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Factors Influencing Wood Adoption in Residential Construction in Germany: Assessing Regional Differences, Homeowners' Preferences, and Flexible Housing Criteria

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Abstract und Zusammenfassung

Abstract

The European construction sector's continuous growth has heightened environmental concerns, especially regarding CO2 emissions and construction waste. As buildings account for significant energy use and greenhouse gas emissions globally, a push towards biomass-based materials such as wood is evident. Despite this, the share of wooden residential buildings in Germany is low compared to Nordic countries and exhibits considerable regional variations. This thesis explores the factors affecting the adoption of wood in residential construction in Germany and the impact of flexible housing criteria on homeowners' preferences for wood. Through data from various sources, including state statistics offices and a nationwide survey, three key factors influencing the adoption of wood in German construction emerged from this thesis: residential area, homeowner age, and environmental sustainability. Rural areas and regions with cultural heritage favor wood, while older homeowners exhibit a stronger preference for wood. Environmental sustainability concerns plays a pivotal role, with homeowners valuing wood for its renewable nature and lower carbon footprint. These factors highlight the need for multi-dimensional strategies to promote sustainable construction practices. The research underscores the necessity of addressing these misconceptions and promoting the environmental benefits of wood in construction. Beyond its academic implications, the findings offer valuable insights for policymakers and the public, pointing towards the need for further research considering cross-national studies, more detailed research on the influence of policies and regulation as well as financial variables on the selection of building materials.

Zusammenfassung

Das kontinuierliche Wachstum des europäischen Bausektors hat die Umweltbelastungen, insbesondere hinsichtlich CO2-Emissionen und Bauschutt, verstärkt. Da der Bausektor und der Betrieb von Gebäuden weltweit einen erheblichen Anteil an Energieverbrauch und Treibhausgasemissionen ausmachen, wird eine verstärkte Nutzung von Biomasse-basierten Materialien wie Holz gefordert. Dennoch ist der Anteil an Holzwohngebäuden in Deutschland im Vergleich zu nordischen Ländern gering und zeigt erhebliche regionale Unterschiede. Die vorliegende Arbeit untersucht die Faktoren, die die Nutzung von Holz im Wohnungsbau in Deutschland beeinflussen sowie die Auswirkungen flexiblem Wohnen auf die Holzpräferenzen der Hausbesitzer. Durch Daten aus verschiedenen Quellen, einschließlich der staatlichen Statistikämter und einer bundesweiten Umfrage, sind in dieser Arbeit drei zentrale Faktoren identifiziert worden, die den Einsatz von Holz im deutschen Bauwesen beeinflussen: Die Struktur des Wohngebietes, das Alter der Hausbesitzer und Umweltverträglichkeit. Ländliche Gebiete und Regionen mit kulturellem Erbe bevorzugen Holz, während ältere Hausbesitzer eine stärkere Präferenz für Holz zeigen. Umweltverträglichkeit spielt eine entscheidende Rolle, da Hausbesitzer Holz aufgrund seiner Nachhaltigkeit und seines geringeren CO2-Fußabdrucks schätzen. Diese Faktoren betonen die Notwendigkeit multidimensionaler Strategien zur Förderung nachhaltiger Baupraktiken. Neben den akademischen Implikationen bieten die Ergebnisse wertvolle Erkenntnisse für politische Entscheidungsträger und die Öffentlichkeit und weisen auf die Notwendigkeit weiterer Forschung hin, die länderübergreifende Studien, detailliertere Untersuchungen zu Einflussfaktoren wie Politik und Vorschriften sowie finanziellen Variablen bei der Auswahl von Baumaterialien berücksichtigt.

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List of Abbreviations

BMEL - Bundesministerium für Ernährung und Landwirtschaft

BMU - Bundesministerium für Umwelt

DHWR - Deutscher Holzwirtschaftsrat (*German lumber council*)

EC - European Commission

EU - European Union

GDP - Gross domestic product

GHG - Greenhouse Gas

Inhab. - Inhabitant

M - Mean

MBO - Musterbauordnung (*Model building code*)

NRW - North Rhine-Westphalia

SD - Standard Deviation

SR - Sub-Research Question

UNEP - United Nations Environment Programme

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1 Introduction

1.1 Background

The construction sector forms an important backbone of the European Union economy, contributing almost 9% of GDP and providing 18 million jobs (EC, 2021). In 2019, EU citizens have invested 5.3% of GDP in housing on average (Eurostat, 2020). Over one million houses are built every year in the EU (Hypostat, 2020). While the construction sector has continuously been growing in most European countries in recent years and, in parallel, the number of private houses built (Hypostat, 2020), this sector also causes substantial negative environmental impacts. The construction industry is a significant contributor to global greenhouse gas emissions and the depletion of natural resources. The production of building materials, such as cement and steel, as well as the use of heavy machinery and transportation for construction all contribute to the release of carbon dioxide and other greenhouse gases (Huang et al., 2018). Construction and use of buildings and infrastructure account for the largest contribution to global energy usage (34%) and greenhouse gas emissions (37%), surpassing any other individual sector (UNEP, 2022). For instance, the production of cement, a key ingredient of concrete, is a substantial driver of carbon dioxide emissions, accounting for roughly 6–7% of global emissions (Khozin et al., 2020). Another environmental issue concerning the construction sector is the tremendous amount of construction and demolition waste, which represents about one third of total waste produced in the EU (EC, 2016). Buildings made with cement and bricks contribute significantly to waste, dust and vegetation pollution (Nan & Jie, 2020).

A more environmentally friendly alternative would be the use of wood in construction, replacing carbon-intensive materials like concrete and steel, which can significantly reduce a building's embodied energy (Sathre & O'Connor, 2010). Substituting

conventional building materials with wood in new construction could provide a 9% reduction of global emissions (Himes & Busby, 2020). This reduction in emissions is crucial to achieve the goal of limiting global warming to below 1.5°C and halve the emissions produced by the built environment by 2030 (UNEP, 2022).

In 2016, the German federal government adopted the Climate Action Plan 2050 to fulfill the demands of the Paris Agreement. Among the main goals and measures is the increased usage of more climate-friendly resources in construction, one of the latter being timber in particular (BMU, 2016). This aim is in accordance with several studies that examine opportunities for facing environmental challenges in construction. By expanding the proportion of wood used in construction, particularly that of private homes, one could reduce the GHG emissions significantly (Spear et al., 2019; Monahan & Powell, 2011). Even though a reduction of embodied carbon within buildings could be achieved through various measures, an increase in stored sequestered carbon can only be achieved by a higher use of biomass-based material like timber (Monahan & Powell, 2011). To increase the use of wood as a building material, the German federal government initiated the ‘Charter for Wood 2.0’ in 2020, which aims to advance sustainable forest management and the utilization of wood as a building material. The Charter seeks to encourage the sustainable use of this material, including promoting timber construction and providing incentives for the adoption of wood as a building material (BMEL, 2021).

In Germany, the use of wood in construction has in fact been growing rapidly, with many new buildings and renovations incorporating wood. In 2021, approximately one-quarter of newly constructed single and duplex family houses were predominantly made of wood (Statistisches Bundesamt, 2022). Nevertheless, the share of wooden residential buildings is quite low, especially in comparison to the Nordic European

countries of Finland, Sweden and Norway, where, even in 2009, up to 90% of detached houses where made of wood (Schauerte, 2010). Additionally, one can observe vast regional differences, whereby the proportion of wooden residential building permits in Germany varies from 5.6% up to 33.4%, depending on the state, and even from 0 to over 50% at the district level (Statistisches Bundesamt, 2022). Despite the growing interest in using wood as a building material, there are no studies in the scientific literature that analyze the reasons behind the regional differences in the proportion of wooden residential buildings. This is also the case for exploring the factors that influence consumers' interest in the selection of wood as the primary building material in the construction and purchase of residential houses. However, this knowledge is highly relevant since this insight plays a crucial role for policy makers in enhancing the proportion of buildings made of wood in general, thus providing them with opportunities to pursue in order to increase climate-friendly construction. By also understanding the decision-making process of consumers when selecting building materials, we can identify potential opportunities for more informed decisions in future construction projects as well as in information and communication activities, thus contributing to a higher use of wood in construction.

1.2 Research aim

The aim of this research is to investigate the diverse factors influencing the adoption of wood as a primary building material in residential construction throughout Germany. By analyzing the multifaceted dynamics of wood usage and considering the role of flexible housing criteria, this study seeks to provide valuable insights into the complex decision-making processes involved in residential construction. Understanding these factors does not only contributes to a deeper understanding of sustainable

development within the housing sector but also offers practical implications for policy-makers, architects, builders, and homeowners alike. Against this background, the main research question of this thesis is as follows:

“What are the factors influencing the adoption of wood as a building material in residential construction in Germany, and how do flexible housing criteria impact homeowners’ preferences of wood?”

To achieve this aim, the research will address the following sub-research questions:

Sub-Research Question 1: “Which factors influence the regional differences in the share of wooden residential building permits in Germany?” This sub-research question focuses on understanding the factors that contribute to the variation in the utilization of wood as a primary building material across different regions in Germany. By examining regional differences in the share of wooden residential building permits, the research aims to identify and analyze the geographical conditions, demographic structure, factors of the construction sector and state regulations that play a role in influencing wood adoption patterns at the regional level.

Sub-Research Question 2: "Which factors influence the selection of wood as a primary building material in the construction and purchase of residential houses in Germany?" This sub-research question aims to delve into the factors that impact the selection of wood as the primary building material in the construction and purchase of residential houses in Germany by consumers. Through a comprehensive analysis, the study intends to explore various determinants when opting for wood as a building material.

Sub-Research Question 3: "To what extent are flexible housing criteria relevant to homeowners?" This sub-research question examines the relevance of flexible housing criteria to homeowners and their impact on housing preferences. By assessing the

extent to which homeowners value adaptable living spaces, flexibility in floor plans, and other related criteria, the research aims to shed light on the significance of flexible housing features and their influence on the decision-making process of homeowners in Germany.

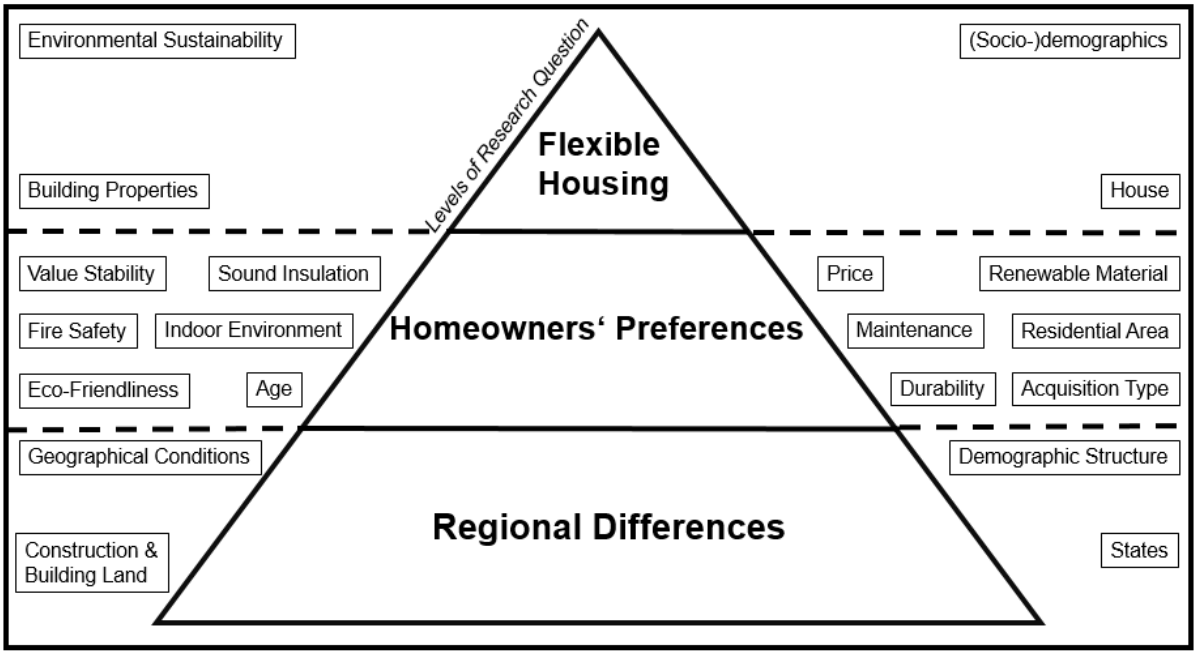
1.3 Structure of the thesis

The thesis is structured in the following manner: Chapter 2 provides a comprehensive literature review and outlines the research framework for this study. Chapter 3 details the research methods and designs utilized. Chapter 4 summarizes this thesis: Paper I analyses the regional differences of wooden residential buildings in Germany. Paper II focuses on the factors influencing the selection of wood as a primary building material for homeowners. Paper III studies the importance of flexible housing for homeowners. Chapter 5 discusses the key findings as well the limitations of this thesis. Chapter 6 concludes with an outlook for future research.

2 Review of the literature

This chapter offers a review of the existing literature concerning the factors influencing the adoption of wood as a building material in residential construction in Germany. It further explores the impact of flexible housing criteria on homeowners' preferences. The literature review creates the foundation for this research, illuminating the key concepts and empirical studies that contribute to the field's current knowledge. The review is structured around a conceptual framework represented by Figure 1, visually presenting the interconnected components linked to the research aim.

Figure 1: Research Framework



Source: Own illustration

At the base of the research framework of this thesis, the focus is on regional differences in the adoption of wooden residential buildings in Germany. The review reports on a broad spectrum of literature to investigate the factors that contribute to the observed variations across different regions in Germany. It covers geographic conditions, the influence of federal states, differences in the characteristics of the construction and building land as well as sociodemographic influences. This rigorous analysis of existing literature provides valuable insights into the factors that shape wood adoption patterns in specific regional contexts, forming a solid basis for this thesis's empirical study.

Progressing up the conceptual research framework, homeowner preferences come into perspective. This segment scrutinizes a rich collection of literature that probes the factors influencing homeowners' selection of wood as the primary building material for their residences. Various individual psychographic factors, such as environmental awareness, estimations related to material characteristics, prejudices and perceived

benefits of wood in terms of sustainability and energy efficiency, are explored. This in-depth review aims to unravel the complex nature of homeowners' decision-making processes and identify the leading factors that promote the adoption of wood in residential construction projects.

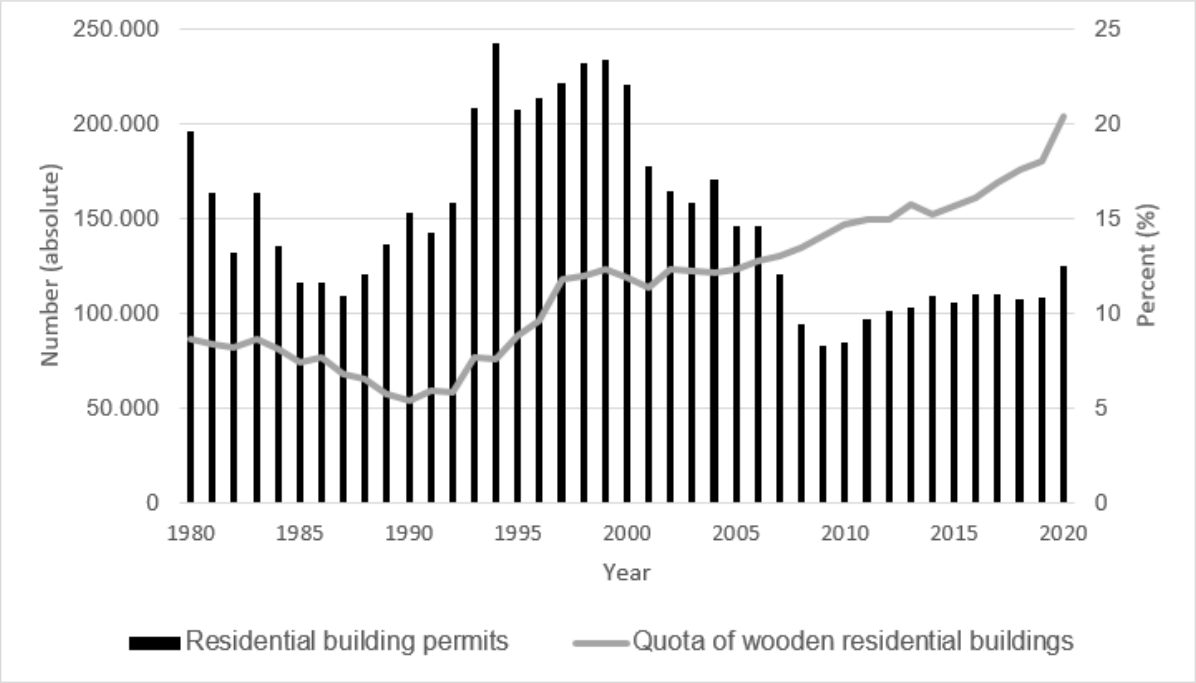
At the pinnacle of the research framework of this thesis, the significance of flexible housing criteria and its relevance to homeowners is explored. This section delves into the emergent literature on flexible housing, a concept that strives to design and construct residential properties capable of adapting to shifting needs and evolving lifestyle preferences. A critical element in this exploration is wood as a sustainable material. Wood, due to its inherent characteristics of renewability, recyclability, and ease of modification, positions itself as an ideal material for flexible housing. Its sustainable nature not only aligns with growing environmental consciousness but also facilitates easier adaptations and modifications over time, accommodating evolving housing needs. This aligns perfectly with the principles of flexible housing, making wood an attractive option for homeowners who value both sustainability and flexibility. By analyzing the existing research, the aim is to uncover the underlying motivations and preferences that influence homeowners' desires for flexibility in their housing choices and the consequential impact on wood adoption.

By synthesizing and analyzing the vast literature within this conceptual framework, this chapter provides a comprehensive and critical overview of the factors influencing wood adoption in residential construction and the importance of flexible housing criteria to homeowners in Germany. This evaluation creates a context for the following chapters, setting the stage for empirical research to address the research questions and contribute novel insights to the existing body of knowledge.

2.1 Development of wooden residential building permits in Germany

Historically, wood was the primary construction material for residential buildings due to its consistent availability and ease of access (Stark & Wicht, 1998). Its use declined dramatically during the 19th century industrial revolution, when steel became more viable for construction (Urbaner Holzbau, 2013) and city fires led to a ban on wood in multi-story buildings (Mahapatra et al., 2012). Germany saw a significant drop in wood's share in construction, from 80% in 1850 to 30% in 1900 (Lißner & Rug, 2000). Industrialization and the two world wars further exacerbated this trend in the first half of the 20th century. Post-1945, a construction boom ensued, but wooden residential buildings were scarce (Urbaner Holzbau, 2013). This period also witnessed structural changes, with shifts in work and family structures driving demand for individual living spaces (Schäfers, 2010). Awareness of environmental impacts of construction practices grew, prompting interest in environmentally friendly strategies (Dangel, 2016). The mid-to-late 20th century marked a return to wood, catalyzed by events such as the 1968 student uprising and the 1970s oil crisis. An increased interest in solar construction, bioclimatic housing, and use of clay and wood ensued (Drexler & El-khouli, 2012). After the reunification of Germany in 1990, the general number of building permits increased significantly in the following years, as can be seen in Figure 1 below. Not only that, but the percentage of building permits based on wood, which reached another low point in 1986, increased significantly in the following years. Reasons for this can be seen mainly by the arrival of specialized wood construction firms, advancements in timber construction technology, and regulatory changes favoring the wood construction sector (Krötsch, 2018; Drexler & El khouli, 2012; Dangel, 2016; Mahapatra et al., 2012).

Figure 2: Residential building permits in Germany (1980–2020)



Source: Own illustration (Statistisches Bundesamt, 1982 – 2021)

2.2 Regional differences

Diving into the literature reveals a rich tapestry of factors influencing the adoption of wood in residential construction in Germany. However, for the sake of clarity and comprehensiveness in this analysis, these factors have been synthesized into four broad categories. These encompass a range of influential aspects, including: the influence of federal states such as e.g. in politics and regulations; geographical conditions within different regions; the socio-demographic structure of regions; and the characteristics of the construction sector within different regions. These categories form the backbone of this section, providing an organizational structure through which the extensive body of literature can be navigated and understood with ease, which serves as the basis for the empirical part that follows in chapter 3.

2.2.1 Influence of Federal States

Even though the total average market share for residential building predominantly made of timber was at an all-time high in 2020 of 20.4% in Germany, the proportion varied between 5.6% and 33.4% at the federal state level. Of all 16 federal states, the highest shares was found in southern Germany, with Baden-Württemberg (33.4%), Bavaria (25.2%), Rhineland-Palatinate (24.1%), and Hesse (24.0%). Saarland (17.0%) can be regarded as the only exception to this finding. Looking at northern and eastern Germany, the percentages were rather low in comparison. In eastern Germany, Thuringia (22.5%) had the highest percentage, followed by Saxony (19.7%), Brandenburg (16.8%), Saxony-Anhalt (13.6%), and Berlin (12.3%). From the northern part of Germany, Schleswig-Holstein (18.5%) and Mecklenburg-West Pomerania (17.8%) had the highest shares, followed by North Rhine-Westphalia (12.8%) and Lower-Saxony (10.9%). The two smallest states, Hamburg (7.5%) and Bremen (5.6%), had the lowest proportion of residential buildings made of wood (Statistisches Bundesamt, 2022). Due to Germany's federalist legislation, the federal states have the right to decide on regulations related to building, public housing, and land use and development, which results in regional differences among the federal states. With the implementation of model building regulation in 2002 (*Musterbauordnung* MBO), the federal building regulations laws were intended to be standardized and simplified within Germany (Dederich, 2013). Furthermore, the MBO extended the usage of timber in construction, allowing wooden residential buildings up to five floors and 13 meters. While the MBO itself is not mandatory, most of the federal states adopted the MBO but did not fully harmonize regulations related to the use of wood in residential buildings. According to the German Timber Council (*Deutscher Holzwirtschaftsrat* - DHWR), Baden-Württemberg's implementation has been the most favorable to wood use in construction. In contrast, the federal states of

Lower-Saxony, Saarland, Hesse, Rhineland-Palatinate, Brandenburg, and North Rhine-Westphalia have had the most restricted building regulations, thus presenting the most barriers to wood use in construction (Walberg et al., 2015).

2.2.2 Geographical conditions

About 90% of Germany's area can be described as rural. It can be characterized by agricultural and forestry land use, small and medium-sized economic structures, and a low population density (DHWR, 2016). While Germany's average population density lies around 233 inhabitants per km^2, the federal states vary strongly in this respect. Whereas Berlin (4112), Hamburg (2453), Bremen (1621), and North Rhine-Westphalia (525) have the highest population densities, the lowest can be found in Saxony-Anhalt (107), Brandenburg (85), and Mecklenburg-West Pomerania (69) (Statistisches Bundesamt, 2021a). Although few studies exist related to the usage of construction material in combination with area, population, and population density, rural areas and districts in particular stand out given their high number of wooden residential buildings (Purkus et al., 2020). Considering the differences in building structures and sizes in different areas, there is an indication that population density does seem to play a certain role. Although buildings comprising one or two dwellings (single-family and duplex houses) were made of wood in 23.1% of cases, only 4.4 percent of multi-family houses in Germany were built using wooden frames (Statistisches Bundesamt, 2021a). This could also contribute to the low proportion of wooden houses in densely populated areas like Hamburg, Bremen, Berlin, and parts of NRW, as well as the high shares of wooden residential buildings in more rural and less densely populated districts. Both the federal states and their districts also differ strongly in relation to their share of forests and corresponding land use, hence the

accessibility of wood as construction material at a short distance. The higher share of woodland areas in southern Germany can be taken as an indication to the above-average figures for wooden residential buildings in this part of the country (Walberg, 2016). Especially the four southern federal states Baden-Württemberg, Bavaria, Rhine-Palatinate and Hesse, having the highest proportion of wooden residential buildings, also have the highest percentage of forestland. In comparison to the southern part of Germany, especially the northern and eastern German states have rather low shares of forest land (Statistisches Bundesamt, 2021b). In addition, studies also showed that most of Germany's timber industry is located in western Germany although eastern German wood production started to emerge after the reunification (Kies et al., 2011). The high number of wooden residential buildings in several areas and districts with a high share of forest and a substantial timber industry could be the outcome of certain path dependencies and building traditions (Purkus et al., 2020) that certainly influence industry professionals' preferences for one building material or another (Walberg, 2016).

2.2.3 Demographic structure

Germany's social and demographic structure is heterogeneous in many ways. On a regional level, there are vast differences between federal states, regions, and districts in regard to the labor market situation, wage gap, regional prices, and unemployment, as well as age, gender, education structure of population. This heterogeneous structure reflects home builders as well, which are diverse with regard to age distribution, gender, education, occupation, marital status, and economic background (Filippi, 2013). Research on the impact of demographics on the use of wood in residential buildings is available, including studies on perceptions of wood in

construction linked to sociodemographics. This suggests a correlation between demographic factors and the prevalence of wood in private construction. Age, education, and income in particular all seem to have an impact on the perception of wood in construction. Høibø et al. (2015) showed that the best target group for wood-based urban housing in particular are younger people because they tend to have strong environmental values and perceive wood to be an eco-friendly material. This goes in accordance with findings of Toppinen et al. (2018) that found younger people raise sustainability-related concerns in regard to construction in general. A study by Petruch & Walchner (2021) concerning young millennials (20 to 29-year-olds) in Austria showed that timber construction is generally perceived positively. 27% of the sample group would choose wood when building a house, which would be a slight improvement on the current proportion of timber buildings in Austria. Moresová et al. (2019) identified age, income, historical events in the given region, and the promotion of wooden houses as the main reasons for the perception of wooden houses in the Slovak Republic. In a study by Gold & Rubik (2009b) based on findings from a representative survey among the German population about people's attitudes towards social issues, the environment, wood, forestry, timber as a construction material, and wooden frame houses, the authors conducted a cluster analysis defining eight consumer types with regard to their disposition toward choosing timber as a predominant construction material for newly constructed houses in Germany. The findings by Gold & Rubik (2009b) suggested that four of the eight consumer types can be regarded as promising target groups for wooden frame houses. The consumers assigned to the four promising types all had rather high education levels, three of the four types also had a higher income, and age was not identified as a supporting factor for a higher share of wood in construction.

2.2.4 Construction and building land

The average price for building land steadily increased in Germany since the first data collection period in 1992 (Statistisches Bundesamt, 2021c), even though the number of residential buildings constructed decreased after 1999 (see Fig. 2). Building land prices usually depend on local conditions, especially in the relationship between supply and demand on a regional level. More rural regions with a lower population density are more likely to have more building area at their disposal than urban regions. This is indicated by decreasing building land prices with a declining population density in many German districts (Gans, 2017). This situation is relevant here because private residential buildings are often concentrated in agglomeration areas. These areas are confronted by a rapid growth rate of multi-family dwellings, in which the share of timber is very low (Kaiser & Mantau, 2013). Additionally, 40% of the newly built multi-family dwellings were built on pre-existing building land, whereas the proportion for single-family and duplex houses only measures around 20%. Additionally, the use of pre-existing building land is a common practice in urban areas, city states, and economically underdeveloped regions, this policy is much rarer in predominantly rural regions (Filippi, 2013). Despite the assumption that the cost of building land likely influences the percentage of newly constructed wooden residential buildings, surprisingly, there's little evidence to support the idea that price variations have a significant impact on the choice of specific construction materials.

2.3 Homeowners' preference

It can be assumed that individuals will choose the most favorable combination of housing based on factors such as income and price limitations to maximize their utility when deciding to rent or buy real estate (Gibler &Tyvimaa, 2014). Householders can

therefore be seen as economically rational actors in the housing market (Littlewood & Munro, 1997). Due to the high involvement in the process and long-term commitment of resources it entails, buying or building a house can be viewed as a strategic decision (Koklic & Vida, 2009). When it comes to complex and high-involvement goods, consumers usually evaluate multiple options, compare them, and then make a decision (Gibler & Nelson, 2003). Major buying decisions will thus serve as premises for future purchases and consumption activities of the household members (Gronhaug et al., 1987). Unlike frequently purchased items, learning through trial and error is not typical when purchasing expensive and intricate products such as houses (Bayus & Carlstrom, 1990). Assuming that individuals are rational actors who make decisions based on available information when buying or building a house, the significance and perception of specific factors are also likely to impact the selection of construction material. Hence, the following comprises an overview of the various factors that can be found in the literature that influence the decision-making process towards wood as a building material.

2.3.1 Prejudice towards wood as building material

The results of recent studies suggest that price can play a significant role in the decision-making process for consumers (Koklic & Vida, 2009). In regard to wood as a primary construction material, it is viewed rather skeptically in terms of cost-competitiveness (Karjalainen et al., 2021; Mühlbachler & Tudor, 2022). The literature also suggests that persisting biases may contribute to concerns about poor value stability of wooden houses (Gold & Rubik, 2009a). Results from a study by Harju & Lähtinen (2022) indicate that for some consumers, environmental or social sustainability aspects are not of particular importance but that economic sustainability

aspects do matter in their purchasing decisions of houses. The durability of construction materials can also be viewed as a significant factor for consumers in the literature. Individuals who rate durability and solidity as important have a very high preference for stone or bricks as building materials compared to consumers who rate durability and solidity as less important (Høibø et al., 2015). Studies also reveal that consumers hold preconceived notions about the durability of wood as a building material since consumers are biased against timber's ability to endure over time (Gold & Rubik, 2009a; Hu et al., 2016; Larasatie et al., 2018; Mühlbachler & Tudor, 2022; Viholainen et al., 2021). Maintenance is also seen as a concern in the case of wooden timber-framed buildings (Viholainen et al., 2020). A study by Leszczyszyn et al. (2022) shows that most of the respondents are of the opinion that wooden houses require more frequent maintenance. In the literature, fire safety and protection of wooden houses are sources of skepticism in many studies (Costa et al., 2011; Gold & Rubik, 2009a; Hu et al., 2016; Karjalainen et al., 2021; Larasatie et al., 2018; Leszczyszyn et al., 2022; Moresová et al. 2019; Viholainen et al., 2020). Consumers hold negative biases towards these aspects, posing a major challenge for wooden houses since fire protection is a critical factor in purchasing decisions (Gold & Rubik, 2009a). Fire safety is reported as the most pronounced prejudice against wood compared to other aspects, and such negative views have been deeply ingrained in consumers' minds for a long time (Hu et al., 2016). Another prejudicial factor in the literature seems to be the view on sound insulation of wood as a material (Gold & Rubik, 2009a; Hu et al., 2016; Morsová et al., 2019). Consumers might hold negative attitudes towards the insulation in terms of sound penetration of wooden houses.

2.3.2 Health benefits and eco-friendliness

With regard to the perception of wood, it can be noted that studies show that consumers have a generally positive opinion on the health benefits of wood (Gold & Rubik, 2009a; Hu et al., 2016; Karjalainen et al., 2021; Leszczyszyn et al., 2022; Mühlbachler & Tudor, 2022; Viholainen et al., 2021). When it comes to wooden houses, most individuals believe that they offer a healthier indoor climate compared to buildings made of non-wood materials (Karjalainen et al., 2021). Studies assume that the health aspect plays a significant role in the decision-making process of consumers (Gold & Rubik, 2009a; Harju & Lähtinen, 2022; Hu et al., 2016). In addition to the assessment of material properties, environmental orientation can also affect the perception of wood as a construction material (Harju, 2022). In most studies, participants' attitudes towards the use of wood in construction are generally very positive in terms of environmental friendliness and sustainability. Wood is perceived as a natural and eco-friendly material (Gold & Rubik, 2009a; Karjalainen et al., 2021; Kylkilahti et al., 2020; Leszczyszyn et al., 2020; Moresová et al., 2019; Mühlbachler & Tudor, 2022; Petruch & Walcher, 2021; Roos et al., 2022; Toppinen et al., 2013; Viholainen et al., 2020). According to Høibø et al. (2015), there is a positive correlation between the level of concern for environmental impacts and the preference for wood products in the built environment over other building materials. Harju & Lähtinen (2022) found that consumers who prioritize sustainable consumption and have a keen interest in environmental, social, or economic sustainability tend to appreciate the characteristics of wooden materials more compared to those consumers who ignore sustainability issues. This indicates that one target group for wooden construction might be consumers who are more environmentally oriented. Roos et al. (2022) found that preference for multi-story wooden buildings is associated positively with the environmental and social sustainability perception of consumers.

Although wood is widely recognized as an environmentally friendly construction material, according to Gold & Rubik (2009a), it does not represent a major factor in the considerations of most consumers and is therefore considered only as an additional benefit for consumers. The findings of Mühlbachler & Tudor (2022) align with this statement, as they have found that although the vast majority of respondents view wood as eco-friendly and consider this factor somewhat important, it does not significantly influence their purchasing decisions. This also applies to results from Viholainen et al. (2020), who found that environmental friendliness used to promote wooden buildings does not currently resonate with consumers when choosing a home because they consider more practical matters, e.g., the layout of the building (Viholainen et al., 2020).

2.3.3 Age and regional characteristics

The literature suggests that personal variables, such as consumers' socio-demographic characteristics, can also affect consumers' perceptions of wooden building material (Harju, 2022). Age significantly influences construction material preferences. Younger consumers, particularly millennials, are more inclined towards environmentally friendly materials such as wood (Høibø et al., 2015; Petruch & Walchner, 2021). They prioritize environmental impact over durability and solidity, fostering preference for wood. Conversely, older individuals favor durability, expressing a preference for stone or brick (Høibø et al., 2015). Toppinen et al. (2018) and Loučanová & Olšiaková (2020b) also underscore the relevance of younger people's sustainability concerns in driving demand for wood-framed houses. Finally, it is important to consider the relevance of regional characteristics. Leszczyszyn et al. (2022) indicate that regional variances influence the use of wood in construction,

reflecting distinct wood market conditions and varying historical-cultural contexts. Furthermore, Lähtinen et al. (2021) found that regional prejudices against wood as a structural material vary significantly, with 45% in Denmark, versus 12-18% in Finland, Sweden, and Norway. The reasons include Denmark's weaker wood-building tradition, protective stance on forests, and climatic factors impacting perceptions of wood as a renewable resource. Roos et al. (2022) found differences between urban and rural regions in the preference of wood as a construction material, which can be explained by a potential association of wood construction in detached housing being more common in rural areas compared to urban areas (Roos et al., 2022). A study by Vehola (2022) found that respondents residing in larger cities tend to have negative beliefs concerning wood construction more often than those residing in the countryside (Vehola et al., 2022).

2.4 Flexible housing

2.4.1 Relevance of flexible housing

The relevance of flexible housing to the adoption of wood in residential construction in Germany is a crucial aspect to explore. Housing shortages and the uncertainty of rental and real estate prices have been prominent issues in Europe, including Germany (Rink & Vollmer, 2019). The increasing demand in expanding urban areas has led to substantial price hikes in properties and rents (Pätzold, 2021). Alongside these challenges, there has been a significant rise in average living space and changing demographics, putting additional pressure on the housing market. The static nature of existing buildings and the uncertainty surrounding the evolving needs of residents in newly constructed buildings highlight the inadequacy and obsolescence of housing when it is considered as a static object (Drexler, 2021). To address the continuous

challenges in the housing market and reduce the overall lifetime carbon footprint of houses, architectural and structural flexibility becomes a relevant factor alongside the adaption of wood. Flexibility enables housing to respond to changing needs and patterns, whether social or technological, ensuring adaptability over time (Schneider & Till, 2007). It allows for timely and effective modifications that accommodate changes in demand, innovative technologies, new regulations, and resource availability (Sethi & Sethi, 1990). The benefits of flexible buildings extend to environmental sustainability, as conventional construction methods often fail to consider the inherent capacity to adapt to new environmental requirements and consequences (Sadafi et al., 2014).

2.4.2 Definition of flexible housing

Various definitions of flexibility have been proposed by researchers. Cellucci & Di Sivo (2015) define flexibility broadly as the ease of modifying a system to meet user needs effectively and in a timely manner. Gerwin (1993) considers flexibility as an adaptive response to environmental uncertainty. Cavalliere et al. (2019) define flexibility as the ability of buildings to adapt to cultural, technological, and economic transformations. Dhar et al. (2013) emphasize flexibility in housing as a means to meet changing needs, prolong a building's lifespan, and reduce resource consumption. Fawcett (2011) defines flexibility as the ability to accommodate changes in function, capacity, and environmental flow within a building. Slaughter (2001) categorizes flexibility into changes in function, capacity, and flows, aiming to save costs during renovations. Schneider and Till (2007) refer to flexibility in housing as the ability to adapt to changing user needs and patterns at both the building and unit levels. Habraken (1972) argues for flexible housing design to promote diversity, individuality, community, and

sustainability. Schmidt et al. (2010) define adaptability as a building's capacity to accommodate evolving contextual demands, maximizing its value over time. Graham (2005) views adaptability as a strategy to prevent obsolescence and incorporate changes efficiently. Russell & Moffatt (2001) see adaptability as a building's capacity to accommodate substantial change. Groák (1992) differentiates between adaptability and flexibility, where adaptability refers to social uses and flexibility pertains to physical arrangements. Till & Schneider (2005) view flexibility as a broader term than adaptability, encompassing housing that can adapt to users' changing physical needs and social issues.

Based on the presented literature, flexibility is understood in this thesis as housing that refers to the ability to modify a system or building in response to user needs, environmental uncertainty, cultural and technological transformations, changing demands, and patterns. It encompasses adaptability, changes in function, capacity, and flows, and plays a role in promoting sustainability, community, diversity, and individuality.

2.4.3 Aspects of flexible housing

The available literature was thoroughly examined to investigate factors that may influence the perceived importance of flexibility in housing from the homeowner's standpoint. While empirical studies and widely accepted understandings on this subject are currently lacking, the existing literature does provide indications and insights into certain aspects that are likely to have an impact on the perceived importance of flexible housing, especially in terms of the adaption of wood. To ensure

clarity and ease of understanding, these factors have been systematically grouped into four distinct aspects, which will serve as research framework for SR-2.

Within the context of the house itself, several factors contribute to the importance of flexibility. One crucial factor lies in the choice of construction material, where wood emerges as a highly advantageous option. Extensive research conducted by Sadafi et al. (2014) and Scuderi (2019) emphasizes the remarkable flexibility, sustainability, and recyclability of wood, surpassing conventional materials such as concrete and brick. Wood not only offers a renewable and environmentally friendly alternative, but its inherent properties enable easier modifications and adaptability over time. The natural characteristics of wood, including its strength, lightweight nature, and ease of construction, make it highly favorable for creating flexible housing designs that can accommodate evolving needs and changing lifestyles. Another significant aspect related to the house is the type of property. The nature of the property plays a decisive role in determining the potential range of uses and the extent to which flexibility can be incorporated. For instance, single-family houses are characterized by their specific structural features, often leading to a limited demand for other housing types. However, considering the long-term usability of such houses, it becomes essential to explore the potential benefits of flexibility, especially when faced with situations where these houses become underused as children move out or residents experience restricted mobility (Drexler, 2021). The amount of space available within the house also contributes to the overall degree of flexibility. The relationship between space and flexibility is complex, and it remains uncertain whether it is the property size, the living space, or the number of rooms that plays the most significant role (Drexler, 2021). However, it is worth considering that having more space with lower technical specifications might be prioritized over a custom-fit and functionalist property layout

when it comes to achieving flexibility (Till & Schneider, 2005). The availability of ample space provides greater potential for accommodating future changes and modifications in the housing environment.

The second group of factors revolves around (socio-)demographic aspects of the residents living in the house. Increased flexibility in housing can offer homeowners the opportunity to effectively utilize the floor space as their needs evolve or as their families grow (Russell & Moffatt, 2001). Flexibility is often optimized to address specific scenarios resulting from shifts in residents' preferences, such as changes related to age, care needs, limited mobility, and other influencing factors (Drexler, 2021). These dynamic factors emphasize the importance of adaptability to cater to the changing circumstances and requirements of the occupants. The socio-demographic characteristics of the residents also play a significant role in determining the importance attributed to flexibility. A study by De Paris & Lopes (2018) revealed that middle and lower-middle-income homeowners tend to make more frequent adaptations to their houses compared to high-income homeowners. These adaptations are often driven by changes in lifestyle, family structure, and the rental market. It can be inferred that individuals' socio-demographic background influences their perception of flexibility and their willingness to embrace changes in the housing environment.

The third aspect encompasses various building properties associated with flexible housing. Flexibility in housing can serve as a strategy to counteract potential obsolescence, extend the lifespan of the building, and reduce maintenance costs (Russell & Moffatt, 2001). Moreover, flexibility can address shifts in property value resulting from environmental uncertainties (Sadafi et al., 2014). Implementing flexibility in housing design can enhance the overall value of the property, allowing homeowners to command a higher price without significant additional investment (Scuderi, 2019).

This aspect is particularly relevant as housing is increasingly viewed as an investment and a vital component of individuals' long-term financial plans, including retirement strategies (Schneider & Till, 2005). Accessibility is also a critical factor that significantly contributes to defining the importance of flexibility in housing. By making spaces accessible for people at all stages of life and with varying physical conditions, flexibility ensures inclusivity and allows for customization based on individual needs (Schmidt et al., 2010). Conventional functionalist buildings, designed and built with specific usage profiles in mind, often struggle to adapt to different user groups or changing requirements such as age-appropriate or wheelchair-accessible apartments and communal living arrangements. Embracing a more flexible approach enhances the potential for diverse utilization and customization, accommodating a broader range of individuals and their unique needs (Drexler, 2021).

Lastly, environmental sustainability is a key consideration in building construction (Sadafi et al., 2014). With the existing building stock representing a substantial financial, physical, and cultural asset globally, the importance of flexible housing becomes even more pronounced in the context of resource scarcity and ecological crises (Russell & Moffatt, 2001). Flexible housing strategies can contribute to extending the overall lifespan of buildings, thereby reducing the need for new construction, utilizing underused or vacant building stock, and promoting the disassembly of components to prolong a building's useful life (Schmidt & Austin, 2016). Compared to new construction, flexibility in housing offers significant environmental advantages, including lower resource consumption, preservation of land, and the ability to utilize existing infrastructure. It also enables homeowners to benefit from technological innovations sooner and at a lower cost, leading to increased operational efficiency and reduced environmental impact (Russell & Moffatt, 2001). It is worth

noting that building obsolescence can occur not only due to technical reasons but also as a result of changing societal preferences, such as evolving room size and layout standards. Post-war buildings from the 1950s and 1960s in Germany serve as examples, where rooms designed for children are considered too small by today's standards (Drexler, 2021). In conclusion, homeowners who prioritize environmental sustainability are likely to value flexibility in housing, as it aligns with the broader goal of sustainable development. Flexibility is fundamentally connected to a sustainable social, environmental, and economic imperative, offering a solution that accommodates uncertainty regarding demographic shifts, social dynamics, and technological progress (Schneider & Till, 2005).

3 Methods and research designs

3.1 Study among regional differences

Since Germany’s regions can be distinguished between the federal state, district, and municipal levels, it was decided upon district level as an examination unit regarding regional differences since it provides the greatest analysis opportunities. Additionally, the respective districts have final jurisdiction over the building permits. For this purpose two kinds of data acquisition strategies were necessary.

(1) The German federal and state statistical departments keep records of building permits, but without specifying construction materials used (Statistische Ämter des Bundes und Länder, 2021). This information is tracked by district authorities and is usually available on request. Therefore, to obtain data on permits issued by material type from 2015 to 2019, contact was made with all 14 German state statistical offices. These offices typically categorize using eight distinct

materials, including wood. Even though wooden houses often contain a considerable amount of non-wooden elements, such details aren't captured in the statistics. Therefore, the analysis couldn't account for these variations. Nevertheless, it was possible to gather data on the number of permits issued per district, distinguishing between wood and non-wood materials, for all 401 German districts over the period 2015-2019. This data was then used to calculate proportions of different building material in the corresponding district.

(2) For the independent variables, only publicly accessible data from federal and state statistical offices was used. The selection of variables was driven by literature-identified influential factors and data availability. Variables, classified as federal states, geographical conditions, demographic structure, and construction and building land were considered. The variables can be found in Table 1.

In order to conduct the analysis, the specifically collected data from the 14 state offices for statistics and the publicly accessible data from the *Statistische Ämter des Bundes und Länder* were assembled into a dataset in which the variables were allocated to specific districts. The dependent variable percentage of wooden residential building permits had a mean of 17.87% for the relevant 5-year period, with a standard deviation of 9.88 and a range of 42.32. The approach adopted for data analysis involved a bivariate analysis as the foundation, leading to a multiple linear regression analysis for the data from the period 2015 to 2019.

Table 1 Variables used for SR-1

	Variables	*Mean*	*SD*	*Min.*	*Max.*
	Wooden residential building permits (in %)	17.87	9.88	2.60	44.92
States	16 Germany States (Dummy Variable)	-	-	-	-
Geographical Conditions	Population (absolute)	206322	241754	34272	3604534
	Area (in km^2)	889.56	724.7	35.7	5495.6
	Population density (inhab. per km^2)	534.11	703.28	36.04	4716.1
	Number of municipalities (absolute)	26.92	32.04	1	234
	Share of woodland (in %)	28.04	14.84	0.41	63.37
Demographic Structure	Mean age (absolute)	44.91	1.94	40.32	50.32
	Old-age dependency ratio	37.21	5.77	23.8	57.12
	Youth dependency ratio	30.62	2.42	22.44	38.34
	Unemployment rate (in %)	5.34	2.41	1.36	13.88
	Laborer, no professional qualification (in %)	12.93	3.65	4.96	25.12
	Laborer with professional qualification (in %)	72.64	8.03	39.34	85.45
	Laborer with academic qualification (in %)	14.43	6.94	6.35	46.81
Construction and Building Land	Average building land size (in m^2)	1468.9	5731.4	576.05	5792.32
	Average building land purchase value (€/m^2)	144.07	192.3	11.5	2362.98
	Number of construction firms (per capita)	.00101	.00047	.00022	.00277

Source: own calculation

3.2 Study among homeowner preferences

In order to address the sub-research questions concerning homeowner's preferences and flexible housing criteria, an online survey was conducted with homeowners in Germany. The survey was carried out in December 2021 with panel members from an international market research company. The sample was comprised of 519 individuals who had either built or purchased a house within the last five years, with a balanced distribution of genders (55.5% female, 44.5% male) and ages (M = 40.94, SD = 11.97). Concerning the house of the respondents, the survey results indicate that 69.9% of respondents opted to buy their homes, whereas 30.1% chose to build. The majority of houses, comprising 72.4%, were either detached single-family or duplex houses (13.9%), with only 2.3% being multi-family units. As for building materials, a significant proportion of homes (83.4%) consisted primarily of either concrete or bricks, while the

remaining 16.6% were constructed using wood. Table 2 displays the variables outlined, along with their mean values, and standard deviations. With the exception of age (metric variable) and residential area size (dichotomous), a five-step Likert scale was used for data collection.

Table 2 Variables used for SR-2

Variable	*Mean*	*SD*
Importance of price of building	4.31	.854
Importance of value stability of building	3.40	1.078
Importance of durability and solidity of building	4.34	.778
Importance of maintenance cost of building	4.02	.859
Importance of fire safety and resistance	3.82	1.010
Importance of sound insulation	3.82	1.016
Importance of healthy indoor environment	4.03	.928
View on eco-friendliness of wood in construction *	3.44	1.006
Importance that building is made of renewable material	2.94	1.152
Age	40.94	11.97
Residential area size (under / over 100 000) **	-	-

Source: own illustration;
* Agreement with statement: “I am generally of the opinion that building with wood as a building material is more eco-friendly than with other building materials (e.g., concrete or bricks)”
** dichotomous; 81.7% of the respondents lived in areas with under 100 000 inhabitants, while 18.3% lived in areas over

3.3 Study among flexible housing

To examine to what extend flexible housing criteria are relevant for homeowners and in what context they stand in terms of adaption of wood in residential construction, the same sample was used as described in chapter 3.2, comprising 519 individuals that had either built or purchased a house within the last five years. As there was no previous research on the consumer view on flexibly criteria, own statements were developed to measure the importance of flexibility criteria using various definitions from the literature, which will be discussed later in more detail. Responses gave insights into the interrelation of different aspects of flexibility. These served as the dependent

variables in predicting the perceived importance of flexibility. Five critical items were selected and rated on a five-step Likert scale.

Table 3 Variables used for SR-3

Variable	*Mean*	*SD*
Item 1: Ability to use of rooms differently without undertaking structural measures	3.82	.991
Item 2: Flexibility of the house for performing physical alterations (such as by connecting, dividing, or merging rooms)	3.37	1.151
Item 3: Flexibility of the house for making changes resulting from plannable life phases (such as children, old age)	3.64	1.115
Item 4: Flexibility of the house in accommodating unexpected events and developments	3.44	1.083
Item 5: Flexibility in terms of the ease of implementing an accessory apartment	2.31	1.391

Source: own calculation

Item 1 refers to a house's ability to accommodate change and adaptation without the need for any structural measures. It implies that a unit's interior layout can be modified to allow for changing physical needs and different social functions of the rooms (Groák, 1992; Till & Schneider, 2005; Schneider & Till, 2007). Item 2 specifies the technical and architectural element of flexibility by ensuring that the unit is designed to allow for uncomplicated and low-cost changes in allocation. Individual units can be designed to be linkable or detachable to allow an expansion or reduction in the size of the unit or specific rooms (such as by connecting, dividing or merging rooms). This design can create cost and resource savings by reducing the time needed to implement the changes (Groák, 1992; Schneider & Till, 2005; Slaughter, 2001). Item 3 relates to the social aspect of flexibility due to changes in family structure, social network, gender composition and educational opportunities. Flexibility in terms of plannable life phases refers to changes in the successive stages of life (younger children, older children, and

elderly parents) as well as issues relating to social opportunities (Dhar et al., 2013; Fawcett, 2011; Schneider & Till, 2005). Item 4 refers to the ability of a house to accommodate environmental uncertainties and unanticipated cultural, economic and, in particular, technical developments. In this context, flexibility is considered to avoid building obsolescence by maintaining the ability of the facility to meet certain performance requirements (Gerwin, 1993; Cavalliere et al., 2019; Slaughter, 2001; Graham, 2005; Russell & Moffatt, 2001). Item 5 refers to the ease of providing an accessory apartment or “granny annex”. This strategy includes the option of reducing the size of the dwelling at any given time, either because the members of the household no longer require the entire area of the house and can divide it into two or more units or they can assign part of the floor space to another dwelling (Cellucci & Di Sivo, 2015). The lack of flexibility of a dwelling often leads to its insufficient use, whereby elderly people continue to live in an apartment that is too large and non-dividable, once their children have moved out. In the absence of such flexibility, properties have to be converted, renovated or rebuilt more frequently (Drexler, 2021). In order to create an index to use as dependent variable, the factorability of five items relating to affinity for building flexibility was assessed. Our examination involved a principal component analysis and an evaluation of internal reliability. The outcomes indicated a satisfactory fit and recommended employing all variables as part of the affinity for building flexibility index ($M = 3.31$, $SD = .825$).

The statistical analysis for this thesis was conducted using two software programs: SPSS (version 26) and JASP (version 0.11.1 to 0.17.1). SPSS was utilized for data management, while JASP was employed for traditional statistical analyses to provide a comprehensive examination of the research findings.

4 Results

This chapter outlines the findings alongside synopses of Paper I, Paper II, and Paper III, each directed at a sub-research question of this thesis. A summarization of the principal outcomes and contributions of every paper is presented herein. The appendix includes the full papers.

4.1 Wood or not? An analysis of regional differences in wooden residential building permits in Germany

The paper “Wood or not? An analysis of regional differences in wooden residential building permits in Germany” was published 2022 by Christian Mergel, Klaus Menrad and Thomas Decker in *Journal of Cleaner Production*. The doctoral candidate was the primary author of the paper and was responsible for data collection, data analysis and writing the manuscript in agreement with the co-authors.

Mergel, C., Menrad, K., & Decker, T. (2022). Wood or not? An analysis of regional differences in wooden residential building permits in Germany. Journal of Cleaner Production, 376, 134328. https://doi.org/10.1016/j.jclepro.2022.134328

The European construction industry's consistent expansion has increased environmental concerns like CO2 emissions and waste. Consequently, there's a shift towards biomass-based materials like wood. Despite this, Germany's wooden residential building share remains low compared to Nordic countries, demonstrating pronounced regional disparities, with proportions ranging from 0 to over 50% at district level.

To explore the research questions, "What factors account for the regional disparities in Germany's wooden residential building permits?" a bivariate analysis was

performed, laying the foundation for a subsequent multivariate analysis, based on the data basis described in chapter 3.1. A total of five multiple linear regression models were employed for the period from 2015 to 2019. The models included area, share of woodland, mean age, unemployment rate, proportion with academic qualification, number of construction firms, and average building land size as independent variables, while the eight other variables were excluded due to collinearity or lack of linearity. The regression models demonstrated a high explanatory power and established similar contexts across the board.

The paper identified four key factors as an explanation for the regional differences of wooden residential building permits in Germany. First, the results indicate an influence of the federal states. This could be due to the fact that the Musterbauordnung (MBO) and other building regulations are often differently designed and implemented between the federal states and this can have varying impacts on the use of wood in the construction of residential buildings. Second, the share of woodland positively influences the share of wooden houses, presumably based on both a benefit to local industry and a historical building tradition and path dependency. Third, highly urban and dense areas have a negative effect on wooden buildings as they are mostly constrained to multi-family houses, in which wood is not preferred or allowed as a construction material. Fourth, economically weak regions have a negative effect on the share of wooden residential buildings as they already have a high percentage of unoccupied and insufficiently used residential buildings and thus do not promote building new family houses, where wood as a building material has the highest relevance.

This study suggests two primary strategies to enhance the use of wood in residential construction for climate benefits. Firstly, the ratio of wood in multi-family houses should

be increased, particularly in densely populated regions, potentially through preferential policies or easing permit acquisition. Secondly, the German government could consider revising building regulations, making wood-related aspects of the MBO mandatory to align with the Paris Agreement's climate protection objectives.

4.2 Which factors influence consumers' selection of wood das a building material for houses?

The paper "Which factors influence consumers' selection of wood as a building material for houses?" was published 2024 by Christian Mergel, Klaus Menrad and Thomas Decker in *Canadian Journal of Forest Research.* The doctoral candidate was the primary author of the paper and was responsible for the data collection, data analysis and writing the manuscript in agreement with the co-authors.

Mergel, C., Menrad, K., & Decker, T. (2024). Which factors influence consumers' selection of wood as a building material for houses? Canadian Journal of Forest Research, 54(4). https://doi.org/10.1139/cjfr-2023-0197

Wood's use in German construction is steadily increasing, with about a quarter of new single and duplex family houses predominantly made of wood in 2021. However, the factors influencing consumers' choice of wood as a primary building material for residential houses remain under-researched. Understanding these consumer decisions can pave the way for better-informed future construction projects and communication strategies, potentially enhancing wood usage in construction. Against this background, this study aims to investigate factors that influence the selection of wood as the primary building material of residential houses.

To answer the research question, a binomial logistic regression with the dichotomous variable building material (wood/other) serving as the dependent variable was conducted. Of all the variables used (described in chapter 3.2), six key influencing factors in the selection of wood as a primary building material in the construction and purchase of residential houses in Germany were found: Individuals are more likely to choose wood as their primary building material if they have a positive view on the eco-friendliness of wood in construction and also if they place emphasis on the importance on the house being made of renewable material. Furthermore, the likelihood of selecting wood increases with age and is also higher among consumers residing in rural areas. Negative effects of the likelihood of selecting wood, however, emanate from the importance of value stability of the house for consumers and, which is even more significant, the importance of durability and solidity of the building.

The findings of this study suggest that wood is often overlooked in favor of other materials due to misconceptions about its durability, value stability, and even its environmental impact. One approach to promote the use of wood in construction is to raise awareness and inform individuals about its eco-friendliness. This approach is especially critical, since a positive perception of wood's environmental sustainability was one of the most significant factors in its selection as a building material. This is especially relevant for urban and densely populated areas that have a very low proportion of wooden houses and most likely rather negative preconceptions towards wood. Intensifying consumer information and communication about the environmental and practical benefits of wood as a building material, as well as opposing prejudices about its use in construction, can have a significant impact on its selection as a more eco-friendly building material. By making informed decisions about sustainable building materials, home builders and home buyers can contribute to a more sustainable and environment-friendly building environment.

4.3 Affinity towards flexible housing – a study among homeowners in Germany

The paper “Affinity towards flexible housing – a study among homeowners in Germany” was published 2023 by Christian Mergel, Thomas Decker and Klaus Menrad in the Journal *Building Research & Information.* The doctoral candidate was the primary author of the paper and was responsible for the data collection, data analysis and writing the manuscript in agreement with the co-authors.

Mergel, C., & Decker, T., & Menrad, K. (2023). Affinity towards flexible housing – a study among homeowners in Germany. Building Research & Information. https://doi.org/10.1080/09613218.2023.2206091

Widespread concerns across Europe are arising from housing shortages and skyrocketing property prices, especially in expanding urban regions. The static nature of architectural approaches, evolving demographics, and societal individualization compound housing market strain. Architectural flexibility could be a solution, adapting to shifting needs and improving environmental sustainability. However, the homeowner's perception and factors influencing the implementation of flexible housing remain under-explored. This paper scrutinizes the relevance and predictors of flexible housing importance to homeowners.

In order to answer the research questions “To what extent are flexible housing criteria relevant to homeowners?” and “What factors predict the importance of flexibility for homeowners?”, a multiple linear regression was conducted, in which affinity for building flexibility represented the dependent variable, and the four categories (house, (socio-) demographics, building properties and sustainability aspects) represented the categories for the independent variables. The results of the regression identified a total

of ten key factors that explain the importance of flexibility to residents. There is a substantial influence exerted by the number of rooms in a property, the size of the residential area, the negative influence of age, the importance of a building's stability and longevity, its accessibility, its value stability, the owners' environmental awareness, the perceived importance of the use of renewable materials, and the perceived importance of a high recyclability of the building materials. The choice of wood could not be found as significant predictor for the importance of flexible housing for homeowners.

This study compensates for the lack of research in the field and furthers researchers' understanding of the homeowner's perspective of flexible housing. This is especially relevant bearing in mind that the use of flexible housing can be crucial when faced with resource scarcities or even an ecological crisis. It also provides a strategy for mitigating negative developments in the housing market, such as uncertain costs and housing shortages. Research into flexible housing plays an important role in the development of a more socially and environmentally sustainable housing market, especially as this can benefit both the residents' and the stakeholders' sides.

5 Discussion

The following sections address the thematic and methodological discussions as well as the limitations of the three paper.

5.1 Thematic discussion

Returning to the conceptual framework established earlier (Fig. 1), the study examined different levels of the framework to understand the factors influencing the adoption of

wood as a construction material in Germany. First of all, the individual factors influencing the three levels or studies will be discussed, and subsequently this chapter brings together the findings from all three papers and identifies the key findings of the thesis as a whole.

Beginning with the lowest level and SR-1 “Which factors influence the regional differences in the share of wooden residential building permits in Germany?”, the analysis revealed that in terms of federal states, all but Bremen, Hamburg, and Berlin could be seen as significant negative predictor for the use of wood in construction in comparison to Baden-Württemberg. This aligns with literature (Dederich, 2013; Wahlberg et al., 2015; DHWR, 2016) that suggests that legislation (that is implemented on the level of the federal states in Germany) might impact the use of wood in construction. Nevertheless, it cannot be ruled out that there might also be general differences in construction material preferences from a micro-perspective, i.e., related to different outcomes of path dependencies and building traditions between the federal states (Purkus et al., 2020; Walberg, 2016). Given these considerations, the results are in line with the existing literature, though the chosen empirical design of the PhD thesis study cannot identify a causal relationship. Geographical conditions — population, area, population density, number of municipalities, and share of woodland — all significantly correlated with the proportion of wooden residential building permits. Rural areas, in particular, had a high percentage of wooden residential buildings (Purkus et al., 2020), with area acting as a constant significant predictor. The number of municipalities and share of woodland also impacted the proportion of wooden buildings, which aligns with existing literature (Walberg, 2016; Kies et al., 2011; Purkus et al., 2020). These findings suggest regions with substantial forests may economically benefit from using wood as a construction material due to existing

building traditions and specialized construction firms. Contradictory to literature (Høibø et al., 2015; Toppinen et. al, 2018; Petruch & Walchner, 2021), a negative correlation was observed between age and the preference for wood as a building material. Other demographic factors, including unemployment rate and proportion of workers with an academic qualification, also showed unexpected correlations. The negative beta coefficient for the proportion of workers with academic qualifications challenged the findings of Gold and Rubik (2009b). This may be due to the high negative correlation between wooden residential building permits and the unemployment rate, indicating economic weakness and consequent demographic shifts in certain regions (Mertens & Haas, 2006). In terms of construction and building land, variables like average building land size and purchase value, and the number of construction firms per capita, showed diverse impacts. While the significant negative correlation of average building land size aligns with the literature (Kaiser & Mantau, 2013), the impact of the average purchase values contradicts Gans' (2017) findings. Furthermore, the average building land size and the number of construction firms per capita were not significant predictors in the regression models.

Arrived on the second level of the conceptual framework and SR-2 "Which factors influence the selection of wood as a primary building material in the construction and purchase of residential houses in Germany?", beginning with the importance of price, no correlation between the latter and the choice of building material was found, despite prior research suggesting skepticism towards the cost-competitiveness of wood (Karjalainen et al., 2021; Mühlbachler & Tudor, 2022). Value stability, however, emerged as a pivotal factor, as suggested by Gold & Rubik (2009a) and Harju & Lähtinen (2022). Buyers emphasizing durability and solidity favored bricks or stone over wood, affirming Høibø et al. (2015)'s findings. This preference possibly stems

from perceptions about wood's durability and associated maintenance costs (Leszczyszyn et al., 2022; Viholainen et al., 2020). Interestingly, commonly cited concerns around fire safety and poor sound insulation were not significant in the study on hand. Regarding the influence of the perceived health benefits of wood the study found no decisive connection, which contradicts a variety of previous studies (Gold & Rubik, 2009; Hu et al., 2016; Karjalainen et al., 2021; Leszczyszyn et al., 2022; Mühlbachler & Tudor, 2022; Viholainen et al., 2021). However, two significant environmental dimensions can be uncovered. First, those respondents with eco-conscious views showed a higher likelihood of choosing wood. Second, a perceived lack of awareness of the environmental advantages of wood might prompt individuals to opt for other materials. The findings underscore the role of the consumer's perspective on the eco-friendliness and renewability of their building material. Those prioritizing these aspects are most inclined to select wood, making these some of the most influential factors in the regression model. Age-wise, literature suggests that younger consumers, expressing more sustainability-related concerns, form the potential market for wood-based housing (Høibø et al., 2015; Petruch & Walcher, 2021; Toppinen et al., 2018). This could not be confirmed by this thesis. Finally, urban residency negatively impacts the rate of wooden buildings (Roos et al., 2022; Vehola et al., 2022), possibly due to prevalent negative perceptions of wood construction in urban settings.

At the top of the research framework and SR-3 "To what extent are flexible housing criteria relevant to homeowners?” the analysis found that homeowners perceive the various aspects of flexible housing as somewhat consistent and meaningful. Although literature cites wood as the most flexible construction material (Sadafi et al., 2014; Scuderi, 2019), no heightened emphasis on flexibility from respondents who opted for

timber houses were found. Similarly, flexibility did not significantly influence the type of property chosen, contrary to Drexler (2021). Within house characteristics, the number of rooms emerged as the most influential predictor of flexibility importance, aligning with Till & Schneider (2005), although the association of room number with space is not necessarily direct. However, property size, living space, and the number of rooms all contribute to residents' affinity for flexibility. Among sociodemographic variables, household size, age, and residential area size significantly influenced perceptions of flexibility. As household size increases, so does flexibility importance, possibly due to complex social networks (Dhar et al., 2013; Fawcett, 2011). Age negatively correlated with flexibility importance, as suggested by Fawcett (2011) and Russell & Moffatt (2001), likely due to diminished need for physical changes as household's age. Increased flexibility importance in larger residential areas may relate to housing shortages, real estate prices, and high rents (Pätzold, 2021). For building properties, longevity and stability align with literature as crucial flexibility motives (Russell & Moffatt, 2001). Accessibility surfaced as highly influential, as it facilitates adaptation to changing needs (Drexler, 2021). Value stability is significant, with flexibility often used to enhance or counteract property value shifts (Sadafi et al., 2014; Scuderi, 2019). Finally, environmental sustainability aspects greatly influenced flexibility importance. Renewable and recyclable material importance, alongside accessibility, emerged as the most influential predictors. This supports the notion of flexible housing as a strategy to reduce resource consumption and enhance component disassembly (Schmidt & Austin, 2016).

Having explored the findings of each study individually, three key factors, namely residential area, the age of the respondents as well as sustainability, consistently

present across the three studies, could be determined. These three factors are illuminated in more detail in the following.

First of all, a crucial determinant that surfaced consistently across all three studies was the impact of the residential area's size respectively its location in a rural or urban environment on construction materials. This finding underscores a potent link between the characteristics of a residential area and for instance the homeowner's material preferences. Urban environments, with their inherent space limitations, higher prices for building ground and higher population densities, typically require different construction approaches compared to less congested suburban or rural settings (Drexler, 2021). In densely populated urban spaces, homeowners may prefer conventional materials such as brick or concrete, since building space is more limited, multi-family houses prevail, with wood often overlooked as a building material (Roos et al., 2022). This is likely due to building regulations and potential negative views of architects and stakeholders towards using wood in multi-family house construction (Roos et al., 2010). On the other hand, in suburban or rural areas with lower population density, the appeal of wood increases significantly, potentially due to the stronger connection to nature and the aesthetic charm of wooden houses that blend seamlessly into such environments (Vehola et al., 2022). This is also implicated by the high influence of the share of woodland on wooden residential building percentage that suggest a regional tradition for wood-based construction, reinforced by specialized construction firms (Walberg, 2016; Kies et al., 2011; Purkus et al., 2020).

The opposite seems to be the case for flexibility, which is significantly more important in agglomeration areas. Firstly, the high demand for living space in such areas necessitates the efficient use of available land. Flexible housing solutions can adapt to changing living requirements over time without necessitating extensive reconstruction,

thus optimizing the usage of space. Secondly, densely populated areas often exhibit higher rates of societal change, including variations in family structure, lifestyle, and working conditions (Dhar et al., 2013; Russell & Moffatt, 2001). This dynamic environment necessitates housing that can adapt swiftly to accommodate these changes (Schneider & Till, 2007). Lastly, the cost of property and construction in densely populated regions can be considerably higher. As a result, flexibility, which can extend the functional lifespan of a building or allow for versatile usage, becomes an economically favorable trait in housing design (De Paris & Lopes, 2018). Therefore, residents and builders alike are more likely to prioritize flexibility in their housing preferences.

In all three studies, age of the respondents surfaced as a key factor in wood usage as construction material, though its influence manifested differently across contexts. Both study 1 and 2 found a strong link between older age of homeowners and a preference for wood in construction. This finding presents a challenge to existing literature that mostly associates younger generations as the primary proponents for wood usage in construction. Most research presupposes that the younger population, with its increasing awareness of sustainability and environmental concerns, would be more inclined towards environmentally friendly building materials like wood (Høibø et al., 2015; Toppinen et al., 2018; Petruch & Walchner, 2021). They are often seen as more open to innovative construction methods, such as those involving wood, and more likely to value wood for its carbon sequestration properties and its potential to contribute to mitigating climate change. However, the analyses carried out in this thesis indicate an alternative narrative - older generations showing a significant preference for wood in their homes. This leaves room for conjecture regarding the underlying causes. One reason could be the health benefit of wood. Since there's

growing evidence that living in wooden houses can have health benefits, including improved air quality and lower stress levels, these advantages might be particularly attractive to older individuals who are more conscious of their health and wellbeing (Häyrinen et al., 2020; Harju, 2021). The preference for wood among older individuals may also be closely tied to their likelihood of living in rural areas (Vehola et al., 2022). As mentioned before, rural environments often have a rich history of traditional wooden architecture due to the local availability of timber. As a result, older individuals in these settings might have grown up around wooden structures, fostering a sense of familiarity and comfort with this material (Viholainen et al., 2020). The rural landscape also typically offers more space, possibly encouraging larger, wood-constructed homes. While it's often younger generations that are associated with environmental consciousness, however, older individuals too can be aware of and value the sustainability aspects of wood. They might appreciate the fact that wood is a renewable resource and that its use in construction can have a lower environmental impact compared to some other materials (Harju & Lähtinen, 2022). Conversely, the third study found that older age groups do not emphasize flexibility in housing as much as their younger counterparts. This could be due to the fact that older individuals generally have settled lifestyles and well-defined needs and preferences, and thus might not value flexibility in the housing structure as much. Their homes are often seen as a solid foundation, and they may prefer a sense of permanence and stability, which they associate with non-flexible structures (Schneider & Till, 2005).

Environmental sustainability emerged as a key factor in all three studies, underscoring its significance in the adoption of wood as a construction material. The findings of this thesis consistently demonstrated that individuals who prioritize environmental sustainability are more inclined to choose wood for their homes. This aligns with the

growing global concern for sustainable and eco-friendly building practices (Gold & Rubik, 2009a). The positive association between environmental awareness and wood adoption suggests that promoting the environmental benefits of wood, such as its renewable nature and lower carbon footprint, could be instrumental in encouraging its wider use in residential construction (Lähtinen et al., 2022; Mühlbachler & Tudor, 2022 Toppinen et al., 2013). The findings highlight the potential for incorporating sustainability considerations into policies, regulations, and communication strategies regarding a more eco-friendly construction sector (Mahapatra et al., 2013). Furthermore, it emphasizes the need for continued research on innovative and sustainable wood construction techniques, as well as the development of sustainable supply chains to ensure the availability of responsibly sourced wood materials (Nan & Jie, 2020). In terms of flexible housing criteria this thesis suggests that despite wood's potential advantages in terms of flexibility, these benefits did not translate into a higher perceived importance of flexibility among individuals who choose timber houses. This could imply that while the theoretical and practical advantages of wood in terms of flexibility are recognized in the literature (Sadafi et al., 2014; Scuderi, 2019), these may not be well understood or appreciated by the general population or individuals interested in wood as building material. Moreover, as wood has been highlighted as a key material in sustainable construction due to its renewability and lower environmental impact compared to materials like concrete or steel, its perceived lack of importance in terms of flexibility presents an interesting contradiction. Sustainability and flexibility are both critical attributes in contemporary construction, reflecting the need for buildings that can adapt to changing needs over time while minimizing their environmental footprint (Russell & Moffatt, 2001; Schmidt & Austin, 2016; Sadafi et al., 2014). Overall, the discrepancy between the inherent flexibility of wood and its perceived importance in

the decision-making process underscores the need for further education and awareness among consumers and stakeholders about the potential benefits of wood, particularly in the context of adaptable and sustainable home ownership.

5.2 Methodological discussion

The study design for this thesis employed two quantitative methods, aimed at providing comprehensive insights into the factors influencing the adoption of wood as a building material in residential construction in Germany. The thesis commenced with a detailed literature review, which set the foundation for the research.

The first quantitative method for thesis relied on public data from the German federal and state statistics departments, which required additional steps to gain insight into the use of specific construction materials. Despite this, the data could still not account for variations within the use of wood in construction, such as the difference between timber-frame and log construction, due to the recording practices of the German statistical authorities. Therefore, the empirical analysis may lack depth in accounting for the full range of construction techniques involving wood. The selection of independent variables, influenced by available literature and data constraints, may also limit the findings' scope. The transformation of categorical variables into multiple dummy variables, while necessary for regression analysis, might oversimplify some nuanced state-level influences. Also, data related to education, while representative of the available statistics, could be insufficiently detailed to fully understand its impact. Geographical conditions, demographic structure, and construction and building land factors were carefully considered, drawing from literature insights. However, given the unprecedented nature of this study, the accuracy of these selected variables in predicting the use of wood in building permits at the district level is yet to be tested.

Future research may reveal other potentially influential factors not included in this study.

In addition, methodological challenges arose concerning multicollinearity, non-linearity, and heteroskedasticity among the variables used for paper 1. Despite significant relationships between certain variables and the dependent variable (share of wooden residential building permits) indicated by non-parametric correlations, variables exhibiting multicollinearity were omitted from the regression models to avoid redundancy and potential bias. However, this decision raises the possibility of omitted variable bias, as excluding these variables could impact the accuracy of the regression estimates. An additional regression incorporating these multicollinear variables would have served as a useful robustness check since the interpretation of federal-state dummy coefficients would remain unaffected by their inclusion. Furthermore, non-linearity among the variables was not fully addressed in the initial regressions, which could have introduced omitted variable bias. To rectify this, a possible solution would be to linearize these non-linear variables for accurate estimation. Similarly, heteroskedasticity, which affects the standard errors of the OLS model, was not explicitly handled. Therefore, recognizing these methodological challenges is crucial for understanding the limitations and potential improvements in the analysis. To address these issues additional models where conducted and can be found in the annex.

Regarding the second quantitative method, the online-survey, certain restrictions were incorporated into the questionnaire selection process to guarantee that the respondents were 18 years or older and also were homeowners. These restrictions ensured that people with experience in the field of housing construction were included in the study. However, the diversity of responses may have been limited by these

restrictions, leading to a potential skew in demographic representation compared to the general German population. Potential biases could arise from a higher proportion of individuals who are inherently interested in the subject of construction, leading to a sample that may not fully represent the entire population. Additionally, our survey may have attracted more highly educated participants, which could influence their perceptions and preferences regarding wood as a construction material. Furthermore, we must consider the possibility of social desirability bias, where participants may respond in a manner they believe aligns with societal expectations, potentially affecting their choices and ratings related to environmental attitudes. While we aimed to mitigate these biases through rigorous sampling methods and data analysis, acknowledging these limitations is crucial in interpreting the study's findings. The study's validity was nonetheless maintained due to the substantial sample size (n=519). To prevent overwhelming the participants, a conscious decision was made to limit the number of attributes considered in the survey. However, this also introduces a limitation in that the selected attributes and attribute levels do not necessarily reflect the full spectrum of considerations when choosing a building material or assessing the flexibility of housing. Hence, the results need to be interpreted cautiously, as there might be other factors influencing homeowners' preferences that were not included in the study.

5.3 Limitations

While this PhD thesis has endeavored to explore and analyze the factors that influence the adoption of wood as a primary material in residential construction in Germany, several limitations should be acknowledged. These limitations pertain to the scope of the geographical focus and the theoretical framework.

One of the main limitations of this research is its geographical focus. This thesis exclusively uses data from Germany, by investigating the share of wooden residential

building permits across various districts in the country and by surveying only homeowners in Germany. This focus is both a strength, as it allows for an in-depth examination of the topic within Germany, and a limitation, as it may hinder the generalizability of the results. While the residential construction sector in Germany may share some similarities with those in other countries, there are undoubtedly specific cultural, regulatory, and economic nuances that make it unique. Therefore, the findings of this thesis may not be directly applicable to other contexts without taking these differences into account. In addition, the geographical focus presents challenges when it comes to the literature used to inform the research. A significant portion of the literature used as a theoretical and empirical foundation for the research comes from sources outside of Germany. While these sources provide valuable insights and perspectives, they may not fully capture the specificities of the German context. The use of literature from different geographical contexts could lead to the overgeneralization of certain concepts or dynamics. These discrepancies between the geographical origin of the literature and the focus of the empirical research could limit the accuracy and relevance of the research framework and the interpretation of the empirical results.

Furthermore, this thesis is primarily based on a comprehensive literature review, which offers a detailed understanding of the current state of research in the field. While this approach provides valuable insights into the status quo and prevailing trends, it lacks a theory that could offer a more structured and systematic analysis of the topics on hand. In the case of this thesis, without a theory, the exploration of use of wood in construction is potentially less systematic and could omit significant factors or relationships. The thesis is primarily reliant on previously established and empirically observed relationships rather than on theoretically predicted connections, which could

yield novel insights or challenge current beliefs. Additionally, without a guiding theory, it becomes challenging to build upon existing knowledge and contribute to theory development in a specific area. While the findings may be useful in understanding factors influencing the adaption of wood usage in German housing, applying these insights to other countries or cultures without a theoretical underpinning can be challenging. However, while the lack of a theoretical framework presents a limitation, the strength of this thesis lies in its empirical, data-driven approach, which offers valuable, ground-up insights into homeowner preferences. Moreover, this work contributes to a growing body of knowledge, which could serve as a springboard for future research, potentially inspiring the development of theoretical frameworks specifically tailored to the areas of housing flexibility and sustainable building materials.

6 Conclusions and future research needs

This section provides a comprehensive summary of the thesis, synthesizing the findings from all three papers. Furthermore, it offers a concise overview of potential future research topics.

In this thesis, three key factors emerged as significantly influential in the adoption of wood in construction in Germany: the residential area, the age of homeowners, and environmental sustainability concerns. The residential area was found to significantly influence wood usage in construction, with rural areas and regions with rich cultural heritage favoring wood more than urban regions. The age of homeowners was another important determinant, with older homeowners exhibiting a stronger preference for wood contrary to the previous literature that focused on younger homeowners. This suggests a complex relationship between age, tradition, possible health benefits, and

the choice of construction material. Lastly, environmental sustainability concerns played a pivotal role across all studies. Homeowners are increasingly conscious of their impact on the environment, seeing wood as a more sustainable choice in construction due to its renewable nature and lower carbon footprint. These factors, individually and interactively, significantly affect the uptake of wood as a construction material, highlighting the need for multi-dimensional strategies in promoting sustainable construction practices.

To increase the use of wood as a climate-friendly building material, efforts should be focused on promoting its adoption in multi-family housing, particularly in large, densely populated cities and districts. This can be achieved through policy interventions, such as providing incentives for wood construction in public projects or streamlining the process of obtaining building permits for wooden multi-family houses. Moreover, enhancing consumer awareness and communication about the environmental and practical benefits of wood as a building material is essential. By debunking misconceptions and biases, and providing information about its sustainability credentials, consumers can make more informed decisions and actively contribute to a more sustainable built environment. Lastly, the study emphasizes the importance of flexible housing and its potential to address resource scarcities and housing challenges. Understanding the homeowner's perspective on flexible housing can guide policymakers and industry stakeholders in developing strategies to promote its adoption. This can lead to more resilient and adaptable housing solutions, mitigating uncertainties in the housing market and fostering a socially and environmentally sustainable housing sector.

However, there are several avenues for future research that would enhance our understanding of this topic. Firstly, conducting similar studies in different countries

would provide valuable insights into whether these factors hold true across diverse cultural and regional contexts. It would help identify any country-specific nuances that influence the adoption of wood as a construction material. Additionally, exploring the financial aspects of wood adoption, such as costs and interest rates, would be crucial in understanding their impact on the decision-making process. Examining how the affordability of wood construction and the availability of financing options influence its adoption could provide valuable information for policymakers and industry stakeholders. This research could help develop strategies to overcome financial barriers and make wood construction more accessible and attractive to a wider range of homeowners. Furthermore, investigating the role of building regulations and policies in promoting wood adoption would be valuable. Understanding how supportive regulations and incentives can influence the decision to choose wood as a construction material would enable policymakers to design effective measures that encourage sustainable and eco-friendly building practices.

In conclusion, this research not only fills the gap in knowledge regarding wood adoption in residential construction but also provides practical implications for policymakers, industry professionals, academia and consumers. By incorporating these findings into decision-making processes, we can pave the way for a more sustainable, resilient, and environmentally conscious future in the construction industry.

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Annex

This annex presents the original multiple linear regression model from paper 1, along with three additional models. Model 2 introduces the variable 'population,' which has been transformed to satisfy linearity requirements. This addition explains an additional 2.5% of the variance. Notably, 'population' becomes significant in Model 2, while the 'unemployment rate' loses its significance. The significance of the remaining variables remains unchanged. However, Model 2 exhibits multicollinearity issues, particularly with high variance inflation factors (VIF) for the variables area (6.7), population (4.8), unemployment rate (4), and number of construction firms (3.8). The original model did not face this issue, with the highest VIF being below 3.

In Model 3, the variables 'population' and 'area' were replaced by a transformed variable, 'population density.' This model maintains the same significance as Model 2, but the high VIFs (population density >7; unemployment rate >5) continue to pose problems.

Model 4 includes an additional transformed variable, 'average purchase price per square meter'. This addition explains an additional 2.4% of the variance in comparison to model 3 and 4.0% in comparison to the original model. Interestingly, the average purchase price is a significant negative predictor. Compared to Model 1, 'average building land size' becomes significant in Model 4, whereas it was not in Model 1. Additionally, the 'unemployment rate' regains its significance in Model 4, similar to Model 1. However, multicollinearity issues worsen in Model 4, with high VIFs for population density (9.2), average purchase price (5.7), unemployment rate (4), laborers with academic qualifications (5), and the number of construction firms (4).

In conclusion, the additional models consistently demonstrate the substantial influence of federal states across all models. Similarly, the variables 'share of woodland' and 'mean age' maintain their significance throughout.

Table 4 – Model 1: Original Model of Paper 1

	Unstandardized Coefficients		Standardized Coefficients		95% CI for B	
Model	**B**	**SE**	**Beta**	**T**	**LL**	**UL**
(Constant)	-33.659*	15.054		-2.236	-63.26	-4.06
Area	4.773***	1.378	.198	3.463	2.06	7.48
Share of woodland	.176***	.032	.231	5.537	.113	.238
Mean age	1.289***	.324	.229	3.985	.653	1.925
Unemployment rate	-1.035***	.322	-.191	-3.218	-1.667	-.403
Laborers academic qual.	-.269	.074	-.175	-3.637	-.414	-.123
Average building land size	-.001	.001	-.047	-1.290	-.002	.000
Number of construction firms	-2720.82	1372.21	-.117	-1.983	-5419	-22.57
Schleswig-Holstein	-12.911***	2.641	-.204	-4.890	-18.86	-7.72
Hamburg	-12.957	7.234	-.058	-1.791	-27.18	1.27
Lower-Saxony	-17.159***	1.795	-.482	-9.559	-20.69	-13.63
Bremen	-8.005	5.519	-.050	-1.450	-18.86	2.85
NRW	-13.599***	1.776	-.410	-7.656	-17.10	-10.10
Hesse	-5.855***	1.882	-.128	-3.111	-9.56	-2.16
Rhineland-Palatinate	-10.237***	1.749	-.260	-5.853	-13.68	-6.80
Bavaria	-6.701***	1.487	-.254	-4.506	-9.63	-3.78
Saarland	-12.134***	3.227	-.131	-3.760	-18.48	-5.79
Berlin	-9.519	7.369	-.042	-1.292	-24.01	4.97
Brandenburg	-18.686***	2.974	-.345	-6.283	-24.53	-12.84
Mecklenburg	-18.154***	3.754	-.196	-4.836	-25.54	-10.77
Saxony	-12.503***	3.241	-.197	-3.858	-18.88	-6.13
Saxony-Anhalt	-18.043***	3.077	-.295	-5.863	-24.09	-11.99
Thuringia	-11.157***	2.441	-.231	-4.570	-15.96	-6.36

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$
$R^2 = .642$; Adjusted $R^2 = .621$

Source: own calculation

Table 5 - Model 2: addition of population

	Unstandardized Coefficients		Standardized Coefficients		95% CI for B	
Model	**B**	**SE**	**Beta**	**T**	**LL**	**UL**
(Constant)	31.425	19.255		1.632	-6.437	69.286
Area	11.564***	1.872	.479	6.176	7.883	15.246
Population	**-5.845*** **	**1.131**	**-.341**	**-5.168**	**-8.069**	**-3.620**
Share of woodland	.136***	.032	.179	4.313	.074	.198
Mean age	.938**	.320	.166	2.934	.308	1.568
Unemployment rate	-.605	.322	-.112	-1.878	-1.238	.028
Laborers academic qual.	-.025	.086	-.016	-.288	-.193	.144
Avg. building land size	-.001	.001	-.050	-1.418	-.002	.000
Numb. construction firms	-4204.6**	1357.997	-.181	-3.096	-6874.92	-1534.31
Schleswig-Holstein	-13.74***	2.559	-.217	-5.370	-18.774	-8.710
Hamburg	-7.53	7.075	-.033	-1.065	-21.446	6.380
Lower-Saxony	-19.93***	1.818	-.560	-10.97	-23.511	-16.363
Bremen	-8.45	5.339	.053	-1.584	-18.957	2.041
NRW	-11.76***	1.754	-.324	-6.704	-15.712	-7.812
Hesse	-5.937***	1.820	-.130	-3.261	-9.517	-2.357
Rhineland-Palatinate	-11.83***	1.720	-.301	-6.881	-15.215	-8.452
Bavaria	-8.45***	1.477	-.321	-5.723	-11.365	-5.552
Saarland	-11.82***	3.122	-.128	-3.789	-17.966	-5.690
Berlin	-1.41	7.298	-.006	-1.194	-15.768	12.935
Brandenburg	-21.12***	2.915	-.390	-7.248	-26.860	-15.396
Mecklenburg	-22.87***	3.744	-.247	-6.109	-30.234	-15.509
Saxony	-10.71***	3.153	-.169	-3.397	-16.914	-4.513
Saxony-Anhalt	-20.51***	3.015	-.335	-6.806	-26.447	-14.590
Thuringia	-13.73***	2.414	-.284	-5.691	-18.481	-8.989

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$
$R^2 = .666$; Adjusted $R^2 = .646$

Source: own calculation

Table 6 – Model 3: Replacement of population and area by population density

	Unstandardized Coefficients		Standardized Coefficients		95% CI for B	
Model	**B**	**SE**	**Beta**	**T**	**LL**	**UL**
(Constant)	19.938	15.622		1.276	-10.781	50.657
~~Area~~						
Population density	**-5.042*** **	**.813**	**-.492**	**-6.201**	**-6.640**	**-3.443**
Share of woodland	.137***	.032	.180	4.350	0.073	.199
Mean age	.978**	.318	.174	3.078	0.353	1.603
Unemployment rate	-.552	.318	-.102	-1.737	-1.177	.073
Laborers academic qual.	.45	.083	.029	.543	-.209	.118
Avg. building land size	-.001	.001	-.050	-1.428	-.002	.000
Numb. of construction firms	-4397.74**	1344.816	-.189	-3.270	-7042.12	-1753.37
Schleswig-Holstein	-13.78***	2.559	-.217	-5.387	-18.817	-8.754
Hamburg	-9.04	6.919	-.040	-1.307	-22.651	4.558
Lower-Saxony	-19.82***	1.814	-.557	-10.926	-23.387	-16.253
Bremen	-8.910	5.321	.056	-1.674	-19.374	1.553
NRW	-12.19***	1.702	-.368	-7.170	-15.845	-8.540
Hesse	-5.918***	1.820	-.130	-3.251	-9.497	-2.338
Rhineland-Palatinate	-11.35***	1.654	-.289	-6.864	-14.604	-8.100
Bavaria	-7.87***	1.366	-.299	-5.774	-10.562	-5.196
Saarland	-11.77***	3.121	-.127	-3.772	-17.911	-5.636
Berlin	-3.52	7.002	-.016	-.503	-17.287	10.248
Brandenburg	-20.85***	2.804	-.384	-7.418	-26.558	-15.143
Mecklenburg	-23.29***	3.721	-.252	-6.261	-30.614	-15.980
Saxony	-11.00***	3.141	-.174	-3.503	-17.179	-4.827
Saxony-Anhalt	-20.55***	3.015	-.336	-6.817	-26.482	-14.627
Thuringia	-13.18***	2.352	-.273	-5.604	-17.806	-8.556

*** p < 0.001, ** p < 0.01, * p < 0.05
R^2 = .666; Adjusted R^2 = .646

Source: own calculation

Table 7 - Model 4: addition of avg. purchase price

	Unstandardized Coefficients		Standardized Coefficients		95% CI for B	
Model	**B**	**SE**	**Beta**	**T**	**LL**	**UL**
(Constant)	32.935*	15.633		2.107	2.195	63.675
Population density	-3.095***	.921	-.300	-3.361	-4.906	-1.284
Avg. purchase price	**-3.497*** **	**.826**	**-.299**	**-4.233**	**-5.117**	**-1.877**
Share of woodland	.138***	.031	.181	4.446	.077	.199
Mean age	.789*	.315	.140	2.506	.170	1.408
Unemployment rate	-.852**	.319	-.158	-2.668	-1.480	-.224
Laborers academic qual.	.118	.091	.075	1.293	-.061	.297
Avg. building land size	-.002**	.001	-.111	-2.962	-.003	-.001
Numb. of construction firms	-2659.29	1381.920	-.114	-1.924	-5376.669	58.086
Schleswig-Holstein	-13.55***	2.507	-.214	-5.408	-18.484	-8.626
Hamburg	-7.75	6.784	-.035	-1.143	-21.096	5.583
Lower-Saxony	-20.05***	1.778	-.564	-11.283	-23.554	-16.563
Bremen	-9.45	5.212	.059	-1.813	-19.702	-.798
NRW	-13.26***	1.685	-.400	-7.871	-16.579	-9.951
Hesse	-6.51***	1.788	-.143	-3.642	-10.030	-2.997
Rhineland-Palatinate	-11.72***	1.622	-.299	-7.230	-14.919	-8.539
Bavaria	-7.77***	1.337	-.294	-5.802	-10.404	-5.137
Saarland	-12.93***	3.069	-.140	-4.215	-18.970	-6.902
Berlin	-2.93	6.861	-.013	-.427	-16.422	10.560
Brandenburg	-21.98***	2.804	-.406	-7.839	-27.594	-16.366
Mecklenburg	-22.58***	3.648	-.245	-6.190	-29.755	-15.408
Saxony	-13.99***	3.158	-.221	-4.431	-20.206	-7.785
Saxony-Anhalt	-22.18***	2.977	-.363	-7.450	-28.036	-16.327
Thuringia	-16.25***	2.416	-.337	-6.729	-21.007	-11.506

*** p < 0.001, ** p < 0.01, * p < 0.05
R^2 = .680; Adjusted R^2 = .660

Source: own calculation