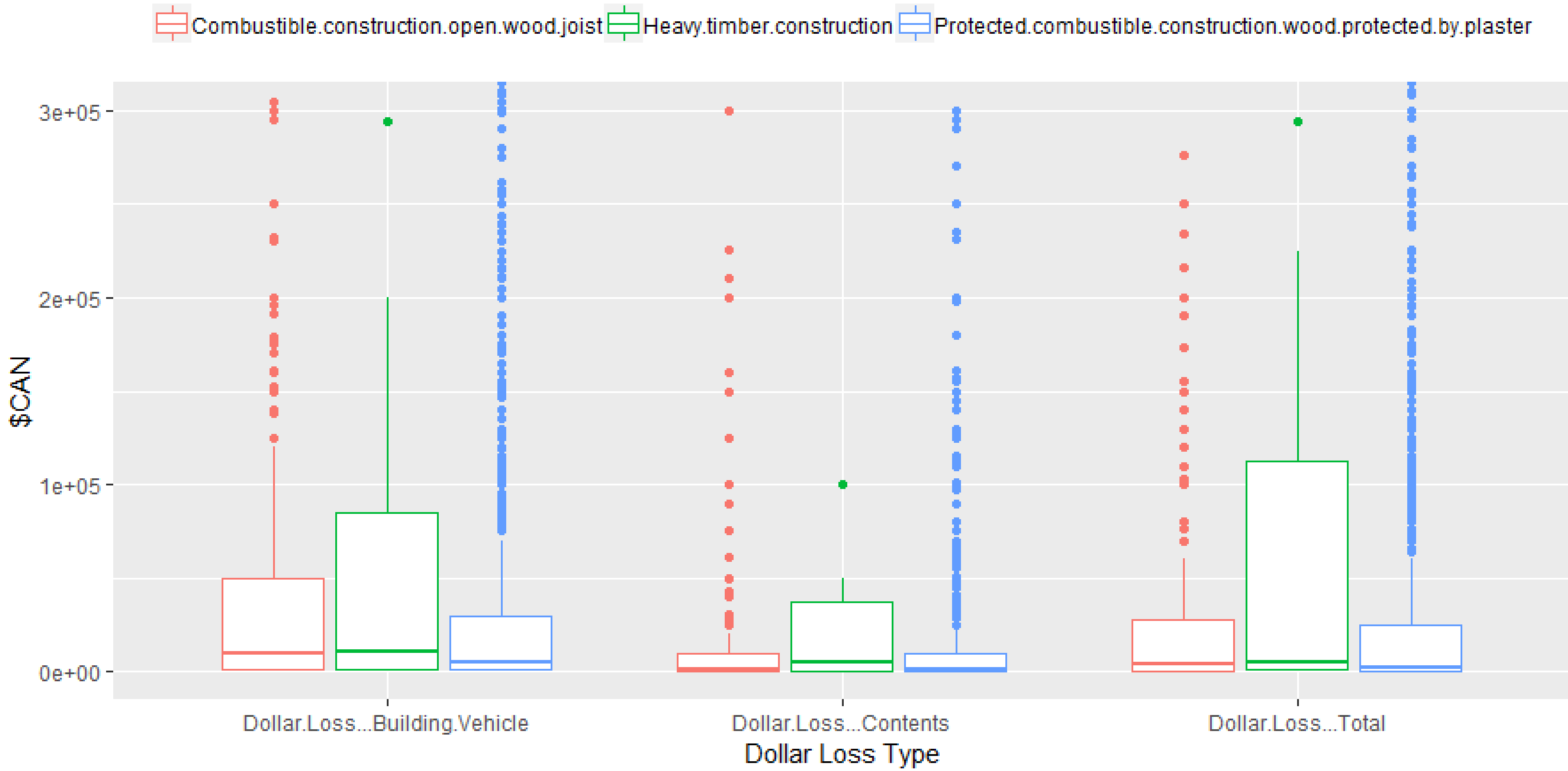


Figure 11. Box-and-whiskers plot by dollar loss type (in Canadian dollars) for combustible constructions, selected values, for the full distribution refer to Figure 28 in the appendix.

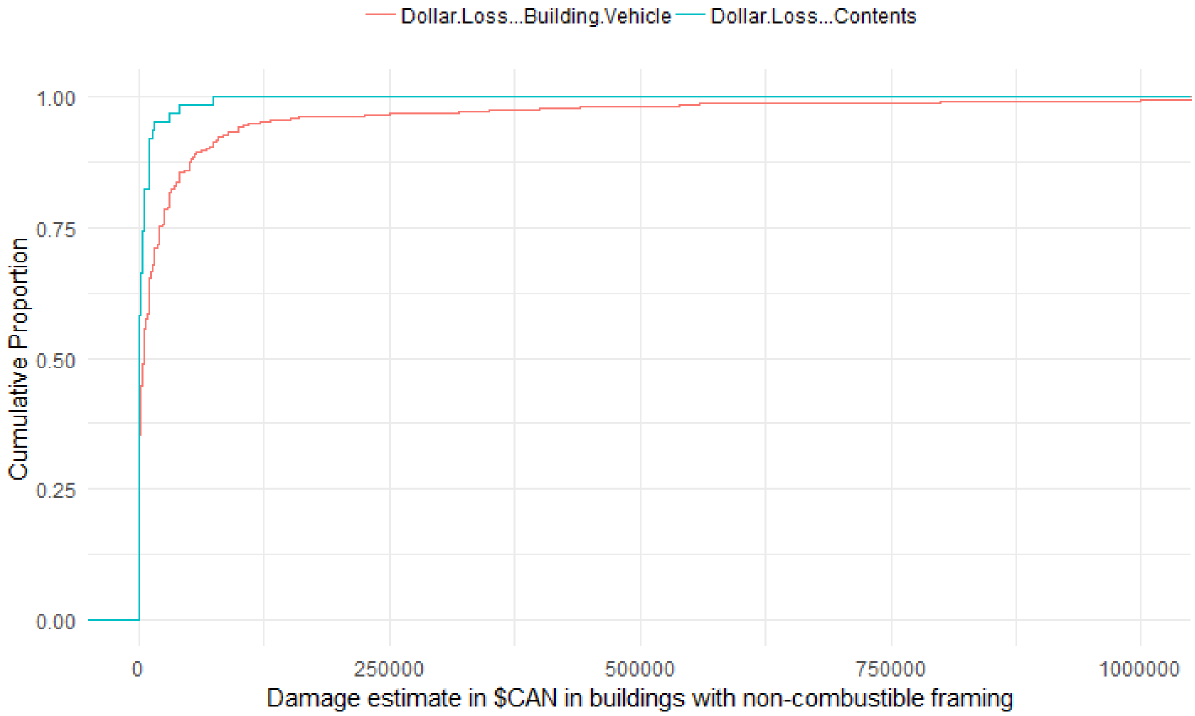


Figure 12. Cumulative distributions by dollar loss type (in Canadian dollars) in buildings with non-combustible framing.

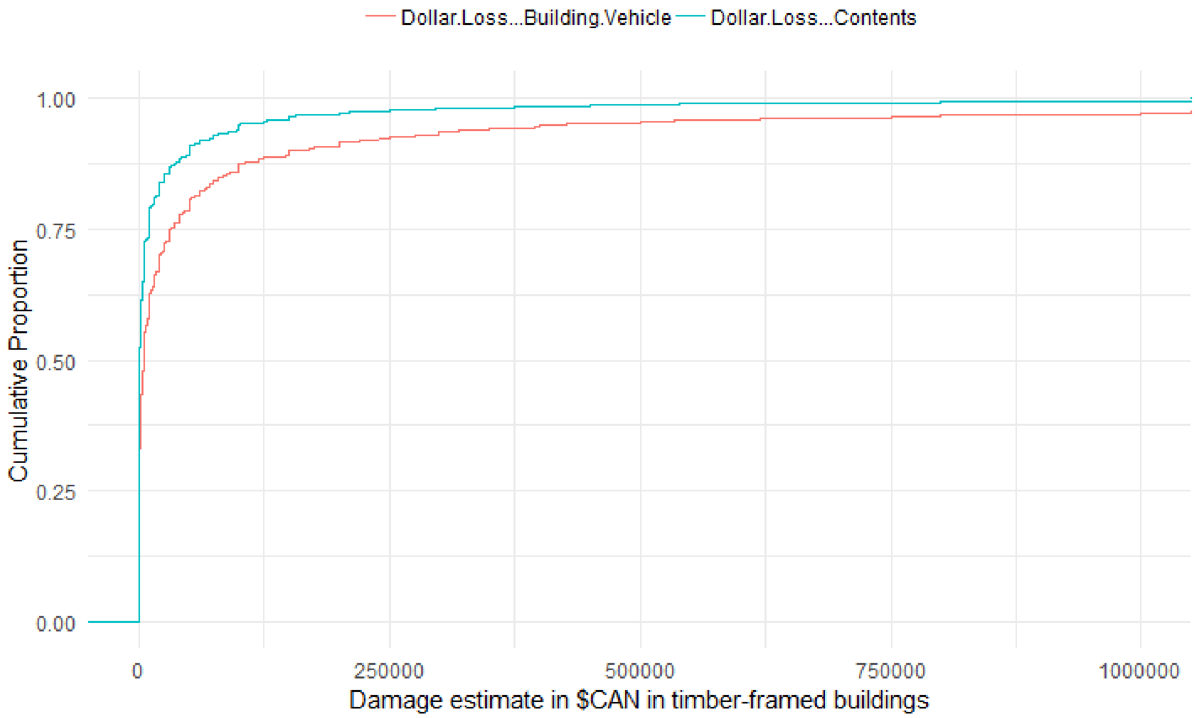


Figure 13. Cumulative distributions by dollar loss type (in Canadian dollars) in buildings with combustible framing.

5.1.2 Pearson Correlations with two-tailed t-test

Correlation is statistical tool that expresses to what extent two variables are, in a broad sense, linearly related, it describes the simple relation of how the variables change together at a constant rate. It does not go into details about cause and effect but can be useful as an indication of a predictive relationship. A common correlation coefficient (the numerical measurement of correlation) is Pearson's correlation coefficient, which only measures linear dependency between two continuous variables. The correlation may be present even if one variable is a nonlinear function to the other. Pearson's correlation assumes a normal distribution and random samples.

The correlation coefficient is tied to a probability, denoted p, which describes the likelihood that the correlation coefficient will be observed if no relationship exists between the two variables, in other words, that the correlation coefficient is significantly different from zero. Probability, p, is used to establish statistical significance, which is conditioned to a pre-set probability, in this analysis 0.05 is used to indicate the lowest level of statistical significance. In this instance, 0.05 indicates that there is a 5% chance that the correlation exists due to error or by coincidence. The value of p is calculated by using the degrees of freedom (sample size minus two) and a t-test which in turn is based on the correlation coefficient and sample size. By using correlations and looking at the resulting coefficients it is possible to draw conclusions on how a variable affects the recorded outcome by looking at the magnitude, direction and statistical significance of the coefficient.

In Table 16, tabulated values of correlation coefficients for buildings with non-combustible framing, and Table 17, combustible framing, Pearson's correlation coefficient for a selection of continuous variables are shown. The coefficient can vary between -1 and 1 where 0 is no correlation and 1 (positive or negative) a perfect linear dependency as previously stated in section 4.2. Statistical significance in the tables is illustrated with a set number of asterisks for a given probability. Bold underlined values are similar in both building types, italic underlined values differ in significance between building types, while larger font size indicates increasing correlation strength/a linear dependency.

Significance levels: *$p<0.05$; **$p<0.01$; ***$p<0.001$; ****$p<0.0001$

Table 16. Pearson's correlation coefficient for continuous variables in buildings with non-combustible framing between -1 and 1 where 0 is no correlation. Bold and underlined font in values that are significant (*) are similar in both building types, italic underlined values differ in significance between building types, while larger font size indicates correlation strength. Significance levels: *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

	1. Dollar loss contents [$CAN]	**2. Dollar loss building vehicle [$CAN]**	**3. Dollar loss total [$CAN]**	**4. Value at risk building [$CAN]**	**5. Value at risk contents value [$CAN]**	**6. Value at risk total [$CAN]**	**7. Number of floors**	**8. Years since construction**
1. Dollar loss building [$CAN]	**0.82********							
2. Dollar loss total [$CAN]	**0.84********	**1.00********						
3. Value at risk building [$CAN]	*-0.13*	*0*	*-0.06*					
4. Value at risk contents value [$CAN]	*-0.1*	*-0.02*	*-0.04*	**0.20*****				
5. Value at risk total [$CAN]	*-0.14*	*-0.05*	*-0.07*	**0.97********	**0.64********			
6. Number of floors	-0.12	-0.06	-0.06	**0.34********	**0.18********	*0.12*		
7. Years since construction	0.55	-0.17	-0.17	0.22	0.21	0.33	*0.33*	
8. Response time of first vehicle [min]	NA#	0.02	NA#	0.01	-0.03	NA#	-0.07	-0.11

#NA's due to missing values.

Table 17. Pearson's correlation coefficient for continuous variables in timber-framed buildings between -1 and 1 where 0 is no correlation. Bold and underlined font in values that are significant (*) are similar in both building types, italic underlined values differ in significance between building types, while larger font size indicates correlation strength. Significance levels: *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

	1. Dollar loss contents [$CAN]	2. Dollar loss building vehicle [$CAN]	3. Dollar loss total [$CAN]	4. Value at risk building [$CAN]	5. Value at risk contents value [$CAN]	6. Value at risk total [$CAN]	7. Number of floors	8. Years since construction
1. Dollar loss building [$CAN]	**0.64**** **							
2. Dollar loss total [$CAN]	**0.79**** **	**0.98**** **						
3. Value at risk building [$CAN]	*0.10*** **	*0.12*** **	*0.09*** **					
4. Value at risk contents value [$CAN]	*0.17*** **	*0.08*** **	*0.08*** **	**0.29**** **				
5. Value at risk total [$CAN]	*0.14*** **	*0.11*** **	*0.10*** **	**0.99**** **	**0.35**** **			
6. Number of floors	-0.02	-0.01	0.01	**0.13**** **	**0.20**** **	*0.08*** **		
7. Years since construction	0.02	0	0.09	0	0.01	0.03	*-0.20***	
8. Response time of first vehicle [min]	NA#	0.03	NA#	0	-0.01	NA#	0.02	0.28

#NA's due to missing values.

5.1.3 Observations from Pearson Correlations with two-tailed t-test

The correlations produced few results of interests, most are easy to guess intuitively.

The interesting variables years since construction and response time of first vehicle lacked data independently of building type and therefore it is hard to draw any conclusions. A weak negative correlation between years since construction and number of floors in timber-framed buildings can indicate that more recently built timber-framed buildings have an increasing number of floors which would be in line with new building regulations coming into effect recently, see Table 17 column 7, row 7.

One interesting difference between the building types is how in timber-framed buildings dollar loss and value at risk have weak positive correlations with strong significance, Table 17 column 2, rows 3, 4 and 5, that in itself is not surprising, but in building with non-combustible framing no such correlation seems to exist as shown in corresponding column and rows of Table 16. It is expected that with increased value at risk the dollar loss would also increase not taking building type into account. A mitigating factor could be that with increased value at risk, the level of fire protection would also increase since an increased level of protection could reduce the potential loss.

In this case of comparison however, the value at risk in buildings with non-combustible framing have a much larger span of distribution when compared to timber-framed buildings, refer to the median in column 4, row 3 of Table 14 and Table 15. That fact would impact any correlation with dollar loss, given that the difference between the dollar losses span of distribution in both building types is much smaller, refer to median in column 7, row 3 of Table 14 and Table 15.

The same is true for value at risk and number of floors, with an increasing number of floors the value at risk should follow, but a positive correlation is only present in timber-framed buildings in Table 17 column 6, row 6. This implicates that the value at risk could be reported incorrectly, or more probable, just differently in a case by case basis. For example, by apartment in some cases and by building in some. In timber-framed buildings this error can have less of an impact due to smaller structures.

In effect, the size of the dollar loss in comparison to the value at risk differ greatly between the building types and that could indicate that the difference between the populations compared are significant, this has to some extent been made clear by the summary statistics.

The next section 5.1.4 will include variables that are categorical as well as continuous, this will provide a basis for how a continuous variable like dollar loss is correlated to a categorical like construction type.

5.1.4 Ordinary least squares (OLS) regression analysis

The least-squares method is a standard approach in regression analysis to try to determine an approximate solution to many sets of equations (more equations than unknowns). In least squares, the best fit has the smallest sum of residuals (the difference between the observed value and fitted value provided by the model). Ordinary least squares regression is in statistics a linear least squares method that approximate unknown parameters in a linear regression model. OLS picks parameters of the linear function (model) from a set of explanatory variables (e.g. observed values of reported variables in NFID) by minimizing the sum of the squares of the differences of the dependent variables in the observed values and the predicted ones. Refer to previous section 4.2 for more information.

Simplified, OLS is summary statistics and Pearson correlations with extra steps, both are needed when making the calculations of an OLS-regression. OLS allows for multiple variables in a single model which is interesting given that many variables impact the outcome of a fire. The main difference from summary statistics being ANOVA (analysis of variance) that test how well fitted the model is compared to the observed values. The following regression models will include the categorical variable construction type as well as a selection of continuous and categorical variables which selection is based on the objective of this thesis, how firefighting and building characteristics impact damage due to fire. The upcoming model's section is termed after the variables it includes, see for example 5.1.4.2 Model 2 – Fixed systems and response time. By using OLS and looking at the results it is possible to draw conclusions on how a variable affects the recorded outcome by looking at the prediction, probability and validity of the model.

The models utilize logistic regression (a form of binary regression) to include categorical variables like construction type. Binary logistic models have a dependent variable with two possible values, here "0" and "1". The corresponding indicator variable is used as the baseline against which all included variables are measured, e.g. combustible construction "1" is compared to non-combustible construction "0".

The regression analysis is presented in the form of a series of tables, the first table for a model displays the dependent and independent variables, the second the regression results, the third a model accuracy assessment. Not all variables can be included in a single model, with each variable introduced the available amount of data is reduced due to missing values.

Listed in Table 19 below (page 52) are results from the log normal[3] transformed linear model where the dependent variable is Dollar Loss Building (estimated dollar value of damages caused by fire to the building). Each 1-unit increase in X multiplies the expected value of Y by e^{β}, except for X=Log(Value at Risk Building), where multiplying X (unlogged) by e is equal to multiplying Y (unlogged) by e^{β}, refer to Table 19 for an interpretation. The general equation is written in this form:

$Log(Y_i\text{=Dollar Loss Building}) = \text{Intercept} + \beta_1 Log(X_1) + \beta_2 * X_2 + \beta_3 * X_3 \ldots.$

Logarithmically transforming variables in a regression model is one way to address non-linear relationships between the independent and dependent variables. Using the logarithm of variables makes the effective relationship non-linear, while still preserving the linear model. Logarithmic transforming can cause a skewed variable to turn into one that is more normally distributed (Benoit, 2011).

The same is true for all regression models presented.

[3] Fire loss is assumed to be a log normal distribution, this gives a model with better accuracy and has been used in previous studies, see (Ramachandra, 1974).

5.1.4.1 Model 1 – Smoke and spread of fire

The variables in Table 18 are based in factors of general construction, number of floors, smoke and fire spread, if the fire was incendiary and the value at risk for the building.

Table 18. Variables included in the regression analysis.

Variable	Description
	Dependent, Y
Log(Dollar Loss Building)	Natural logarithm of estimated dollar value of damages caused by fire to the building.
	Independent, X_i
General Construction	Factor variable, indicates combustible construction.
Number of Floors	Continuous numeric variable.
Flame Spread Horizontal Openings	Factor variable, indicates if flame spread through horizontal openings is a factor.
Flame Spread Vertical Openings	Factor variable, indicates if flame spread through vertical openings is a factor.
Flame Spread Interior Finish	Factor variable, indicates if flame spread on interior finish is a factor.
Smoke Spread	Factor variable, indicates if smoke spread is a factor.
Extent of Fire	Factor variable, indicates if the fire extends beyond the area of origin.
Extent of Damage	Factor variable, indicates if the damage caused by the fire extends beyond the area of origin.
Act of Omission Group	Factor variable, indicates if the fire is classified as incendiary.
Log(Value at Risk Building)	Natural logarithm of estimated dollar value of the building.

As shown below in Table 19, if smoke and fire spread was a factor it increased the expected loss to a large extent. When the fire was classified as incendiary the expected loss decreased slightly. When the value at risk increased the expected loss increased marginally. Variables general construction and number of floors were not significant.

Table 19. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, *β*	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	5.11	0.66	7.77	0.00***	Expected Y for all X=0
General construction (Combustible construction)	-0.08	0.24	-0.33	0.74	Not significant
Number of Floors	-0.01	0.02	-0.54	0.59	Not significant
Flame Spread Horizontal Openings	1.20	0.29	4.10	0.00***	1-unit increase in X =3.32*Y=+220% in Y
Flame Spread Vertical Openings	0.91	0.29	3.19	0.002**	1-unit increase in X =2.50*Y=+150% in Y
Flame Spread Interior Finish	0.85	0.15	5.50	0.00***	1-unit increase in X =2.34*Y=+134% in Y
Smoke Spread	0.17	0.14	1.18	0.24	Not significant
Extent of Fire (outside area of origin)	0.76	0.26	2.94	0.003**	1-unit increase in X =2.14*Y=+114% in Y
Extent of Damage (outside of area of origin)	1.83	0.17	10.82	0.00***	1-unit increase in X =2.5*Y=+150% in Y
Act of Omission Group (incendiary)	-0.48	0.18	-2.63	0.009**	1-unit increase in X =0.62*Y=-38% in Y
Log(Value at Risk Building)	0.12	0.04	3.05	0.002**	10% increase in X≈1% in Y

The ANOVA in Table 20 shows a relatively good fit with a large portion of the observed values (variance) explained by the model, however only 740 values where included in the model, the rest were deleted due to missing values.

Table 20. Model accuracy assessment.

Model accuracy assessment (ANOVA)				
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.4423	0.4348	1.884	58.62 on 10 739 Degrees of freedom	< 2.2e^-16
Interpretation				
Roughly 40% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 23% error rate.	P-value of the F-statistic 58.62 is smaller than 0.001 and therefore we can reject that additional variables provide no value. 7283 observations deleted due to missingness.	Significant, coefficients included in model improved the model’s fit.

5.1.4.2 Model 2 – Fixed systems and response time

The variables in Table 21 are based in factors of general construction, fixed systems and response time of the first vehicle.

Table 21. Variables included in the regression analysis.

Variable	Description
	Dependent, Y
Log(Dollar Loss Building)	Natural logarithm of estimated dollar value of damages caused by fire to the building.
	Independent, X_i
General Construction	Factor variable, indicates combustible construction.
Sprinkler Protection	Factor variable, indicates if the building is not completely sprinkler protected.
Fixed System Other Than Sprinkler	Factor variable, indicates if the building has no other fixed system.
Automatic Fire Detection System	Factor variable, indicates if the building is not equipped with a central alarm.
Fire Detection Devices	Factor variable, indicates if no detection devices were installed.
Response Time of First Vehicle	Continuous numeric variable.

No independent variables in where significant as shown in Table 22.

Table 22. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, β	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	8.12	0.27	30.16	0.00***	Expected Y for all X=0
General construction (Combustible construction)	0.18	0.20	0.93	0.35	Not significant
Sprinkler Protection (No)	-0.05	0.19	-0.25	0.81	Not significant
Fixed System Other Than Sprinkler (No)	-0.15	0.19	-0.80	0.42	Not significant
Automatic Fire Detection System (No)	0.32	0.21	1.54	0.12	Not significant
Fire Detection Devices (No)	0.63	0.39	1.61	0.11	Not significant
Response Time of First Vehicle	0.00	0.01	-0.05	0.96	Not significant

The model proved to be a poor fit, none of the independent variables in the model seemed to have an impact on the expected loss, refer to Table 23 below.

Table 23. Model accuracy assessment.

Model accuracy assessment (ANOVA)				
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.005872	0.001528	2.578	1.352 on 6 1373 Degrees of freedom	< 0.23
Interpretation				
Roughly 0.5% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 32% error rate.	P-value of the F-statistic 2.352 is larger than 0.001 and therefore we cannot reject that additional variables provide no value. 6653 observations deleted due to missingness.	Not significant

Figure 14 below might provide some insight on why, for example, sprinkler protection does not seem to have an impact in 5.1.4.2 Model 2 – Fixed systems and response time.

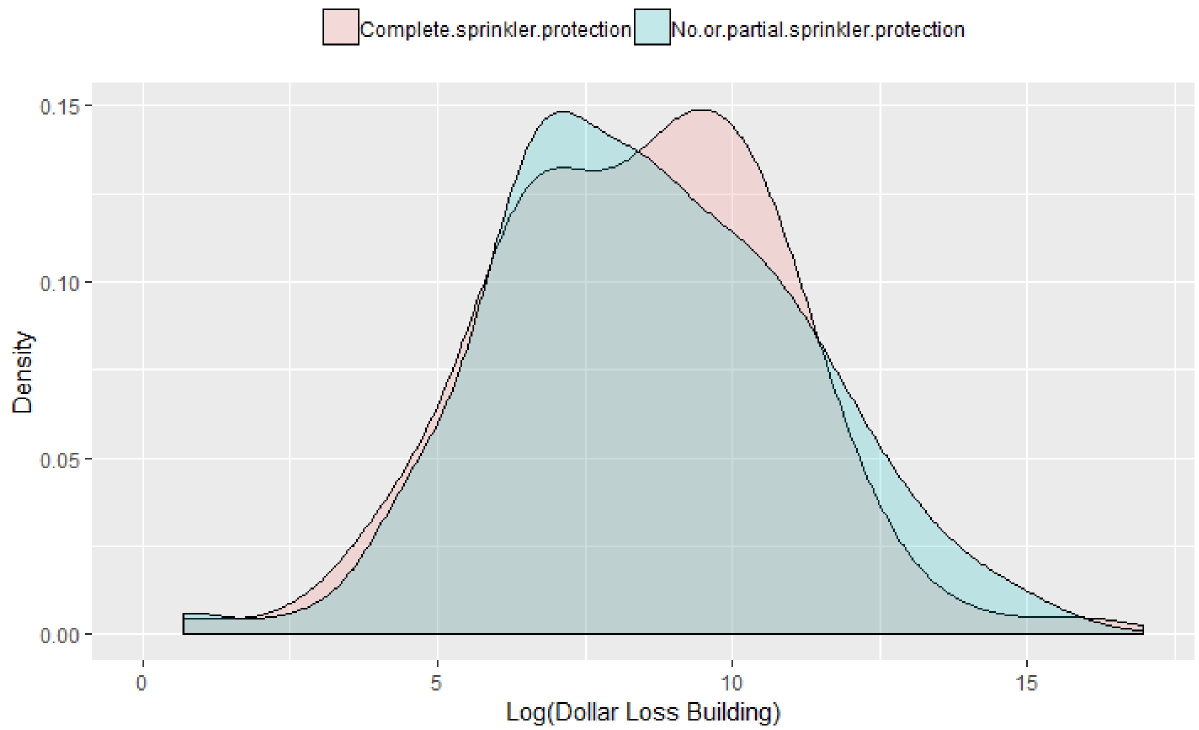


Figure 14. The density of the lognormal distribution of dollar loss building in buildings with and without complete sprinkler protection.

The right-left skewing of the distributions is somewhat inverted, canceling each other out. No or partial sprinkler protection owns a larger portion of the major contributions to dollar loss, but a significant part of complete sprinkler protection owns the mid to higher end of the curve. A theory is that complete sprinkler protection is associated with a higher value at risk and which has been shown previously to be significantly correlated to dollar loss, but not in all construction types.

5.1.4.3 Model 3 – Outside fire protection

Table 24 includes the independent variables general construction and outside fire protection.

Table 24. Variables included in the regression analysis.

Variable	Description
	Dependent, Y
Log(Dollar Loss Building)	Natural logarithm of estimated dollar value of damages caused by fire to the building.
	Independent, X_i
General Construction	Factor variable, indicates combustible construction.
Outside Fire Protection	Factor variable, indicates if <u>no</u> hydrant was available.

Table 25 shows positive and significant correlations in all independent factor variables. The probability of general construction being significant is in the lower end.

Table 25. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, *β*	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	8.24	0.12	68.20	0.00***	Expected Y for all X=0
General construction (Combustible construction)	0.31	0.13	2.42	0.02*	1-unit increase in X =1.36 *Y=+36% in Y
Outside Fire Protection (No hydrant)	0.89	0.20	4.54	0.00***	1-unit increase in X =2.43*Y=+143% in Y

Table 26 shows a poor grade of explanation for variance of the observed values but a significant model none the less.

Table 26. Model accuracy assessment.

		Model accuracy assessment (ANOVA)		
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.005692	0.005267	2.577	13.4 on 6 4682 Degrees of freedom	< 0.1572e^-6
		Interpretation		
Roughly 0.5% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 30% error rate.	P-value of the F-statistic 13.4 is smaller than 0.001 and therefore we can reject that additional variables provide no value. 3348 observations deleted due to missingness.	Significant, coefficients included in model improved the model's fit.

Figure 15 show a different left-right skewing when compared to Figure 14. The difference is clear, but it should be noted is based on a small sample considering the number of buildings without fire hydrants is limited, refer to Table 43. The variable in itself can create effects, no hydrant is probably rarely reported, not only because there are few buildings lacking fire hydrants within a reasonably short distance from a fire station but it might only be reported if it was a large contributing factor in the outcome of the fire. Most likely, lack of hydrant protection is more prevalent outside of cities where smaller structures are more common, which are more often timber framed, which in turn impact the significance level of the general construction variable. Assumptions made above is supported by the statistics presented in this thesis (prevalence of hydrant protection and timber-framed buildings being smaller).

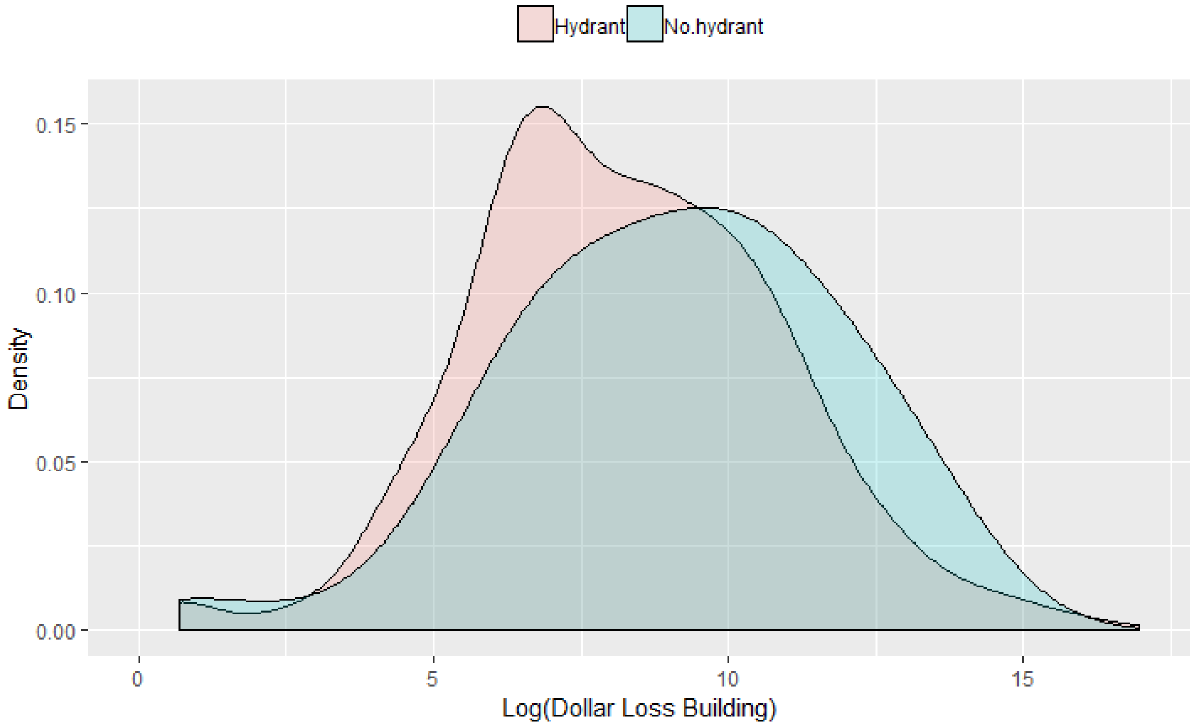


Figure 15. The density of the lognormal distribution of dollar loss building in buildings with and without hydrants.

5.1.4.4 Model 4 – Manual fire protection facilities

Table 27 show included independent variables general construction and the availability of manual fire protection facilities.

Table 27. Variables included in the regression analysis.

Variable	Description
	Dependent, Y
Log(Dollar Loss Building)	Natural logarithm of estimated dollar value of damages caused by fire to the building.
	Independent, X_i
General Construction	Factor variable, indicates combustible construction.
Manual Fire Protection Facilities	Factor variable, indicates if <u>no</u> manual firefighting equipment was available.

Table 28 shows positive and significant correlation in the independent factor variable for manual fire protection facilities.

Table 28. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, *β*	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	8.12	0.13	64.60	0.00***	Expected Y for all X=0
General construction (Combustible construction)	0.25	0.13	1.90	0.06	Not significant
Manual Fire Protection Facilities (No)	1.00	0.10	10.23	0.00***	1-unit increase in X =2.72*Y=+272% in Y

Table 29 shows a slightly less poor grade of explanation for variance of the observed values when compared to Table 26 and a significant model.

Table 29. Model accuracy assessment.

Model accuracy assessment (ANOVA)				
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.02618	0.02572	2.537	57.07 on 2 4246 Degrees of freedom	< 2.2e^-16
Interpretation				
Roughly 2% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 30% error rate.	P-value of the F-statistic 57.07 is smaller than 0.001 and therefore we can reject that additional variables provide no value. 3784 observations deleted due to missingness.	Significant, coefficients included in model improved the model’s fit.

The above results for manual fire protection facilities as well as fire hydrants are easy to guess intuitively but are hereby used to illustrate the different impact choice of variables can have on the results of the model.

5.2 Finland

The available fire loss data covered fires in residential buildings with at least three stories in Finland during 1996-2018 in two split datasets (1996-1999, 2000-2018). Economic losses are estimated (in Euros) in two categories', building and property. Building loss includes damages to building structures, property loss indicates the damages to moveable belongings in the building.

Total recorded losses during the recorded years is in the range of 141 million Euros, in comparison that is less than half the yearly average of estimated total direct fire losses in Finland as reported by The Geneva Association.

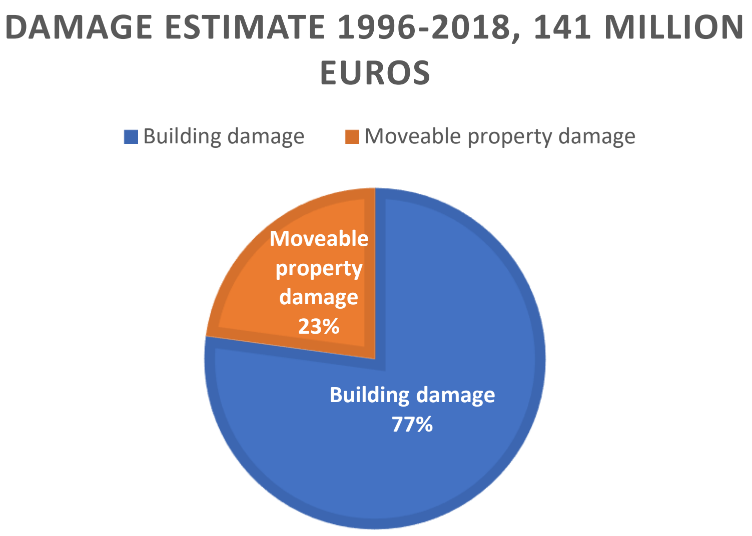


Figure 16. Estimated euro loss in all incidents independent of type of construction.

Recorded losses included consequential losses due to interruptions for years 2000-2008, unfortunately, it is not always recorded and is seldom recorded in residential buildings, and most of it is accrued in other building uses that naturally has more potential of such losses like industrial and warehouse buildings and it is therefore not included here.

Material of the load bearing structure is also seldom reported. One possible workaround this is to look at class P1- and P2-buildings separately. P1-buildings of at least three stories are always constructed using non-combustible materials due to class constraints, see 2.2.1, while class P2 allows for combustible materials but with constraints on total building area and fire compartment area. This can undoubtedly lead to P2 non-combustible buildings being accounted for as combustible, however, if steel or concrete is used it would be beneficial to have the building in class P1 which allows for no limitations of total floor area and restrictions in regards to firecell area and insulating materials/surface linings. How building class data is recorded is not known, e.g. building records from when the building was constructed or assessment on site, and any error is therefore hard to estimate.

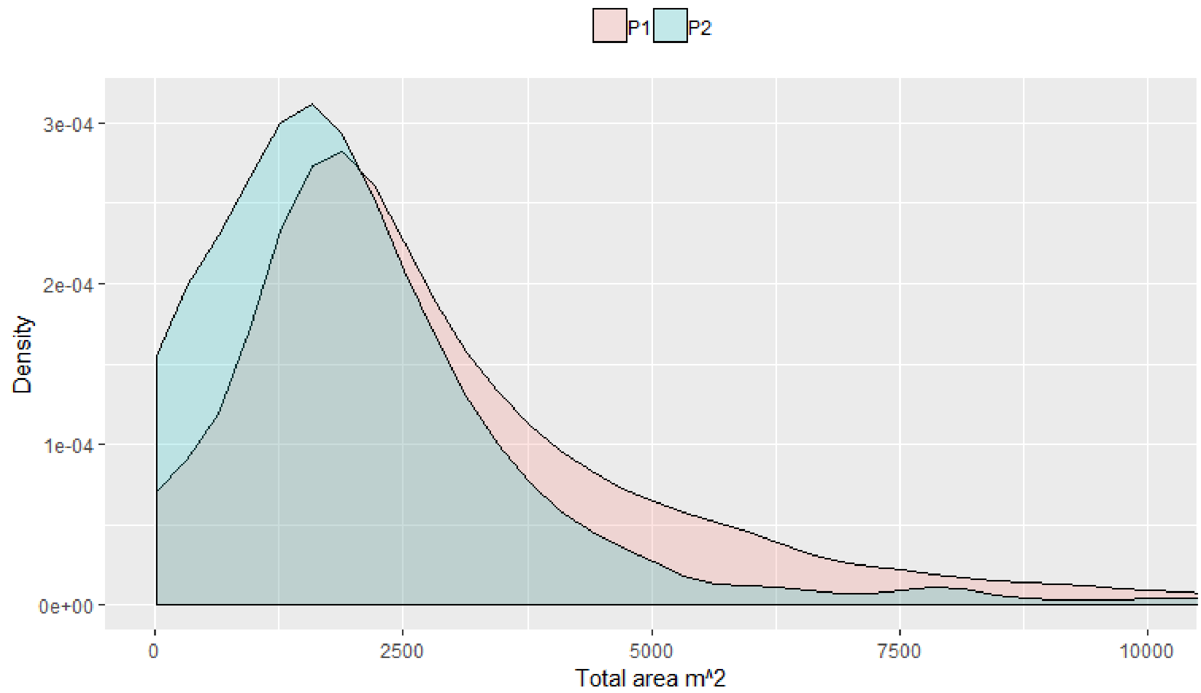


Figure 17. Density of total area of the building in class P1 and P2.

The skewing of class P2 to the left indicates that P2-buildings are often smaller which makes sense in the context of the Finnish regulatory requirements.

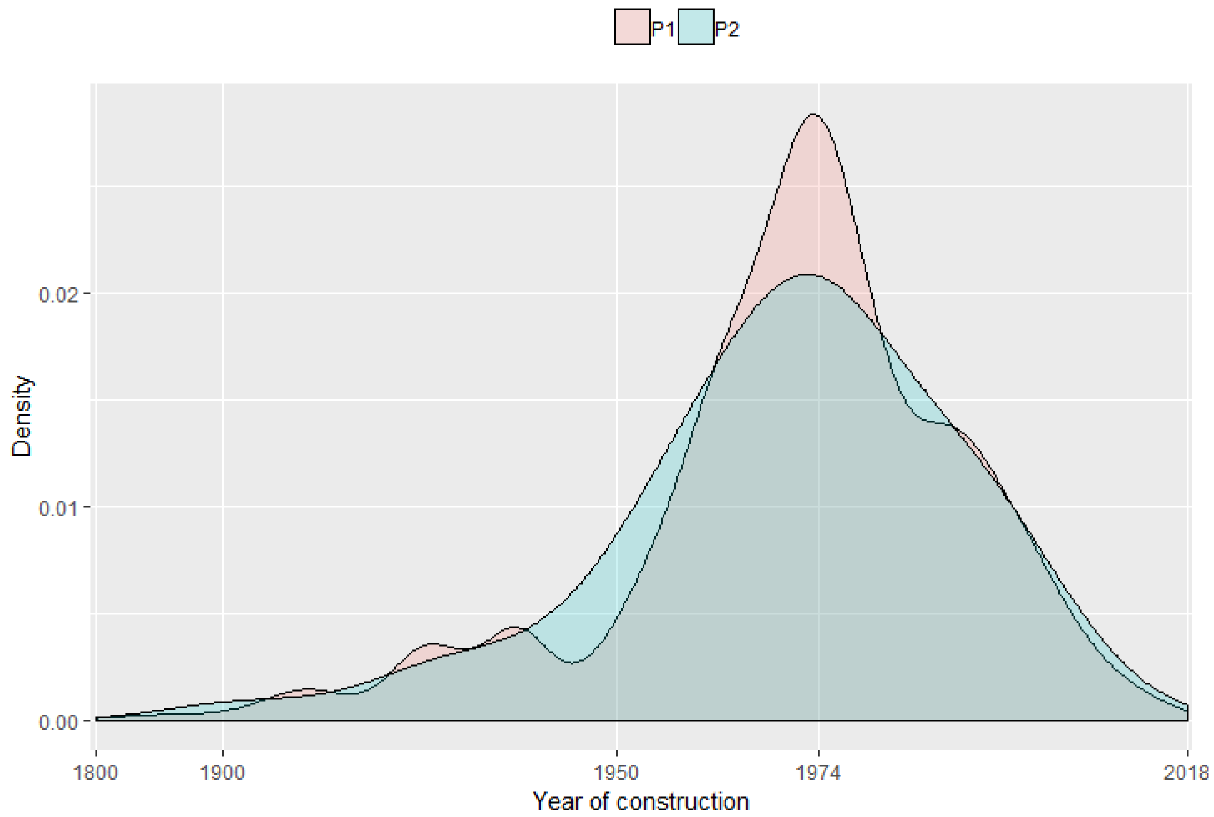


Figure 18. Density of year of construction in P1- and P2-buildings. Significant parts of the building stock are divided in pre and post 1974. Most buildings built before 1974 and later into the 80's has likely been renovated since.

Summary statistics (when applicable) following this paragraph include data from 2000-2018 in P1- and/or P2-buildings only and statistics recorded before is disregarded due to small sample size of P2-buildings. This is in line with expectations given class constraints and recent changes in the building code in Finland.

5.2.1 Summary statistics with references to figures and tables

In Table 30 and Table 31 (pages 63 and 64) summary statistics on continuous variables are shown by building class. The variable (years since construction) shown in both tables below are calculated as the difference of the recorded value year of construction and the year of the incident. As you can see in the tables below and in the appendix 7393 and 516 values out of 12 783 and 719 are missing.

Following the tables are box-and-whiskers plots. The plots are divided into damage type categories for easier comparison. For each plot there are two versions, one showing the entire distribution (refer to the appendix Figure 29 Figure 30, Figure 31, Figure 32 and Figure 33) and one showing a smaller sample, see Figure 19 and Figure 20 below (page 65), to visualize more clearly the nuances of the distributions, if all outliers are shown the boxes become very small.

The summary statistics chapter closes with a comparison of cumulative functions of euro loss by type as well as damage area and firecell area in P2- and P1-buildings, see Figure 21, Figure 22, Figure 23 and Figure 24 (pages 66 and 67).

Box-and-whiskers plots, tabulated values describing the distributions and cumulative distribution functions follows this short summary of observations. The summary statistics section covers a comparison of response time (time to first unit on site), building age (years since construction), total number of responders, number of floors, floor of origin, building area (total area), fire compartment area (area of firecell), area of space where ignition occurred, building damage (in euro), damage to movable property (in euro), estimation of quantity of water and the total damage area. All continuous variables in P1 versus P2-buildings.

In general, P2-buildings in the gathered statistics are or have when compared to P1-buildings:

1. **Longer response time for the rescue service.**
   The median, mean and 3rd quantile for P2-buildings are higher compared to P1-buildings see Table 30 and Table 31 column 1.
2. **Usually around the same building age.**
   The rate of construction seems constant enough with a peak around 1974 as shown in Figure 18 (page 59). If the ration between the building stock of P1 and P2 is constant and if the probability of a fire is assumed constant across the building stock the difference (if any) between P1 and P2 variable *years since construction* should remain constant, see Table 30 and Table 31 column 2.
3. **Fires that evoke a smaller rescue service response.**
   Refer to median, mean, 3rd quantile and max of Table 30 and Table 31 in column 3. This variable should depend on the availability of resources and the value at risk as previously mentioned in 3.1.3, however we know very little about those two in this case. P1-buildings are generally larger as shown below, which indicates a difference in value at risk.
4. **Only a minor difference in building height.**
   The difference is much less prominent when compared to buildings in Canada as shown in the precious section 5.1. P2-buildings being most likely of combustible construction having slightly less floors compared to P1-buildings. See median, mean and 3rd quantile in Table 30 and Table 31 column 4.
5. **Have a smaller total area.**
   This is expected and in line with Finnish building regulations. In most cases a larger floor area would indicate a large value at risk. See Table 30 and Table 31 column 6.
6. **About the same firecell area.**
   If building use is the same in P1- and P2-buildings this variable should be quite similar when compared, i.e. apartments are compared to other apartments and not detached houses to apartments. See Table 30 and Table 31 column 7.
7. **About the same area of space where ignition occurred.**
   The same argumentation applies here as in the firecell area above.
8. **About the same damage (euro loss) regardless of type.**
   The 1st quantile, median, mean and 3rd quantile are not significantly different in column 9. Column 10 does ha differences but outliers are a factor, compare max in row 6 of Table 30 and Table 31.
9. **Considerably lower estimation of quantity of water**.
   This is caused by outliers; most values are 0 or close to 0. Probably not a very trustworthy variable given the discrepancies in how it is reported.
10. **A smaller recorded total damage area.**
    This is probably due to the difference in total area, P1-buildings being larger. However, area of space where ignition occurred and area of firecell does not indicate a size difference, refer to columns 6, 7, 8 and 12 of Table 30 and Table 31. P1 does have a larger portion of the mid-range and more outliers, but the variable sample is also the smallest sample and is therefore the most unreliable.

The cumulative distributions for estimated euro loss are the same as in Canada, P2 or buildings with combustible framing have a larger portion of the bigger losses. Size of firecell and total damage area contain relatively few values, especially in P2-buildings, but as shown in Figure 23 and Figure 24, firecell area seems to cross the function for total damage area later in P2-buildings which could indicate that P2-buildings comprise of more single firecell structures. As in, when total damage area is larger than the firecell area we can have a spread beyond the first compartment firecell.

Outliers are also a factor that is relevant to note as shown in the box-and-whiskers plots. Rerecorded incidents in P2-buildings spike in recent years, the only conclusion is that is in part caused by how statistics are gathered. One could attribute it to an increase in the number of P2-buildings in line with

Finnish building regulations, i.e. more timber-framing, but that does not rhyme well with the recoded years since construction in P2-buildings.

Table 30. Summary statistics continuous variables for building class P1 2000-2018, N=12783.

	1. Time to first unit on site* [s]	2. Years since construction	3. Total number of responders	4. Number of floors	5. Floor of origin	6. Total area [m^2]	7. Area of firecell [m^2] (added 2009)	8. Area of space where ignition occurred (added 2009)	9. Building damage [Euro]	10. Damage to moveable property [Euro]	11. Estimation of quantity of water [m^3]	12. Total damage area [m^3]
1. Min.	15	0	1	3	-2	10	0	0	0	0	0	0
2. 1st Qu.	275	22	4	3	1	1500	30	5	50	0	0	5
3. Median	349	34	7	4	2	2327	45	10	2000	600	1	35
4. Mean	374.7	35.7	10.5	4.9	2.7	3142	53.4	18.4	15 778	4194	4.2	68.4
5. 3rd Qu.	444	45	16	6	4	3899	60	20	11 890	3000	2	60
6. Max	4444	208	308	25	30#	60 000	5000	3006	1 860 460	1 856 784	1000	4417
7. NA's	1500	7393	1619	2	4669	1169	3816	3816	6889	6889	852	10 604

*Single digit and zeroes are counted as NA's.
#Does not add up given number of floors.

Table 31. Summary statistics continuous variables for building class P2 2000-2018, N=719.

	1. Time to first unit on site* [s]	2. Years since construction	3. Total number of responders	4. Number of floors	5. Floor of origin	6. Total area [m^2]	7. Area of firecell [m^2] (added 2009)	8. Area of space where ignition occurred (added 2009)	9. Building damage [Euro]	10. Damage to moveable property [Euro]	11. Estimation of quantity of water [m^3]	12. Total damage area [m^3]
1. Min.	69	0	1	3	0	15	0	0	0	0	0	0
2. 1st Qu.	299	24.5	4	3	1	1000	5	5	10	0	0	3.5
3. Median	374	36	6	3	2	1679	45	10	2000	450	0	25
4. Mean	410.9	37.4	8.4	4.2	2.5	2159	52.9	18.5	15 951	3203	0.9	50.2
5. 3rd Qu.	475	47.5	11	5	3	2599	60	20	10 000	2000	0	50
6. Max	1731	107	46	15	30*	35 000	940	600	570 000	82 000	50	650
7. NA's	38	516	45	1	232	80	164	164	485	485	246	640

*Does not add up given number of floors.

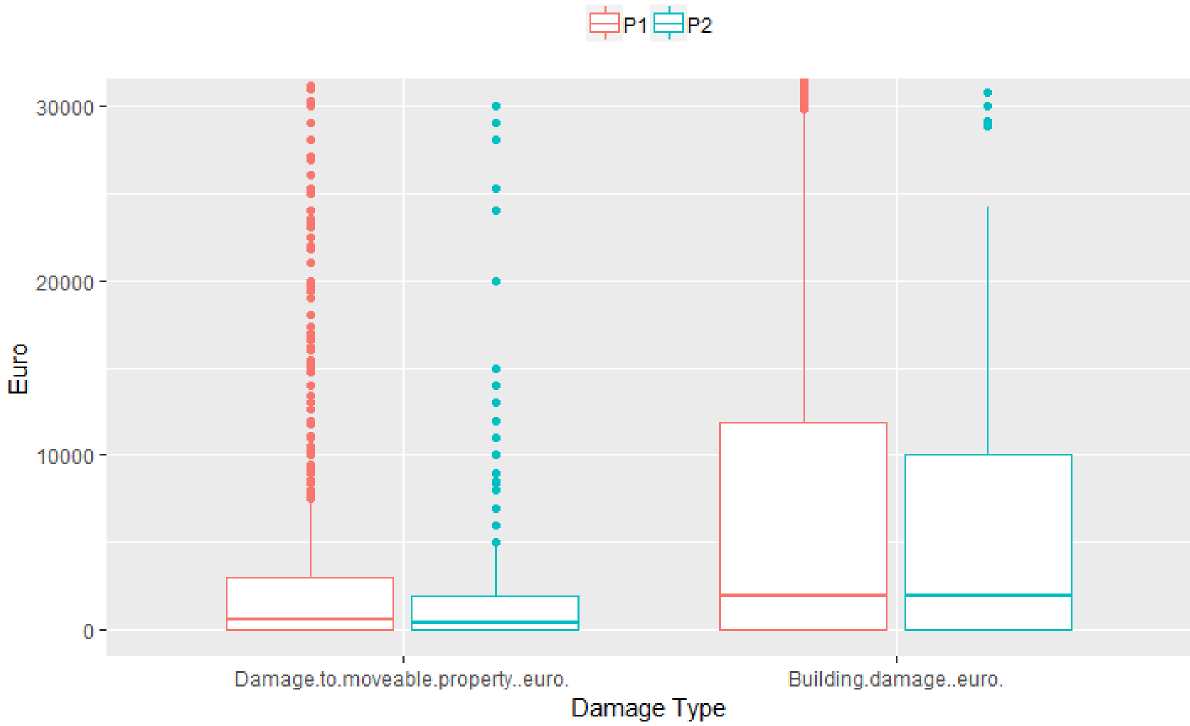


Figure 19. Box-and-whiskers plot by damage type in P1- and P2-buildings. 50% of reported values are zero or close to zero, most values are NA. Selected values, for the full distributions refer to Figure 29 and additional information in the appendix.

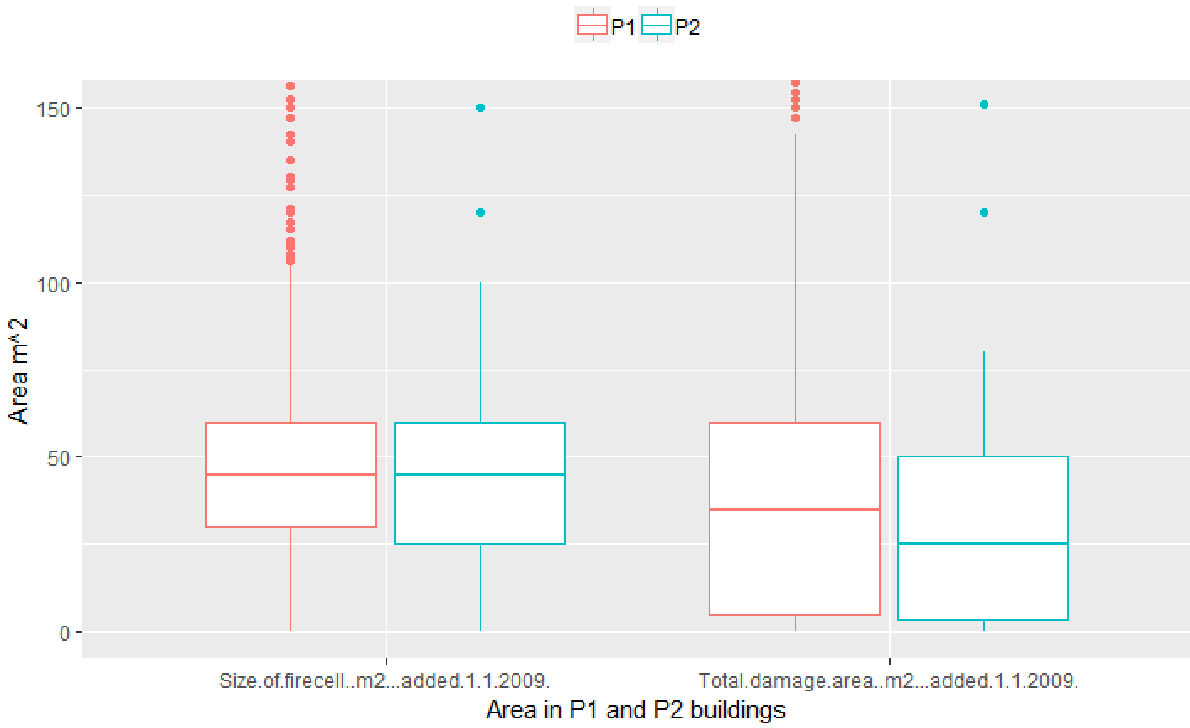


Figure 20. Box-and-whiskers plot by size of firecell and total damage area in P1- and P2-buildings. When recorded the value is often not zero but NA, the parameter was added in 2009 and contains relatively few values. Selected values, for the full distributions refer to Figure 31 and additional information in the appendix.

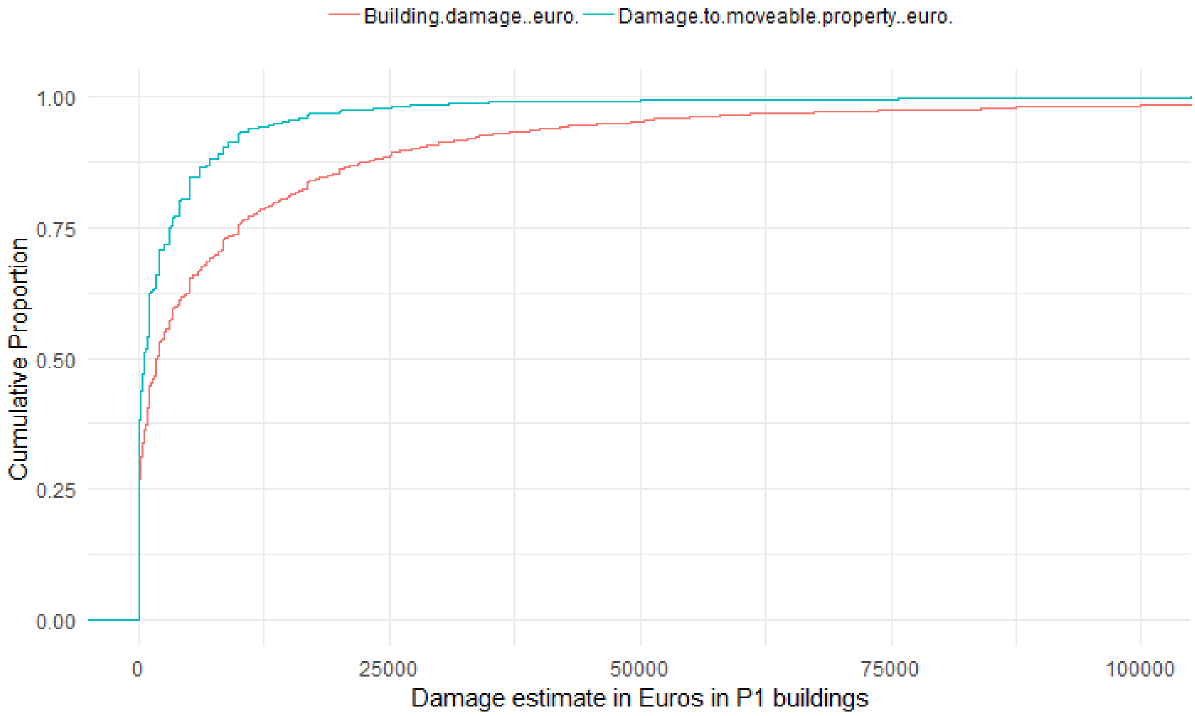


Figure 21. Cumulative distribution by damage type in P1-buildings 2000-2018.

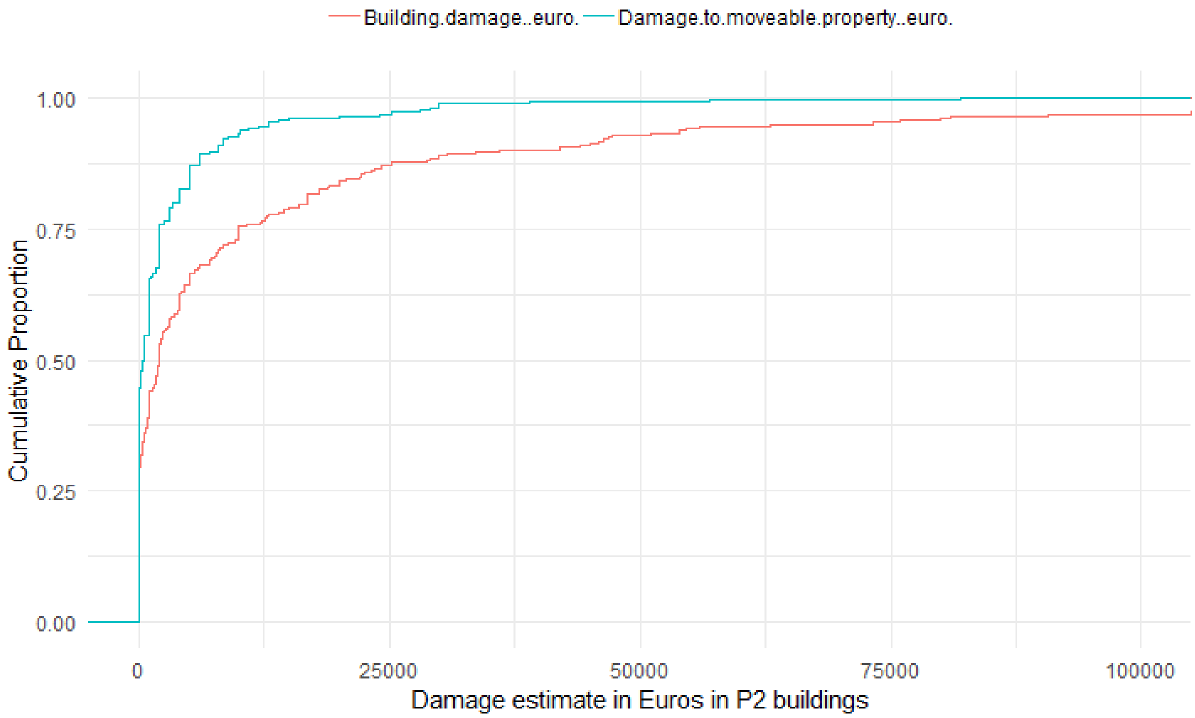


Figure 22 Cumulative distribution by damage type in P2-buildings 2000-2018.

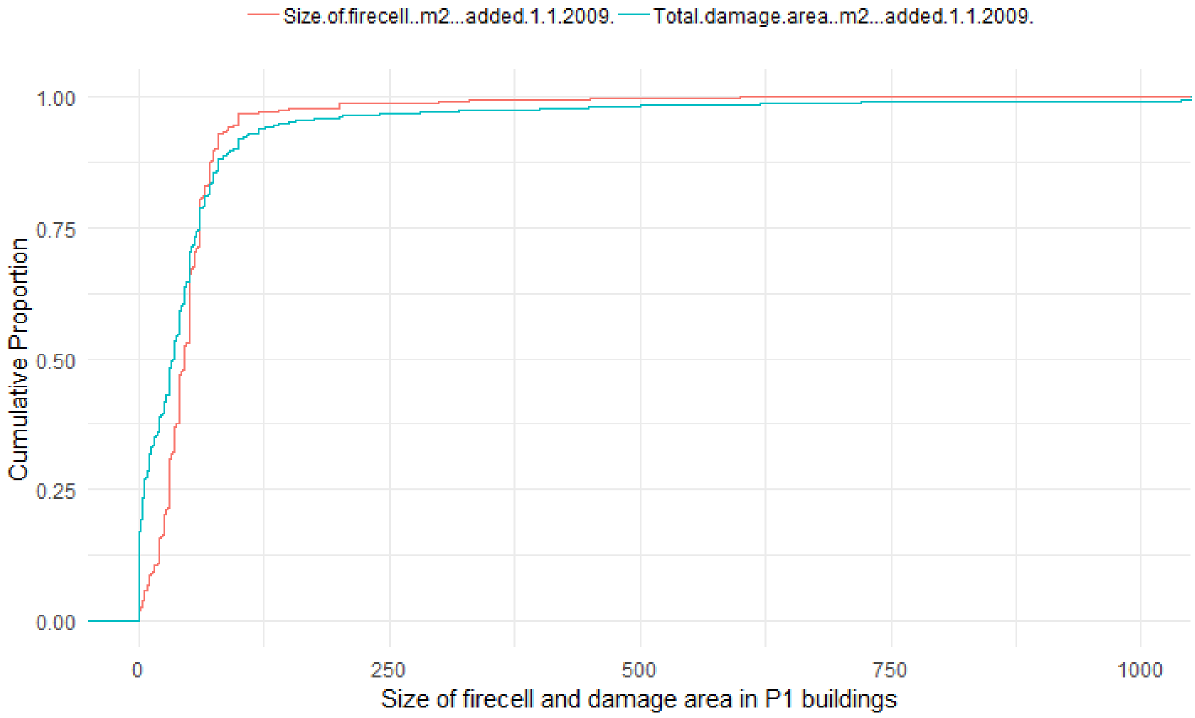


Figure 23. Cumulative distribution of size of firecell and total damage area in P1-buildings.

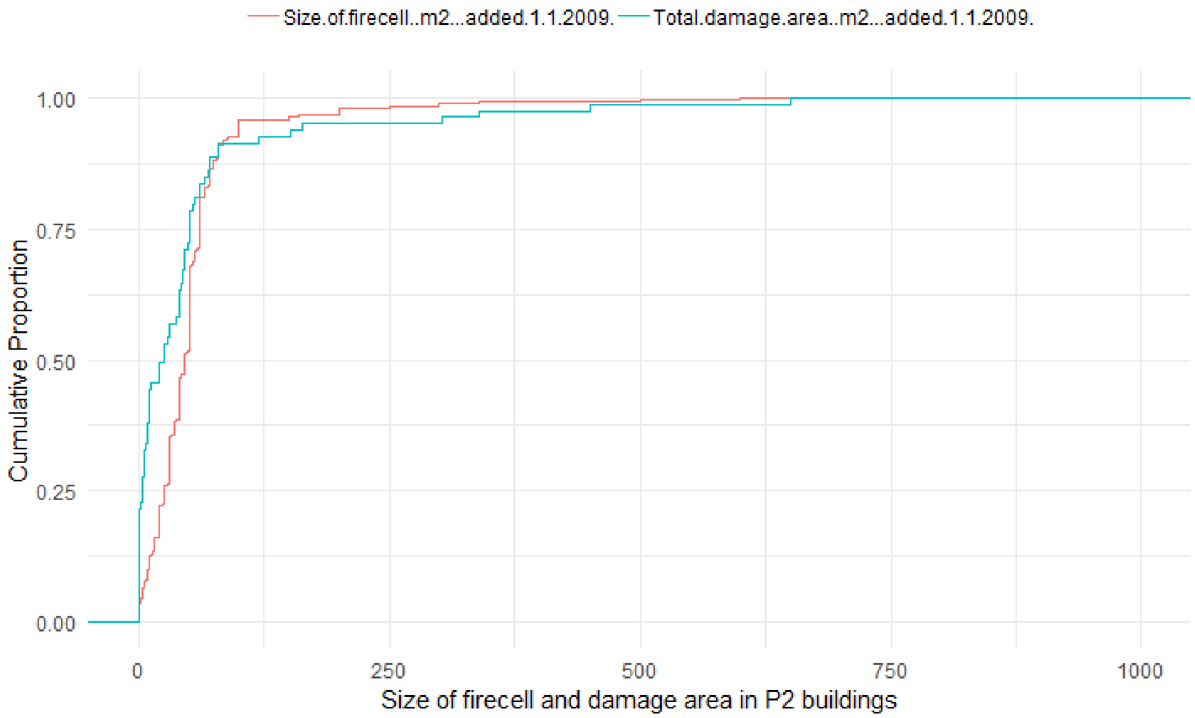


Figure 24. Cumulative distribution of size of firecell and total damage area in P2-buildings.

5.2.2 Pearson Correlations with two-tailed t-test

In Table 32 and Table 33 Pearson's correlation coefficient for continuous variables are shown, the coefficient can vary between -1 and 1 where 0 is no correlation. The t-test describes the likelihood that the given correlation coefficient will be observed if no relationship exists between the two variables and is illustrated with a set number of asterisks for a given probability. Refer to previous sections 5.1.2 and 4.2 for more information.

Table 32. Pearson's correlation coefficient for continuous variables in P1-buildings. Bold and underlined font in values that are significant (*) are similar in both building types, italic underlined values differ in significance between building types, while larger font size indicates correlation strength. *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

	1. Size of firecell [m²]	2. Floor of origin	3. Total damage area [m²]	4. Time to first unit on site [s]	5. Total number of responders	6. Total area [m²].	7. Building damage [Euro]	8. Damage to moveable property [Euro]	9. Estimation of quantity of water [m³]	10. Years since construction
1. Floor of origin	-0.02									
2. Total damage area [m²]	**0.33******	-0.01								
3. Time to first unit on site [s]	0.00	**-0.03****	*0.05**							
4. Total number of responders	**0.09******	*0.02**	**0.24******	*-0.05****						
5. Total area [m²]	*0.07****	*0.16****	0.00	*-0.07****	*0.05****					
6. Building damage [Euro]	*0.25****	*0.08***	**0.51******	0.01	*0.28****	0.01				
7. Damage to moveable property [Euro]	*0.16****	*0.07**	**0.36******	0.00	**0.25******	0.01	**0.43******			
8. Estimation of quantity of water [m³]	*0.01*	0.00	0.01	0.01	**0.06******	-0.01	**0.05****	**0.06*****		
9. Years since construction	**0.14******	0.04	**0.05***	*-0.16****	*0.07****	*0.11****	0.00	0.04**	-0.01	
10. Number of floors	0.00	**0.37******	*0.06**	**-0.10******	**0.06******	**0.40******	0.03*	0.02	*-0.01*	*0.08****

Table 33. Pearson's correlation coefficient for continuous variables in P2-buildings between. Bold and underlined font in values that are significant (*) are similar in both building types, italic underlined values differ in significance between building types, while larger font size indicates correlation strength*p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

	1. Size of firecell [m²]	2. Floor of origin	3. Total damage area [m²]	4. Time to first unit on site [s]	5. Total number of responders	6. Total area [m²].	7. Building damage [Euro]	8. Damage to moveable property [Euro]	9. Estimation of quantity of water [m³]	10. Years since construction
1. Floor of origin	-0.05									
2. Total damage area [m²]	**0.25***	0.10								
3. Time to first unit on site [s]	0.06	**-0.10***	*0.15*							
4. Total number of responders	**0.08***	*-0.02*	**0.28***	*-0.03*						
5. Total area [m²]	*0.05*	*0.08*	-0.11	*-0.05*	*0.01*					
6. Building damage [Euro]	*0.15*	*0.09*	**0.72********	-0.05	*0.05*	-0.03				
7. Damage to moveable property [Euro]	*0.18*	*0.13*	**0.90********	-0.02	**0.15***	-0.06	**0.74********			
8. Estimation of quantity of water [m³]	*0.13**	0.00	*0.78*****	0.06	**0.21********	0.00	**0.24*****	**0.42********		
9. Years since construction	**0.28***	0.15	**0.25***	*-0.05*	*0.03*	*-0.01*	-0.05	0.03	0.00	
10. Number of floors	-0.07	**0.39********	*0.02*	**-0.11*****	**-0.09***	**0.24********	-0.08	-0.06	*-0.10**	*-0.04*

5.2.3 Observations from Pearson Correlations with two-tailed t-test

The correlations analysis produced conflicting results, the correlations found in P1 can be found in P2 but to a higher level of significance and strength, compare column 1 and 5 of both tables for example. The row variables in column 5 of both tables should be somewhat positively correlated to the total number of responders, the variables for recorded damage in particular, however this is not the case in class P2 for building damage. The same is true for size of firecell in column 1.

Furthermore, the estimation of quantity of water in P1-buildings is strongly and significantly correlated to total damage area, which is to be expected, but not so in P1-buildings, refer to column 3 row 7 in Table 32 and Table 33. A theory is that this relationship is connected to the type of structures most common in P1 and P2 building classes, according to Tillander's (2004) dissertation, timber-framed buildings were more commonly detached houses. A fully developed fire in such a compartment is hard to put out and can be considered a waste to try to put out given the expected result. A more reasonable approach is trying to limit the spread, this is true in any rescue operation involving housing in my opinion. The amount of water required to limit spread from a single detached building should be lower (non if wholly detached/no risk of spread and if left to burn out) when compared to the traditional building comprising of several apartments, most commonly in the P1-category. A single detached house in a rural setting, is also very different in terms of size of firecell and in a rescue service response perspective when compared to the typical apartment building.

Given the discrepancies between the two building classes' regression tables one can assume that the amount of available data or lack thereof has an effect of increasing the variance and thusly skewing the regression results. This has to do with fire as a phenomenon, it naturally creates outliers due to its exponential behavior in terms of, for example, heat release rate. The smaller sample (P2) might also have more factors in common in terms of fire protection features or be too small for relevant comparison. Being more selective in the data cleaning can be central in getting more consistent results.

Once again, arguably, the comparison seems to indicate that there are major differences between the compared populations.

The statistics from PRONTO had a lot more data on time to first unit on site and years since construction in comparison to the data gathered from NFID. Years since construction has a small positive correlation with total damage area in both building types, it is not correlated to recorded damage in euros and it is therefore hard to draw any conclusions, see columns 3,7, 8 and row 9 in Table 32 and Table 33. Time to first unit on site is only correlated to total damage area in P1-buildings, given that it is a single case of weak correlation with minor significance it is safe to assume that time to first unit on site and damage is mostly uncorrelated, see columns 3, 4 and row 3. These two correlations change in the following section's OLS-regressions in 5.2.4.1 Model 1 and 5.2.4.2 Model 2 which goes to show that input variables and the accompanied selection of data has an impact on correlation results.

5.2.4 Ordinary least squares regression analysis

The OLS-regression is presented in the same way and utilizes the same methods as presented in 5.1.4.

5.2.4.1 Model 1 – Factors of firecell and cause of fire in relation to continuous variables

Variables in the regression analysis are shown in Table 34.

Table 34. Variables included in the regression analysis.

Variable	Description
Dependent, Y	
Log(Building Damage Euro)	Natural logarithm of estimated euro value of damages caused by fire to the building.
Independent, X_i	
Building Classification	Factor variable, indicates P2-building.
Fire Separation Intact	Factor variable, indicates if fire separation is not intact.
Likely Cause of Fire	Factor variable, indicates if cause of fire is classified as incendiary.
Number of Floors	Continuous numeric variable.
Estimation of Quantity of Water	Continuous numeric variable.
Time to First Unit on Site	Continuous numeric variable.
Total Number of Responders	Continuous numeric variable.
Log(Size of Firecell)	Natural logarithm of size of firecell.

Table 35 shows many significant variables, including building class which is has the highest probability for deemed significance (p<0.05). Building class is negatively correlated, which means class P2 is expected to a have lower loss when compared to P1. If the fire is classified as incendiary it is strongly correlated to a bigger loss. Increasing any continuous variable is also correlated to an increased loss with the exception of quantity of water, which is not significant, and number of floors which is negatively correlated.

Table 35. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, *β*	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	6.13	0.24	25.30	0.00***	Expected Y for all X=0
Building Classification (P2)	-0.39	0.20	-1.97	0.05*	1-unit increase in X =0.68*Y=-32% in Y
Fire Separation Intact (No)	0.65	0.10	6.69	0.00***	1-unit increase in X =1.92*Y=+192% in Y
Likely Cause of Fire (Incendiary)	0.33	0.09	3.52	0.00***	1-unit increase in X =1.39*Y=+139% in Y
Number of Floors	-0.05	0.02	-2.64	0.008**	1-unit increase in X =0.95*Y=-5% in Y
Estimation of Quantity of Water	0.00	0.00	0.14	0.9	Not significant
Time to First Unit on Site	0.00	0.00	4.29	0.00***	10-unit increase in X =1.01*Y=+1% in Y
Total Number of Responders	0.05	0.00	12.62	0.00***	1-unit increase in X =1.05*Y=+5% in Y
Log(Size of Firecell)	0.45	0.05	9.25	0.00***	10% increase in X≈4% in Y

The ANOVA in Table 36 shows a comparatively high grade of explanation of variance and that the model is significant.

Table 36. Model accuracy assessment.

Model accuracy assessment (ANOVA)				
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.2257	0.2214	1.295	51.82 on 8 1422 Degrees of freedom	< 2.2e^-16
Interpretation				
Roughly 23% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 21% error rate.	P-value of the F-statistic 51.82 is smaller than 0.001 and therefore we can reject that additional variables provide no value. 12 071 observations deleted due to missingness.	Significant, coefficients included in model improved the model's fit.

5.2.4.2 Model 2 – Surface classifications, fire resistance rating and building characteristics

Variables included in the model are shown in Table 37.

Table 37. Variables included in the regression analysis.

Variable	Description
	Dependent, Y
Log(Building Damage Euro)	Natural logarithm of estimated euro value of damages caused by fire to the building.
	Independent, X_i
Building Classification	Factor variable, indicates P2-building.
Separation Rating (EI60)	Factor variable, indicates if fire separation is class EI60 or more.
Floor Classification (A1 or A2)	Factor variable, indicates if floor is class A1 or A2.
Ceiling Classification (A1 or A2)	Factor variable, indicates if floor is class A1 or A2.
Surface Lining Classification (A1 or A2)	Factor variable, indicates if floor is class A1 or A2.
Type of Building (Apartments)	Factor variable, indicates if building is classified as an apartment building.
The Fireload Group of the Firecell (Less Than 600 MJ/m^2)	Factor variable, indicates if fireload is less than 600 MJ/m^2.
Years since construction	Continuous numeric variable.
Log(Total Area)	Natural logarithm of total area.

Table 38 shows that no significance was calculated in any of the variables included and thusly no correlation seems to exist between the factors and the expected loss.

Table 38. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, *β*	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	9.31	0.86	10.88	0.00***	Expected Y for all X=0
Building Classification	0.21	0.42	0.50	0.61	Not significant
Separation Rating (EI60)	0.22	0.17	1.30	0.19	Not significant
Floor Classification (A1 or A2)	-0.08	0.16	-0.49	0.63	Not significant
Ceiling Classification (A1 or A2)	0.56	0.37	1.54	0.12	Not significant
Surface Lining Classification (A1 or A2)	0.39	0.37	1.07	0.29	Not significant
Type of Building (Apartments)	-0.09	0.31	-0.29	0.77	Not significant
The Fireload Group of the Firecell (<600 MJ/m^2)	-0.23	0.22	-1.02	0.31	Not significant
Years since construction	0.00	0.00	0.00	1.00	Not significant
Log(Total Area)	-0.08	0.09	-0.89	0.38	Not significant

Given the results of the ANOVA shown in Table 39 one can stipulate that the variables do have an impact on the expected loss but no single relationship probably exists. Surface lining for example does of course have impact on how a fire develops, but, in this model, it is not enough to cause a trend in expected loss. It is important to note that the results are based on a relatively small sample of the population, 523 observations. This might not be enough for reliable results, and given that so much data is missing, skewing of the results due to a selection of certain incidents where the factors above have been recorded is expected.

Table 39. Model accuracy assessment.

Model accuracy assessment (ANOVA)				
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.09014	0.07446	1.621	5.746 on 9 522 Degrees of freedom	1.259^e-7
Interpretation				
Roughly 9% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 17% error rate.	P-value of the F-statistic 5.746 is smaller than 0.001 and therefore we can reject that additional variables provide no value. 12 970 observations deleted due to missingness.	Significant, coefficients included in model improved the model's fit.

5.2.4.3 Model 3 – Flame spread and total damage area

Table 40 contains the variables included in the regression model.

Table 40. Variables included in the regression analysis.

Variable	Description
Dependent, Y	
Log(Building Damage Euro)	Natural logarithm of estimated euro value of damages caused by fire to the building.
Independent, X_i	
Building Classification	Factor variable, indicates P2 building.
Flame Spread on Interior Finish	Factor variable, indicates if interior finish flame spread is a factor.
Flame Spread External	Factor variable, indicates if external flame spread is a factor.
Log(Total Damage Area)	Natural logarithm of total damage area.

As expected and shown in Table 41, total damage area shows a near perfect linear positive correlation with expected loss, flame spread and building classification are not significant. Flame spread was a significant variable in previous models based on the NFID-data. However, it is somewhat similar results when compared to model 2 in the previous chapter. If surface linings are non-combustible (A1 or A2) flame spread should not be a factor.

Table 41. Multiple linear regression results, p-values of individual predictor variables are visually interpreted by the significance stars *p<0.05; **p<0.01; ***p<0.001.

Variable, X	Regression weights, *β*	Std. error	t-value	Pr(>|t|)	Interpretation
Intercept (all coefficients zero, that is the reference/baseline group)	6.00	0.07	84.79	0.00***	Expected Y for all X=0
Building Classification	-0.08	0.13	-0.62	0.53	Not significant
Flame Spread on Interior Finish	0.02	0.05	0.31	0.53	Not significant
Flame Spread External	0.00	0.08	0.00	0.76	Not significant
Log(Total Damage Area)	0.89	0.02	47.70	0.00***	10% increase in X≈9% in Y

Table 42 shows a large part of the variance is explained by the model, much thanks to the good fit between total damage area and the expected loss.

Table 42. Model accuracy assessment.

Model accuracy assessment (ANOVA)				
R-squared	**Adjusted R-squared**	**Residual standard deviation**	**F-statistic**	**F-statistic p-value**
0.583	0.582	0.9703	580.9 on 4 1662 Degrees of freedom	< 2.2e^-16
Interpretation				
Roughly 58% of the observed values are explained by the model.	Adjusted R for number of coefficients.	The standard deviation of the difference between predicted value and observations. Corresponds to 11% error rate.	P-value of the F-statistic 5.746 is smaller than 0.001 and therefore we can reject that additional variables provide no value. 11 835 observations deleted due to missingness.	Significant, coefficients included in model improved the model’s fit.

6. Discussion

The objectives in this thesis consisted of estimating the impact on the damage caused by fire considering firefighting and building characteristics as two factors. The impact was estimated utilizing data gathered in databases and analyzed statistically. A comparison between timber-framed buildings versus other types of construction was performed in relation to these factors. Data from two countries and two databases was used.

6.1 Summarized observations

First off, regulatory requirements were reviewed for each respective country included in the study. Small, perhaps indifferent, differences were found, for example the applied fire-resistance rating, 45 minutes in Canada (Alberta and British Columbia) versus 60 minutes in Finland. In other respects, the countries codes are very much similar. Combustible surface linings are accepted, and four or more floors require sprinklers using an acceptable solution. Both countries allow for performance-based solutions that differ from a prescriptive design. This is also true when taking into account the different test methods used to measure performance in fire tests of construction materials. Differences of more importance are probably located in historical use of construction materials and in the end the total building stock. Residential timber-framed buildings of at least three stories are a lot more common in Canada in comparison to Finland. This most likely means a more varied distribution of building characteristics in comparison to the Finnish building stock of buildings with combustible construction. In the end this will impact any comparison made between populations, if they are different already from the start. This inherently obscures any findings and the actual impact is unknown.

Secondly, general fire statistics were observed for each respective country to try to identify any clear differences that could skew factors in a certain way. The statistics showed the prevalence of missing data and, perhaps, that Scandinavian countries seemed to suffer larger losses to fire due to a lower spending on fire protection measures. If this is true, it is hard to prove, especially in contrast to fire deaths that have previously been shown to be to a large extent impacted by for example income, education level and use of tobacco and alcohol, factors that are very different from spending on fire protection measures.

Following the general fire statics were two studies performed using NFID and PRONTO, the same databases used in this thesis. The NFID-study also applied the same methodology used in this thesis, OLS-regressions, and showed conflicting results between provinces (Alberta and British Columbia) for correlations of construction material to a certain type of measured loss due to fire. The authors attributed it to a lack of granularity to the data. This is not surprising considering that the results were based on two models that contained “all” (any data they chose to use) available data, meaning that building use, for example, was not a factor in data selection. This increases the amount of data available which could provide validity but also imposes the previously mentioned constraining factors when making comparisons between populations, if different from the start any comparison can be skewed.

The Finnish study that used data from PRONTO concluded that the total loss in wood-framed apartment buildings was larger and the cumulative distributions of fire loss in the subgroups showed differences between the materials that were statistically significant. The reason for this was spread of fire beyond the fire compartment/firecell as well as the contributing factor of the surface layer, both which more often contributed to a larger loss in timber-framed building when compared to buildings of non-combustible construction. The same results regarding cumulative distributions were reproduced in this thesis, and the importance of spread of fire outside of the first compartment firecell, but not the importance of surface linings. That does not mean that surface linings are irrelevant but rather one of many factors in how a fire develops, contents of the firecell being the obvious second in terms of fire load which in turn impacts fire loss.

Lastly an analysis of data gathered from NFID and PRONTO was performed. The analysis covered summary statistics, Pearson's Correlations with two-tailed t-test and OLS-regression. The number of observations where inverted in the two databases in terms of building type, Canada's NFID contained many timber-framed buildings and few buildings of non-combustible construction and vice versa in Finland. This of course, is a state for concern given that the two populations were compared by country and building type. In the best of worlds, the distributions would have been more evenly distributed. However, the samples are not small in a general sense and often included hundreds of values, but this number is small in comparison to thousands in a sense. This impacts reliability of the results and any comparison. Note that not all results are presented or commented on in this chapter.

That said, summary statistics showed a larger portion of higher loss values for timber-framed buildings. It also showed differences in the populations compared, non-combustible construction being more often larger, having shorter response time for the rescue service (less rural perhaps?) and probably being more recently constructed, but not always.

Pearson's correlations of continuous variables produced results that were consistent with the expectations, but the larger sample (timber-framed building from NFID and P1 buildings from PRONTO) produced more and more significant correlations. Why this is, is hard to say. A larger sample does create better conditions in terms on independence and normality of distribution but contrasting correlations can also be derived from differences in the populations compared. Estimation of quantity of water and total number of responders are a good example of such variables, they produced expected correlations but for the most part in only one sample. No comparison between countries was possible based on those variables due to them not being collected in NFID. Variables common in both datasets, years since construction and response time, lacked data in NFID and showed little to no correlation to expected loss using data from PRONTO.

OLS-regression showed no clear correlation of timber framed-buildings being more damage-prone due to the construction type, it proves that it is hard to find given that other correlations easy to guess intuitively like hydrant protection, manual fire protection facilities and an intact firecell does provide a reduction in expected loss. This stands in stark conflict with negative correlations, or rather the lack off, in fixed systems and the presence of combustible linings/surface classifications. No consistent results between smoke and spread of fire due to external spread or internal surfaces was shown when comparing models made using the data, in Alberta and British Columbia it was very much a factor that increased the expected loss which was not the case in the PRONTO-models that showed no correlation. Furthermore, if the fire was classified as incendiary in the Finnish database, it was a contributing factor when compared to other causes, the relationship was the other way around in Canada.

6.2 Human judgment and chosen limitations on data

Manipulation of raw data has a big impact on how result can be interpreted. To assume all variables are measured without error is generally impossible in this kind of research and regression solutions are highly dependent on the combination of variables included (Hemström, 2015). The most common/probable timber-framed residential building in this study has three stories, lacks a sprinkler system and has combustible surface linings, based on the regulations and statistics above. Four or more floors generally require sprinklers and a higher fire resistance rating. To negate the differences and improve the distributions (closer to normal) a higher or lower floor limitation should have been set.

6.3 Limitation on linear models and about correlations

Linear models presented in this thesis have no real-world applications since many of the assumptions of linear modeling are not met to satisfaction. Transforming the data may solve the problem; for example, by addressing the positive skewness of recorded damages by removing outliers and identifying non-linear relationships between predictors and dependent variables since fire as a phenomenon is not linear but exponential. In the case of these models I argue that since no significant differences were discovered when comparing linear models of timber-framed constructions versus other types one could assume that the difference (if there is one) is very small in comparison to other factors affecting fire loss.

Using a linear model to try to quantify fire loss is in my opinion the wrong approach, but it can be used to show simple correlations (negative or positive) and perhaps give an indication of the magnitude of a change in a factor affecting fire loss, for instance when fire separations fail. Another issue with using a linear model, especially when you combine multiple variables, in addition to losing a lot of data due to missing values, is that the variables are often far from independent. One example of this is fire spread, smoke spread, water damage and number of responders, all of which more or less likely depend on each other in some way. This could be addressed by simplifying and adding categorical variables together with a tradeoff in precision. Looking at each individual variable is also an option, but the results are far more general in the sense that the factor of having no fire hydrant also probably means a lot more that is not considered, e.g. the property is in a more rural location etcetera, which can have a major impact on the results.

Correlations are very sensitive to outliers; infrequent observations can impact the results significantly. Considering fire as a phenomenon that is unpredictable by nature it is hard to deem what is an outlier. Furthermore, a simple correlation does not prove or imply causation. It is merely an indication of whether a mutual relationship, causal or not, exists. One can, however, draw conclusions based on previous experiences and/or logical reasoning. Having manual fire protection facilities i.e. extinguishers or hoses, is sometimes required by law, which in turn is often based on experiences and/or what authorities having jurisdiction deem appropriate; in this case to mitigate consequences of fire. Having such facilities should therefore be linked to a decrease in severity of consequences of fire. This may be a poor and very evident example of such reasoning, but I think it illustrates the simplicity of the methods applied in this thesis to compare timber-framed buildings to other construction types using statistics. It is basically like smashing something with a blunt object, only to care about the big shards and ignoring any uneven edges.

6.4 Final notes and improvement suggestions

Looking back a century or so, timber constructions caused city wide fires and it would be foolish to ignore this fact that timber is characteristically flammable. Current building regulations concerning timber-framed buildings in the applicable countries are likely to have taken this into consideration. To try and examine the impact of the difference’s regulation wise in the different datasets and the differences between the populations is hard. To limit this impact, one could increase the number of floors to at least five instead of three and remove more extreme values, this would make a fairer comparison. In the future, collaboration between countries regarding data collection using common definitions of variables is an interesting and tantalizing concept for this kind of research.

7. Conclusions

The following conclusions can be made from this study which used statistics from Canada and Finland:

1. There does not seem to be a significant difference between combustible and non-combustible construction regarding monetary loss due to fire. If there is one, it is inconclusive, that is only no correlation or contrasting results with low significance was found when using OLS regression. However, the distributions of recorded loss do differ in favor of a non-combustible construction, this in my view, is explained by a difference in the populations compared.
2. Apparent correlations that are easy to guess intuitively are easy to reproduce, this gives the model some credit.
3. Fire protection features in the sense of active measures seem to have a bigger impact on the expected loss when compared to classifications of building materials.
4. The largest contributing factor to expected loss is spread beyond the compartment of origin and total damage area which is connected to the value at risk. Spread beyond compartment of origin is rare and/or rarely recorded and not useful in comparison between construction types in this instance.
5. Reduced arrival time for rescue services has a positive or, in Canadas case (where the variable was plagued by missing values), not significant impact on the outcome of an incident. Manual fire protection equipment and hydrants have a positive impact on the outcome which would indicate that intervention is important.

Extrapolation to other countries regarding these summarized observations is ill-advised. Instead, additional research for each respective country is encouraged. Additional data can be found in, for example, the United States, which gathers data on incidents using similar methodology and can be found in the National Fire Incident Reporting System (NFIRS). The National Fire Data Center (NFDC) of the U.S. Fire Administration (USFA) publishes statistical overviews of fires in the United States.

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Appendix

Table 43. Frequencies and percentages of categorical variables in timber and steel/concrete buildings 2000-2015 in Alberta and British Columbia.

Jurisdiction	N=5700 Timber (%)		N=613 Steel/concrete (%)	
Alberta	1993	34.96%	382	62.32%
British Columbia	3707	65.04%	231	37.68%
General construction				
Open wood joist	824	14.46%	0	0.00%
Heavy timber construction	51	0.89%	0	0.00%
Exposed steel	0	0.00%	35	5.71%
Wood protected by plaster	4825	84.65%	0	0.00%
Protected steel or concrete	0	0.00%	578	94.29%
Act of omission group				
Construction design or installation deficiency	75	1.32%	4	0.65%
Human failing	2122	37.23%	188	30.67%
Incendiary fires	682	11.96%	72	11.75%
Mechanical electrical failure malfunction	515	9.04%	68	11.09%
Miscellaneous	37	0.65%	2	0.33%
Misuse of equipment	109	1.91%	7	1.14%
Misuse of material ignited	566	9.93%	93	15.17%
Misuse of source of ignition	829	14.54%	113	18.43%
Vehicle accident	0	0.00%	0	0.00%
NA's	765	13.42%	66	10.77%
Property classification subgroup				
One and two-family dwellings	758	13.30%	15	2.45%
Apartment, tenement, flat, townhouse, condominium	4526	79.40%	507	82.71%
Rooming, boarding, lodging house, hostel	119	2.09%	15	2.45%
Hotel, inn, lodge	205	3.60%	61	9.95%
Motor hotel, motel	32	0.56%	1	0.16%
Dormitory	23	0.40%	9	1.47%
Camp, retreats – seasonal use	4	0.07%	0	0.00%
Miscellaneous	33	0.58%	5	0.82%
Flame spread interior finish (only Alberta)				
Not a factor	502	8.81%	111	18.11%
Spread on ceiling and floor finish	6	0.11%	2	0.33%
Spread on ceiling and wall finish	96	1.68%	17	2.77%
Spread on ceiling finish	12	0.21%	2	0.33%
Spread on ceiling wall and floor finish	100	1.75%	10	1.63%
Spread on floor finish	47	0.82%	5	0.82%
Spread on wall and floor finish	18	0.32%	6	0.98%
Spread on wall finish	113	1.98%	15	2.45%
NA's	4866	85.37%	445	72.59%
Flame spread vertical openings (only Alberta)				

By way of the exterior of the building	58	1.02%	5	0.82%
Not a factor	740	12.98%	159	25.94%
Through airhandling ducts	7	0.12%	1	0.16%
Through failure of a rated assembly	11	0.19%	0	0.00%
Through inadequate firestopping	32	0.56%	0	0.00%
Through unenclosed stairwell or elevator shaft	5	0.09%	0	0.00%
Through utility shaft	6	0.11%	1	0.16%
NA's	4841	84.93%	447	72.92%
Flame spread horizontal openings (only Alberta)				
Doors burned through in rated assembly	5	0.09%	0	0.00%
Not a factor	743	13.04%	159	25.94%
Through airhandling ducts	4	0.07%	0	0.00%
Through attic spaces ceilings or concealed spaces	40	0.70%	0	0.00%
Through corridor	31	0.54%	3	0.49%
Through doors open in rated assembly	12	0.21%	1	0.16%
Through utility openings	4	0.07%	1	0.16%
Through windows	17	0.30%	2	0.33%
NA's	4844	84.98%	447	72.92%
Smoke spread avenues (only Alberta)				
Not a factor	390	6.84%	80	13.05%
Through airhandling ducts	18	0.32%	3	0.49%
Through openings in construction	60	1.05%	8	1.31%
Through the corridor	316	5.54%	60	9.79%
Through the elevator shaft	0	0.00%	2	0.33%
Through the stairwell	58	1.02%	5	0.82%
Through utility openings horizontal walls	10	0.18%	0	0.00%
Through utility openings in floors	6	0.11%	0	0.00%
NA's	4842	84.95%	455	74.23%
Extent of fire				
Confined to building of origin	716	12.56%	36	5.87%
Confined to floor level of origin	277	4.86%	41	6.69%
Confined to object of origin	2024	35.51%	247	40.29%
Confined to part of room or area of origin	1785	31.32%	180	29.36%
Confined to roof	39	0.68%	2	0.33%
Confined to room of origin	620	10.88%	82	13.38%
Extended beyond building of origin	111	1.95%	5	0.82%
NA's	122	2.14%	20	3.26%
Extent of damage				
Confined to building of origin	452	7.93%	39	6.36%
Confined to floor level of origin	618	10.84%	92	15.01%
Confined to object of origin	15	0.26%	2	0.33%
Confined to part of room or area of origin	1596	28.00%	202	32.95%
Confined to roof	141	2.47%	6	0.98%
Confined to room of origin	1686	29.58%	169	27.57%
Extended beyond building of origin	1037	18.19%	83	13.54%
NA's	155	2.72%	20	3.26%
Action taken				
Burned out no extinguishment attempted	534	9.37%	47	7.67%

Extinguished by automatic system	245	4.30%	47	7.67%
Extinguished by fire department	2366	41.51%	225	36.70%
Extinguished by occupant	1561	27.39%	137	22.35%
Minor fire no action taken	68	1.19%	7	1.14%
NA's	926	16.25%	150	24.47%
Manual fire protection facilities				
Extinguishers	2528	44.35%	111	18.11%
Extinguishers and standpipe system	1348	23.65%	346	56.44%
No manual fire protection	1025	17.98%	31	5.06%
Standpipe system	59	1.04%	26	4.24%
NA's	740	12.98%	99	16.15%
Sprinkler protection				
Complete sprinkler protection	1140	20.00%	208	33.93%
No sprinkler protection	3233	56.72%	210	34.26%
Partial sprinkler protection	451	7.91%	65	10.60%
NA's	876	15.37%	130	21.21%
Fixed system other than sprinkler				
Alarm to fire departments	126	2.21%	43	7.01%
Local alarms only	118	2.07%	11	1.79%
No fixed system	1412	24.77%	244	39.80%
Supervised or watchman service	42	0.74%	15	2.45%
NA's	4002	70.21%	300	48.94%
Automatic fire detection system				
Central alarm	1239	21.74%	293	47.80%
No central alarm	1164	20.42%	29	4.73%
NA's	3297	57.84%	291	47.47%
Fire detection devices				
Heat detectors	22	0.39%	7	1.14%
Heat detectors and smoke detectors in return air ducts	10	0.18%	4	0.65%
Heat detectors and specialty detectors	1	0.02%	2	0.33%
Heat detectors smoke detectors and specialty detectors	25	0.44%	6	0.98%
No detection devices	85	1.49%	12	1.96%
Smoke detectors	1272	22.32%	182	29.69%
Smoke detectors and specialty detectors	33	0.58%	16	2.61%
Smoke detectors heat detectors and smoke detectors in return air ducts	218	3.82%	81	13.21%
NA's	4034	70.77%	303	49.43%
Outside fire protection				
Municipal fire department only	66	1.16%	5	0.82%
Municipal hydrant protection and fire department	5213	91.46%	569	92.82%
Municipal hydrant protection and no fire department	18	0.32%	1	0.16%
Private fire department only	164	2.88%	17	2.77%
Private hydrant protection and fire department	164	2.88%	5	0.82%
Private hydrant protection and no private fire department	4	0.07%	1	0.16%
NA's	71	1.25%	15	2.45%
Year				
2005	383	6.72%	39	6.36%
2006	422	7.40%	36	5.87%
2007	472	8.28%	38	6.20%

2008	537	9.42%	58	9.46%
2009	535	9.39%	50	8.16%
2010	493	8.65%	81	13.21%
2011	521	9.14%	41	6.69%
2012	563	9.88%	58	9.46%
2013	643	11.28%	65	10.60%
2014	543	9.53%	67	10.93%
2015	588	10.32%	80	13.05%

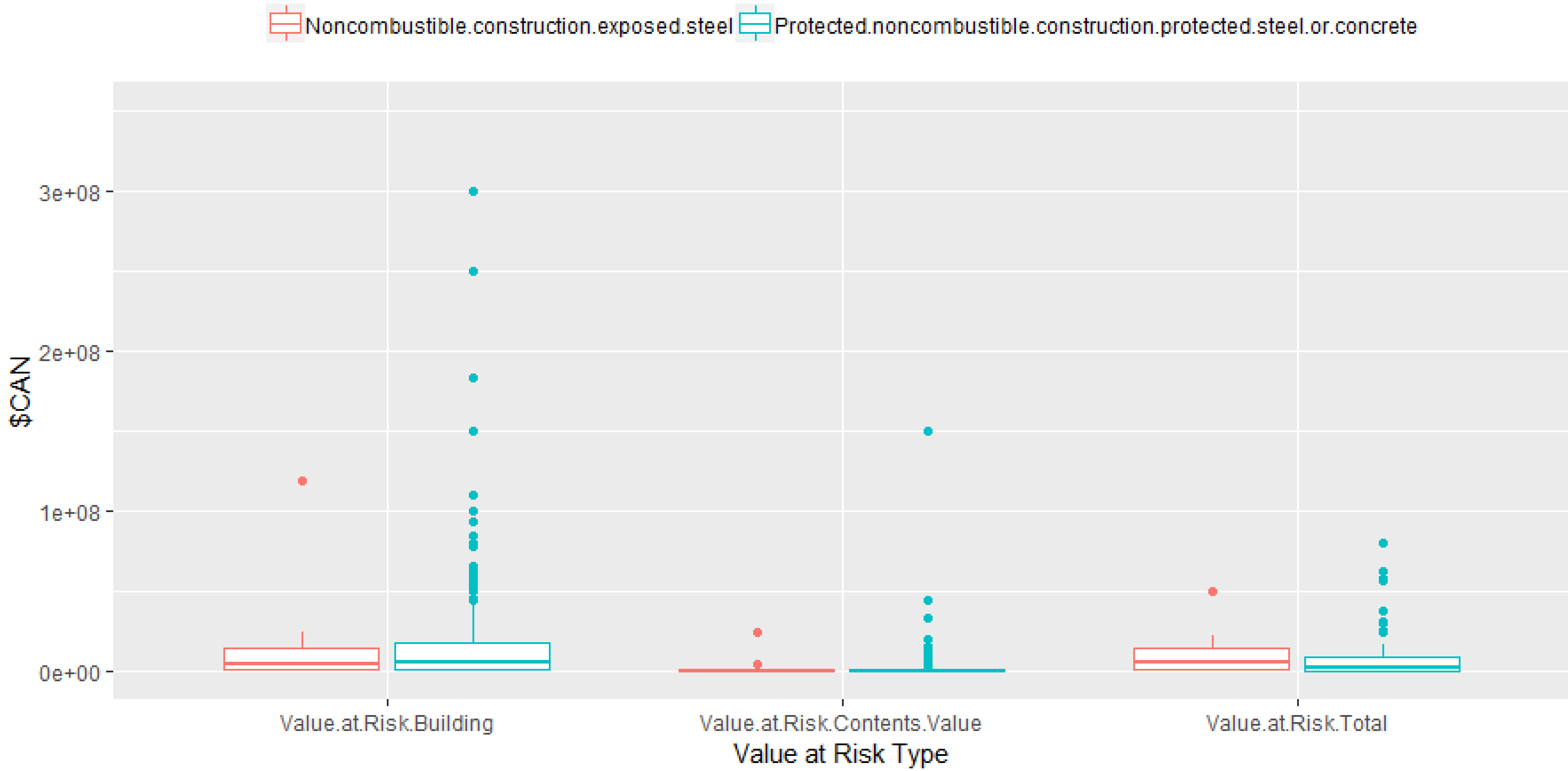

Figure 25. Box-and-whiskers plot by value at risk type in non-combustible buildings, all values.

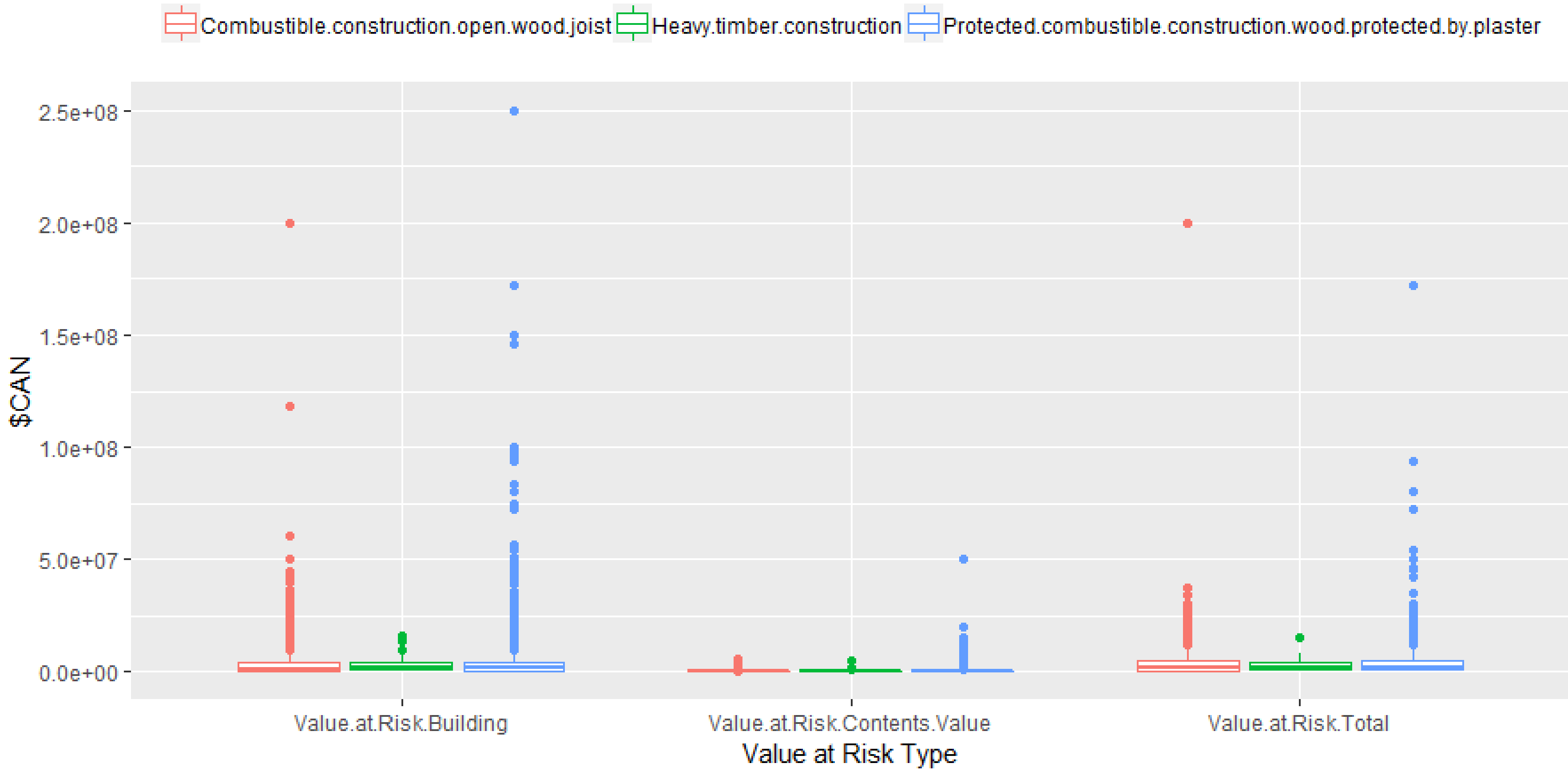

Figure 26. Box-and-whiskers plot by value at risk type combustible constructions, all values.

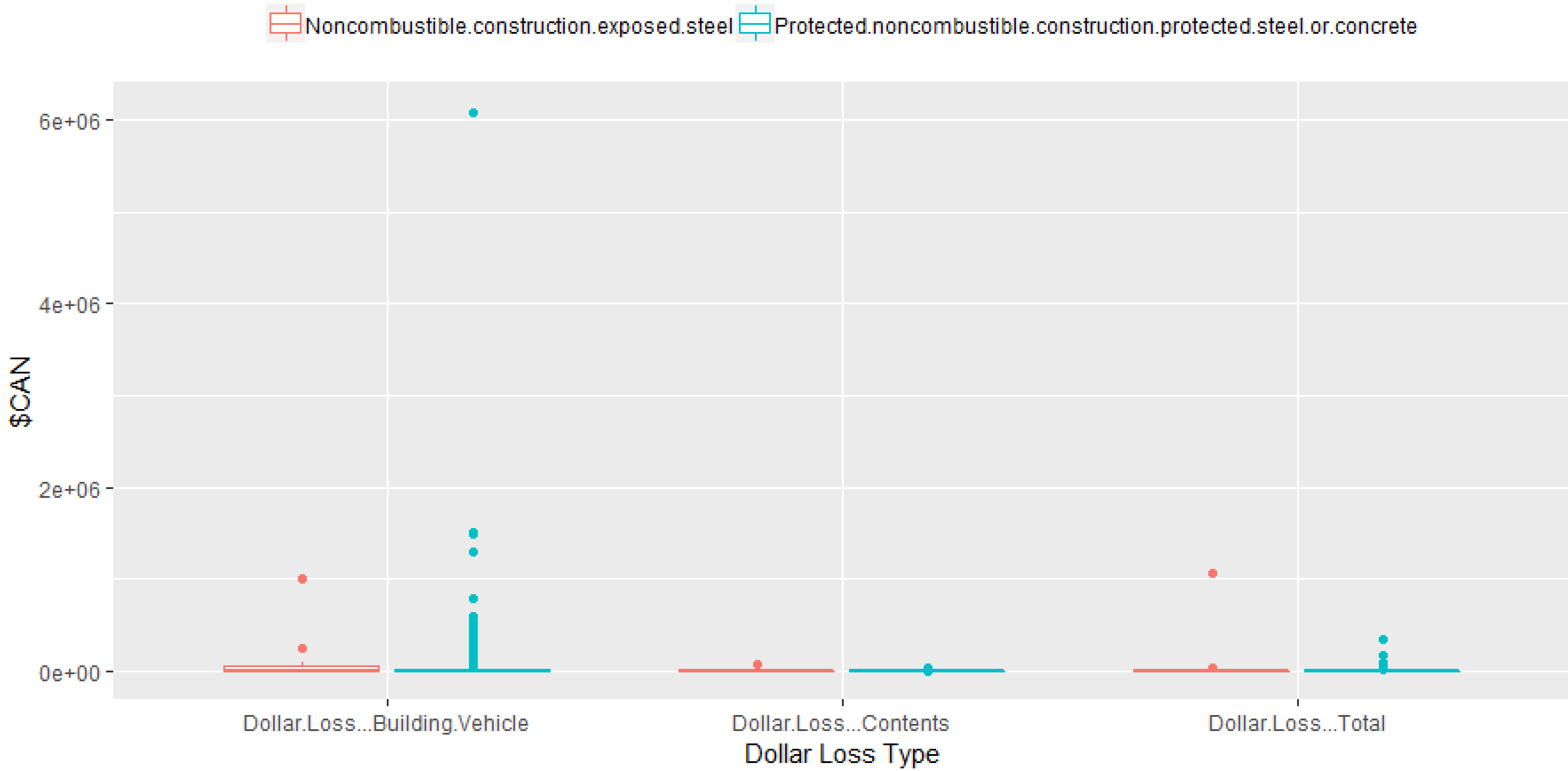

Figure 27. Box-and-whiskers plot by dollar loss type non-combustible constructions, all values.

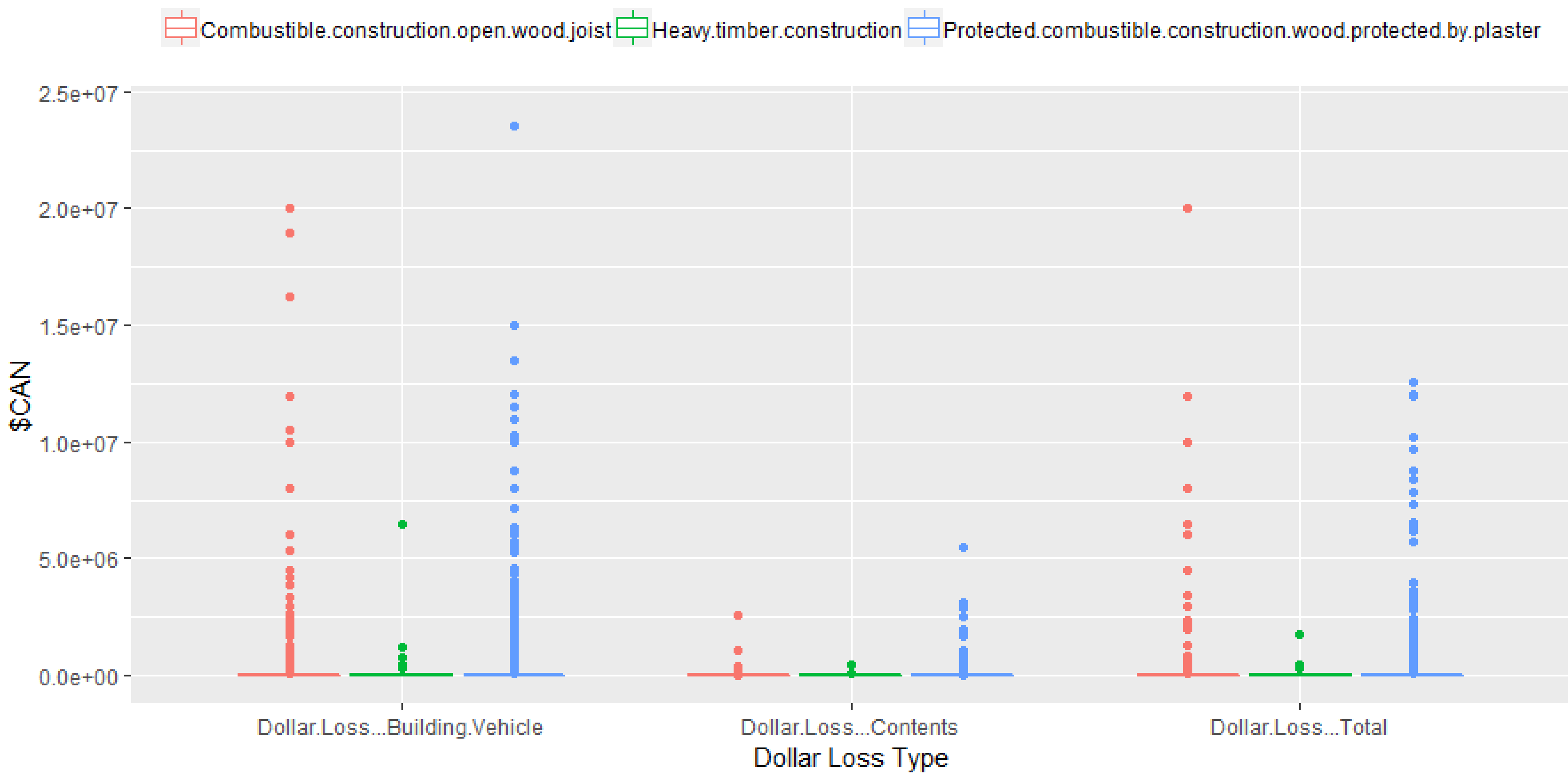

Figure 28. Box-and-whiskers plot by dollar loss type combustible constructions, all values.

Table 44. Summary statistics categorical variables in Building class P1 and P2 2000-2018.

Likely cause of fire, classification 2009	N=719 Class P2 (%)		N=12783 Class P1 (%)	
Unsupervised cooking	217	30.18%	3357	26.26%
Cigarette or other tobacco product	82	11.40%	1464	11.45%
Other cooking	67	9.32%	821	6.42%
Electrical fault or fault caused by neglect	50	6.95%	991	7.75%
Improper use of equipment	43	5.98%	730	5.71%
Cannot be assessed	35	4.87%	812	6.35%
Other	225	31.29%	4608	36.05%
Type of building				
Apartment	608	84.56%	11718	91.67%
Hotel	18	2.50%	230	1.80%
Single house	2	0.28%	12	0.09%
Boarding house	16	2.23%	331	2.59%
Loft apartment	29	4.03%	206	1.61%
Retirement home	15	2.09%	199	1.56%
Row house	6	0.83%	8	0.06%
Other	25	3.48%	79	0.62%
The surfaces effect on the fire (removed 31.12.2007)				
Delayed the fire	40	5.56%	1233	9.65%
No effect	56	7.79%	1324	10.36%
Contributed to the fire	10	1.39%	232	1.81%
Cannot be assessed	12	1.67%	94	0.74%
Not recorded	601	83.59%	9900	77.45%
The effect of internal surfaces (slowed down or sped up) on the early fire (added 1.1.2008)				
Yes	22	3.06%	758	5.93%
No	81	11.27%	1853	14.50%
Not known	10	1.39%	269	2.10%
Not recorded	606	84.28%	9903	77.47%
The effect of external surfaces (slowed down or sped up) on the early fire (added 1.1.2008)				
Yes	11	1.53%	235	1.84%
No	94	13.07%	2468	19.31%
Not known	8	1.11%	177	1.38%
Not recorded	606	84.28%	9903	77.47%
The effect of the interior walls on the fire (added 1.1.2008)				
Delayed the fire	15	2.09%	526	4.11%
No effect	3	0.42%	82	0.64%
Contributed to the fire	3	0.42%	143	1.12%
Cannot be assessed	1	0.14%	11	0.09%
Not recorded	697	96.94%	12021	94.04%
Surface lining classification				
A1	15	2.09%	510	3.99%
A1, A2	13	1.81%	518	4.05%
A2	10	1.39%	119	0.93%

B	20	2.78%	1064	8.32%
D	9	1.25%	353	2.76%
Other	10	1.39%	108	0.84%
Not recorded	642	89.29%	10111	79.10%
The effect of the ceiling on the fire (added 1.1.2008)				
Delayed the fire	15	2.09%	448	3.50%
No effect	5	0.70%	192	1.50%
Contributed to the fire	2	0.28%	97	0.76%
Cannot be assessed	0	0.00%	23	0.18%
Not recorded	702	97.64%	12023	94.05%
Ceiling classification				
A1	14	1.95%	562	4.40%
A1, A2	13	1.81%	442	3.46%
A2	8	1.11%	82	0.64%
B	22	3.06%	1057	8.27%
D	9	1.25%	301	2.35%
Other	7	0.97%	68	0.53%
Not recorded	646	89.85%	10271	80.35%
The effect of the flooring on the fire (added 1.1.2008)				
Delayed the fire	13	1.81%	294	2.30%
No effect	8	1.11%	388	3.04%
Contributed to the fire	1	0.14%	51	0.40%
Cannot be assessed	0	0.00%	26	0.20%
Not recorded	697	96.94%	12024	94.06%
Floor classification				
A1	7	0.97%	388	3.04%
A2	27	3.76%	643	5.03%
D	16	2.23%	613	4.80%
Not recorded	669	93.05%	11139	87.14%
Loadbearing structure intact				
Yes	226	31.43%	5552	43.43%
No	3	0.42%	17	0.13%
Not recorded	490	68.15%	7214	56.43%
Space of origin (added 1.1.2009)				
Studio apartment	102	14.19%	1917	15.00%
Two rooms	178	24.76%	2933	22.94%
Three rooms	51	7.09%	1108	8.67%
Four rooms	9	1.25%	208	1.63%
Five rooms	2	0.28%	34	0.27%
Other	43	5.98%	796	6.23%
Not recorded	334	46.45%	5787	45.27%
Area of firecell (m2) (removed 31.12.2008)				
-100	35	4.87%	1202	9.40%
101-300	4	0.56%	63	0.49%
301-400	1	0.14%	3	0.02%

401-800	0	0.00%	14	0.11%
801-1600	0	0.00%	3	0.02%
1601-2400	1	0.14%	0	0.00%
Not recorded	678	94.30%	11498	89.95%
Separation rating				
EI30	30	4.17%	408	3.19%
E30	11	1.53%	155	1.21%
EI60	58	8.07%	2216	17.34%
Other	14	1.95%	188	1.47%
Not Recorded	606	84.28%	10004	78.26%
The fireload group of the firecell				
-600 MJ/m2	116	16.13%	3757	29.39%
601-1200 MJ/m2	12	1.67%	374	2.93%
1201- MJ/m2	1	0.14%	49	0.38%
Not Recorded	590	82.06%	8603	67.30%
Assessment of the fireload in the firecell with regards to the use of the building (added 1.1.2008)				
Less than normal	15	2.09%	266	2.08%
Normal	60	8.34%	1806	14.13%
More than normal	14	1.95%	247	1.93%
Cannot be assessed	0	0.00%	33	0.26%
Not recorded	630	87.62%	10431	81.60%
Was the connection open between the firecell of origin and other firecells (added 1.1.2009)				
Yes	40	5.56%	1170	9.15%
No	34	4.73%	823	6.44%
Not known	1	0.14%	56	0.44%
Not recorded	643	89.43%	10743	84.04%
Fire separation intact				
Yes	191	26.56%	5057	39.56%
No	29	4.03%	612	4.79%
Not recorded	499	69.40%	7114	55.65%
Fire separating object that failed 1				
Door	16	2.23%	298	2.33%
Hatch	3	0.42%	13	0.10%
Window	2	0.28%	43	0.34%
Loadbearing wall	0	0.00%	5	0.04%
Non-loadbearing wall	0	0.00%	5	0.04%
Channel penetration	1	0.14%	15	0.12%
Cable penetration	0	0.00%	13	0.10%
Pipe penetration	0	0.00%	33	0.26%
Intermediate joists	1	0.14%	18	0.14%
Upper joists	2	0.28%	7	0.05%
Fire separation instead of firewall	0	0.00%	1	0.01%
Other	0	0.00%	42	0.33%
Not recorded	694	96.52%	12290	96.14%
Fire separating object that failed 2				

Door	0	0.00%	7	0.05%
Window	1	0.14%	8	0.06%
Channel penetration	0	0.00%	9	0.07%
Cable penetration	0	0.00%	2	0.02%
Drain penetration	0	0.00%	1	0.01%
Pipe penetration	0	0.00%	8	0.06%
Upper joists	0	0.00%	2	0.02%
Other	0	0.00%	2	0.02%
Not recorded	718	99.86%	12744	99.69%
Fire separating object that failed 3				
Loadbearing wall	0	0.00%	1	0.01%
Non-loadbearing wall	0	0.00%	2	0.02%
Channel penetration	0	0.00%	1	0.01%
Other	1	0.14%	1	0.01%
Not recorded	718	99.86%	12778	99.96%
Cause of failure in fire separation 1				
Open door/window/hatch	8	1.11%	192	1.50%
Fire damper not working properly	0	0.00%	2	0.02%
Other opening or leakage in the construction	11	1.53%	133	1.04%
Failure of fire separating construction	2	0.28%	42	0.33%
Fire spread beyond fire separating construction	1	0.14%	27	0.21%
Improper joining of fire separating construction	0	0.00%	13	0.10%
Improper sealing of penetration	0	0.00%	16	0.13%
Other reason	3	0.42%	68	0.53%
Not recorded	694	96.52%	12290	96.14%
Cause of failure in fire separation 2				
Open door/window/hatch	1*	0.14%	6	0.05%
Fire damper not working properly	0	0.00%	2	0.02%
Other opening or leakage in the construction	0	0.00%	17	0.13%
Failure of fire separating construction	0	0.00%	1	0.01%
Fire spread beyond fire separating construction	0	0.00%	1	0.01%
Improper sealing of penetration	0	0.00%	3	0.02%
Other opening or leakage in the construction	0	0.00%	1	0.01%
Other reason	0	0.00%	4	0.03%
Not recorded	718	99.86%	12749	99.73%
Cause of failure in fire separation 3				
Open door/window/hatch	1*	0.14%	1	0.01%
Fire damper not working properly	0	0.00%	1	0.01%
Other opening or leakage in the construction	0	0.00%	1	0.01%
Fire spread beyond fire separating construction	1*	0.14%	0	0.00%
Improper joining of fire separating construction	0	0.00%	1	0.01%
Other reason	0	0.00%	2	0.02%
Not recorded	717	99.72%	12777	99.95%
Year				
2018	76	10.57%	784	6.13%

2017	72	10.01%	969	7.58%
2016	46	6.40%	930	7.28%
2015	58	8.07%	922	7.21%
2014	73	10.15%	1040	8.14%
2013	50	6.95%	927	7.25%
2012	37	5.15%	916	7.17%
2011	47	6.54%	916	7.17%
2010	59	8.21%	809	6.33%
2009	46	6.40%	851	6.66%
2008	34	4.73%	701	5.48%
2007	34	4.73%	482	3.77%
2006	26	3.62%	393	3.07%
2005	13	1.81%	440	3.44%
2004	12	1.67%	285	2.23%
2003	8	1.11%	313	2.45%
2002	9	1.25%	362	2.83%
2001	6	0.83%	308	2.41%
2000	7	0.97%	435	3.40%

*The number of failures does not add up.

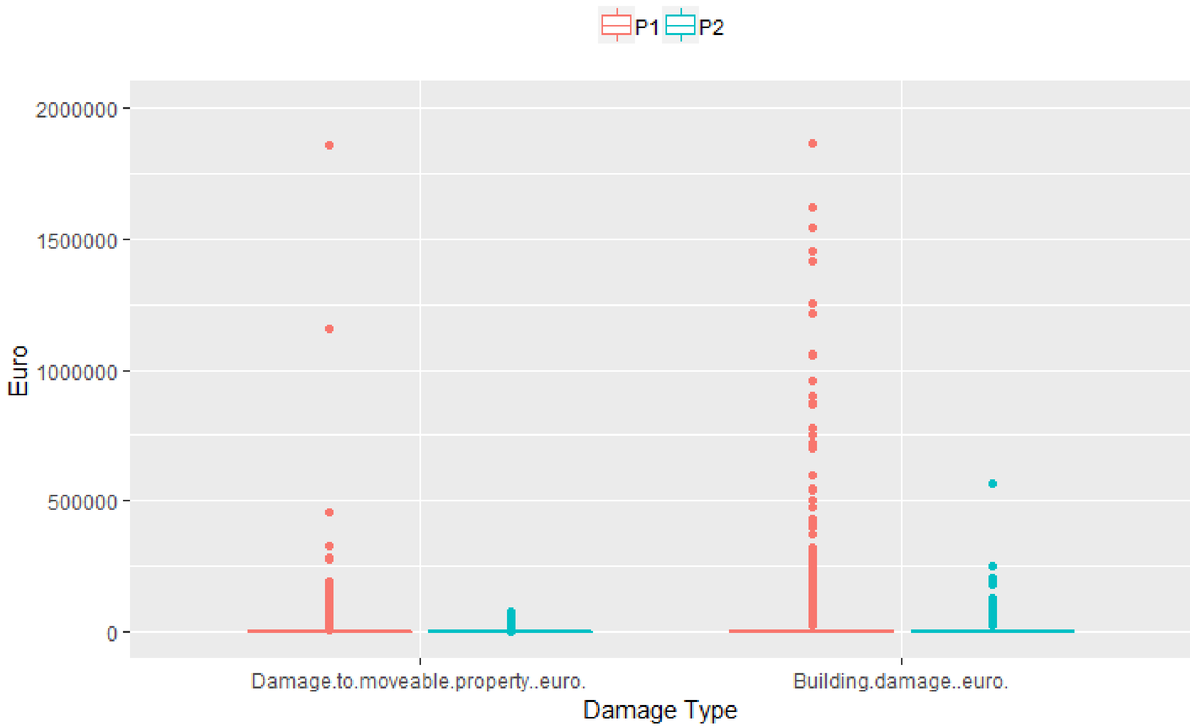

Figure 29. Box-and-whiskers plot by damage type in P1 and P2 buildings. Outliers creates very small boxes.

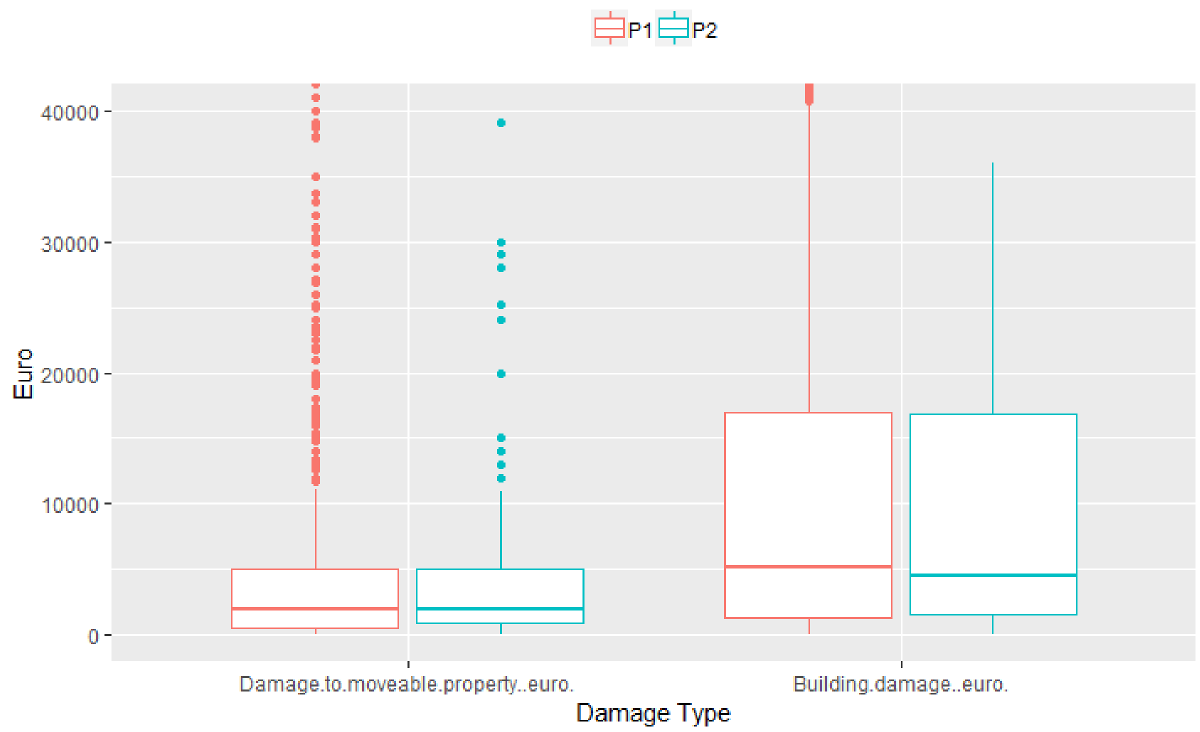

Figure 30. Box-and-whiskers plot by damage type in P1 and P2 buildings, values recorded as zero removed. Note the change of scale on the y-axis compared to Figure 19.

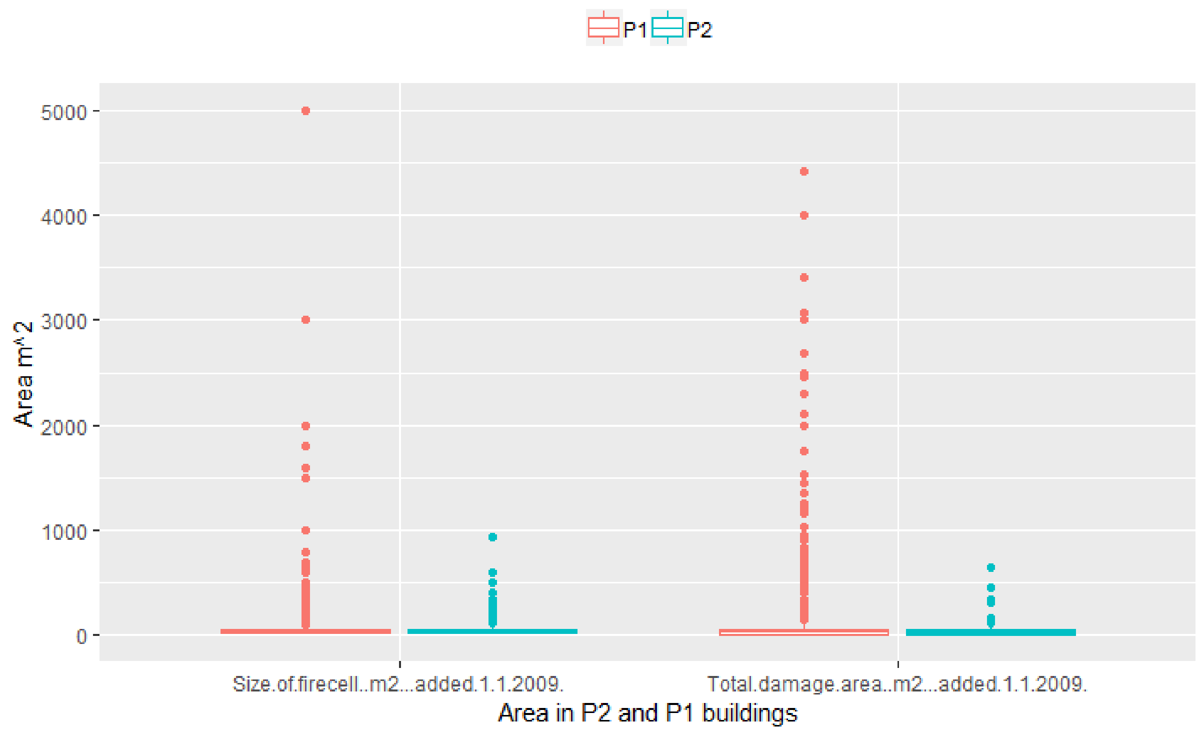

Figure 31. Box-and-whiskers plot by size of firecell and total damage area in P1 and P2 buildings. Outliers creates very small boxes.

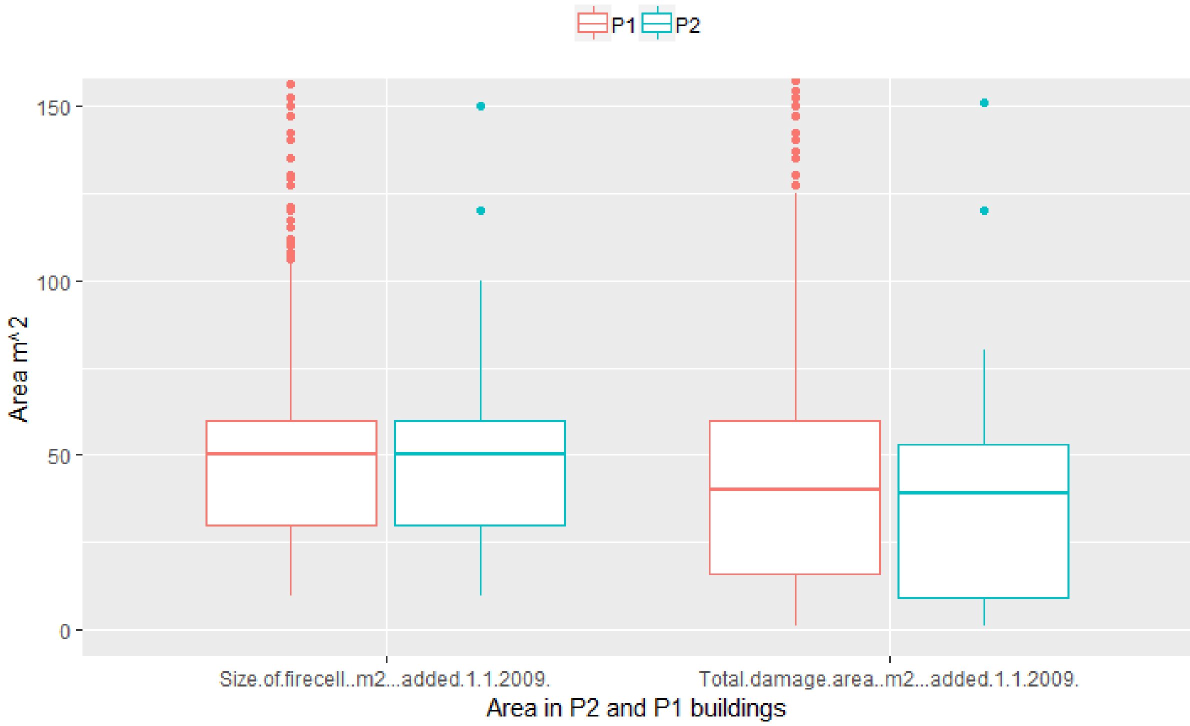

Figure 32. Box-and-whiskers plot by size of firecell and total damage area in P1 and P2 buildings, values recorded as zero- and single-digit size of firecell removed.

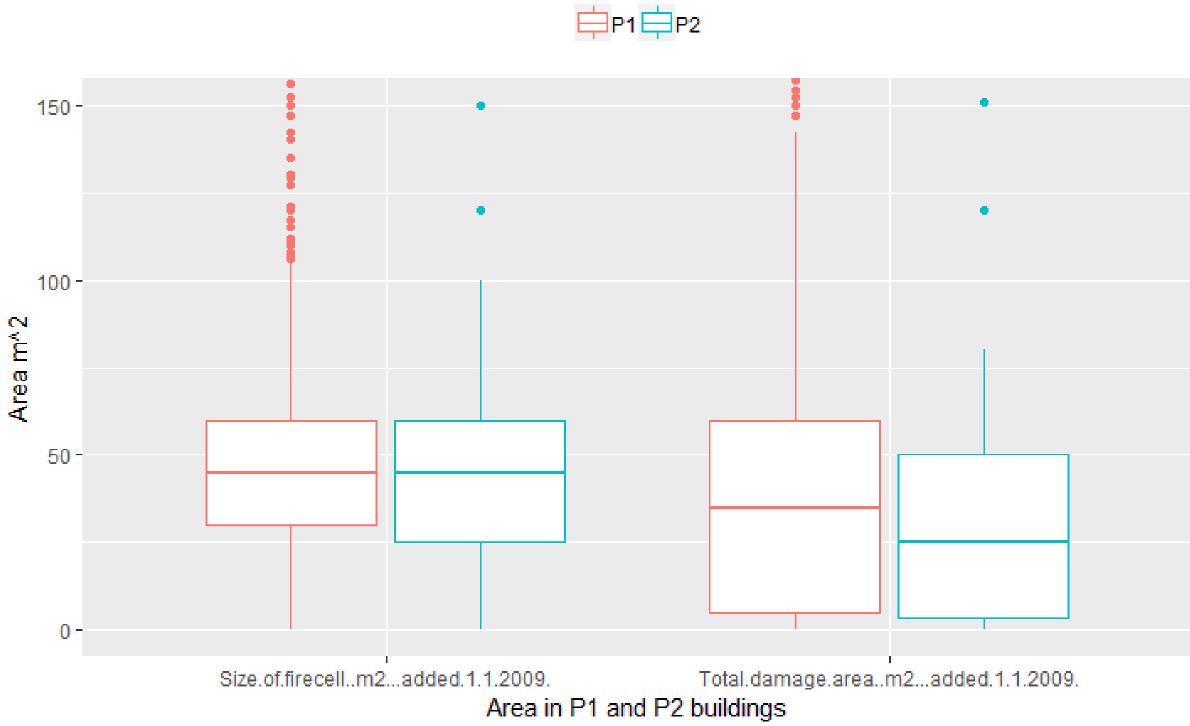

Figure 33. Box-and-whiskers plot by size of firecell and total damage area in P1 and P2 buildings, values recorded as zero- and single-digit size of firecell removed. Size of fire cell and damage area limited to 500 m^2.