MASTER

The Willingness to Pay for Sustainable Material Use in the Dutch Multi-Family Housing Sector

Dirx, Joep J.W.

Award date:
2024

GRADUATION THESIS

THE WILLINGNESS TO PAY FOR SUSTAINABLE MATERIAL USE IN THE DUTCH MULTI-FAMILY HOUSING SECTOR

J.J.W. Dirx

1259989

Supervisors

prof. dr. T.A. Arentze (chair)

Eindhoven University of Technology

Department of the Built Environment

ir. S.J.E. Maussen, MRE

Eindhoven University of Technology

Department of the Built Environment

P.H. Lee

Eindhoven University of Technology

Department of the Built Environment

Eindhoven, January 2024

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Department of the Built Environment

MSc. Architecture, Building & Planning

Urban Systems & Real Estate

Colophon

Title	The Willingness to Pay for Sustainable Material Use in the Dutch Multi-Family Housing Sector
Date	23/01/2024
Author	J.J.W. (Joep) Dirx
ID Number	1259989
Institute	Eindhoven University of Technology
Department	Department of the Built Environment
Master Program	Architecture, Building & Planning – Urban Systems & Real Estate
Course Code	7Z45M0
Study Load	45 ECTS
Graduation Supervision Committee	prof. dr. T.A. (Theo) Arentze ir. S.J.E. (Stephan) Maussen, MRE P.H. (Pei-Hsuan) Lee
In collaboration with	VORM Holding B.V. Supervisors: Maarten Sakkers & Mark van Stijn

Preface

This report presents a study on the willingness to pay (WTP) for sustainable materials in the Dutch multi-family housing sector and functions as the graduation thesis for the track Urban Systems & Real Estate (USRE) in the Architecture, Building & Planning (ABP) master's program at the Eindhoven University of Technology (TU/e). The aim of this study is to determine people's preferences regarding sustainable material alternatives in the residential construction sector and if people are willing to pay more for sustainable materials in comparison to traditional construction materials. Conducting this study has given me the chance to apply the knowledge and skills acquired during my studies. Resulting in a more profound understanding of sustainability in the construction sector and people's sustainable behaviour.

I would like to express my gratitude to my supervisors Stephan Maussen, Theo Arentze, and Pei-Hsuan Lee for their guidance and feedback during the project. I am especially thankful to Stephan Maussen for the insights he gave me from a practical and substantive perspective. I would like to thank Theo Arentze for his guidance on the methodological aspects of this study and I would like to thank Pei-Hsuan Lee for sharing her knowledge on sustainability from an academic point of view. Furthermore, I want to express my profound gratitude for the guidance my supervisors from VORM gave me. Maarten Sakkers and Mark van Stijn gave me a real insight into the world of project development, providing me with a great impression of the real estate sector and facilitating the practical implementation of my graduation project. Additionally, I want to thank four experts on sustainability, who provided me with an understanding of sustainability in the real estate sector, which supported my graduation thesis significantly. Special thanks to Mathew Vola (Arup), Jesse Plas (DGMR), Wester Regelink (W/E Adviseurs), and Martin Dunnink (Nieman).

I want to express my appreciation to Study Association SERVICE, who provided me with many cups of coffee, offering support during working sessions and stimulating engaging and enjoyable conversations. Additionally, heartful thanks to the members of both SERVICE and CHEOPS for ensuring that there was enough time to relax and have fun besides studying. Lastly, my sincere appreciation goes to my friends and family for their unwavering support throughout my graduation process. A special acknowledgement goes to my friends from Floor 5 in Vertigo, who shared the graduation process with me, offering mutual support during this significant period.

I genuinely hope that reading this thesis brings you as much enjoyment as I experienced in creating it.

Joep Dirx

Eindhoven, January 2024

Samenvatting

De bouwsector is één van de sectoren die het meeste bijdraagt aan de wereldwijde vervuilding. Deze sector is verantwoordelijk voor 38% van de totale wereldwijde CO_2-uitstoot, waarvan 11% direct toegeschreven kan worden aan materiaalgebonden emissies. Gelet op de urgentie van het aanpakken van klimaatverandering hebben de Verenigde Naties als doel gesteld dat de wereldwijde temperatuurstijging niet meer mag bedragen dan 2 graden Celsius. Er wordt gestreefd naar een beperking van de temperatuurstijging tot maximaal 1,5 graden Celsius. In lijn met deze mondiale doelen heeft Nederland in 2019 een uitgebreid klimaatplan geïmplementeerd. Het plan stelt als doel om de CO_2-uitstoot tegen het jaar 2050 met 95% te verminderen ten opzichte van de uitstoot van 1990. Een cruciaal element om deze vermindering te realiseren, is het verbeteren van de duurzaamheid binnen de bouwsector.

In de afgelopen periode heeft de bouwsector zich voornamelijk gericht op het verminderen van emissies tijdens de gebruiksfase van een gebouw, ook wel energiegebonden emissies genoemd. Deze vermindering is bereikt door verbeterde isolatie, de integratie van zonnepanelen en verbeterde gebouwinstallaties, wat heeft geleid tot een aanzienlijke afname van de energiegebonden emissies van gebouwen. Echter, een gevolg hiervan is een toename van materiaalgebonden emissies. Deze emissies komen voort uit de productie- en bouwprocessen van een gebouw. Als gevolg hiervan zijn emissies aan het begin van de gebruiksfase van een gebouw gestegen, en materiaalgebonden emissies kunnen nu tot 50% van de totale emissies van gebouwen uitmaken. Om de algehele milieueffecten van de bouwsector effectief aan te pakken, zijn er meer inspanningen nodig om duurzame materialen te gebruiken. Een uitdaging vormen de algemeen waargenomen hogere kosten van duurzame materialen, wat leidt tot hogere bouwkosten. Om ervoor te zorgen dat de ontwikkeling van huizen in Nederland duurzaam plaatsvindt, is duidelijkheid nodig over de mate waarin huiseigenaren belang hechten aan het gebruik van duurzame materialen bij het kopen van een huis. Deze studie beoogt dit aspect te verkennen door de bereidheid om te betalen van huiseigenaren voor duurzame materiaalalternatieven te bepalen. Om dit te bereiken, is de volgende onderzoeksvraag geformuleerd:

> *Wat is de bereidheid om te betalen voor duurzaam materiaalgebruik in de Nederlandse meergezinswoningensector en in hoeverre wordt de berieidheid om te betalen beïnvloed door het materiaaltype en de sociaal-demografische kenmerken van de gebruiker?*

Literatuuronderzoek over gebouw emissies dient als basis voor de bepaling van duurzaam materiaalgebruik. Opvolgend literatuuronderzoek geeft inzicht in de sociaal-demografische kenmerken die van invloed zijn op de bereidheid om te betalen voor duurzaamheid. Na het vaststellen van duurzame materiaalalternatieven zullen specifieke materiaalprofielen worden opgesteld, inclusief de milieu prestaties en materiaalkosten van deze materialen. De materiaalprofielen worden gebruikt om een keuze-experiment te ontwerpen, waarin respondenten hun voorkeuren uiten met betrekking tot woningopties die variëren in materiaalgebruik en prijsniveau. Na het bepalen van de voorkeuren van de respondenten via het keuze-experiment, biedt de analyse van de verzamelde gegevens inzicht in de voorkeuren van individuen voor duurzame materiaalalternatieven in woningsector en de bereidheid om te betalen voor deze materialen.

Materiaalgebonden emissies worden geproduceerd gedurende alle vijf levenscyclusfasen van een gebouw: de productiefase, de bouwfase, de gebruiksfase, de eindfase en de hergebruiksfase. Deze emissies zijn het gevolg van de productie, bouw, onderhoud en vervanging van bouwmaterialen. Met de verbetering van de energieprestaties van gebouwen zijn materiaalgebonden emissies toegenomen en hebben nu een grotere invloed op de levenscyclusanalyse (LCA) van gebouwen. Bij het onderzoek naar de duurzame overgang kan men duurzame materiaalalternatieven voor traditionele bouwmaterialen in twee groepen classificeren: circulaire en biobased bouwmaterialen. Biobased materialen, waaronder hout en andere op planten gebaseerde producten, bieden structurele en thermische eigenschappen en verminderen de afhankelijkheid van koolstof intensieve materialen. Circulaire materialen, zoals gerecycled beton en demonteerbare modules, dragen bij aan afvalvermindering en efficiënt gebruik van hulpbronnen in de bouw.

Een cruciaal onderdeel voor de overgang naar een duurzame samenleving en een duurzame bouwsector is het begrijpen van hoe individuen zich aanpassen aan duurzaam gedrag. Duurzaamheid wordt door het brede publiek

vaak achterwege gelaten vanwege de vermeende verhoogde kosten en het beperkte begrip van de voordelen ervan. Het overbruggen van de kloof tussen consumentenverlangens en hun begrip van duurzaamheid vormt een uitdaging, maar het kan worden aangepakt door middel van informatieve campagnes, structurele interventies, slimme technologie en gewoonteontwikkeling. Consumentenperceptie en kennis van duurzaamheid spelen een cruciale rol in betrokkenheid en bereidheid om te betalen voor duurzame alternatieven. Financiële voordelen, zoals groene hypotheken, motiveren huiseigenaren om duurzame keuzes te maken. Naast het impliceren en bevorderen van duurzaam gedrag wordt dit ook beïnvloed door sociale normen en sociaal-demografische kenmerken. Een hoger inkomen en een hoger behaald opleidingsniveau zijn kenmerken die een positieve invloed hebben op de bereidheid om te betalen voor duurzame producten of diensten. Kijkend naar leeftijd is er geen éénsgezindheid in de resultaten uit literatuur. Hoewel jongere personen over het algemeen milieubewuster zijn, beïnvloeden externe factoren zoals kosten hun bereidheid om te betalen. Geslacht en huishoudsamenstelling kunnen ook van invloed zijn op de betrokkenheid bij duurzaamheid, zij het waarschijnlijk in mindere mate.

De bouwsector bevordert actief duurzaam gedrag door duurzaamheidsbenchmarks en certificeringen te introduceren, zowel verplicht als vrijwillig. Deze normen dienen als gidsen en meetinstrumenten voor het beoordelen van de milieuprestaties van gebouwen, waardoor ontwerpers en projectontwikkelaars worden gestimuleerd om de bouw van meer duurzame structuren te prioriteren. Er zijn acht benchmarks voor milieuprestatie beoordeeld aan de hand van zes criteria om de meest geschikte benchmark te identificeren die in dit onderzoek als indicator voor de milieuprestaties kan worden gebruikt. Na evaluatie op zes criteria kwam de "Milieuprestatie Gebouwen" (MPG) naar voren als voor dit onderzoek de meest geschikte indicator voor milieuprestaties. De MPG is een gebouw-specifieke indicator van milieuprestatie, berekend met behulp van de Milieukosten Indicator (MKI) van de bouwmaterialen die aanwezig zijn in een gebouw. Opgenomen in de "Nationale Milieudatabase" (NMD) vormt de MKI de basis voor het beoordelen van de milieueffecten van bouwmaterialen. In de verdere fasen van deze studie wordt de MKI gebruikt als bepalende factor voor de milieuprestaties van bouwmaterialen.

Om verschillende duurzame materiaalalternatieven te definiëren, zijn drie materiaalprofielen samengesteld. Deze profielen zijn gebaseerd op de drie materiaaltypes gedefinieerd tijdens het literatuuronderzoek naar de duurzaamheidstransitie en zijn als volgt: traditionele, circulaire en biobased bouwmaterialen. Omdat een gebouw uit veel componenten en materialen bestaat, is een selectie gemaakt van zes bouwcomponenten die veel voorkomen en variatie in materiaal toelaten: fundering, bouwstructuur, binnenwanden, gevelbekleding, raamkozijnen en dakbedekking. Voor elk bouwcomponent zijn materialen geselecteerd om de traditionele, circulaire en biobased profielen te vertegenwoordigen. Met behulp van de MKI-waarden gepresenteerd in de GPR Materiaal-software is de milieuprestatie van de materialen bepaald. De materiaalkosten worden bepaald aan de hand van materiaalkosteninformatie van een projectontwikkelaar uit Rotterdam. De analyse concludeert dat zowel circulaire als biobased materiaalalternatieven resulteerden in aanzienlijke verminderingen in milieueffect, variërend van ongeveer -30% tot -85%. De circulaire en biobased profielen resulteerde in verhoogde materiaalkosten, waarbij de kosten voornamelijk vielen binnen het bereik van +10% tot +20% in vergelijking met het kosteneffectieve traditionele profiel. Deze extra materiaalkosten resulteren in een verhoogde koopprijs voor huiseigenaren, variërend van +7% tot +14% in de koopprijs van de woning, aangezien materiaalkosten een deel bijdragen aan de totale ontwikkelingskosten.

De verzamelde informatie bij het opstellen van de materiaalprofielen is gebruikt bij het opzetten van een keuze-experiment (stated choice experiment) met als doel de bereidheid om te betalen te bepalen voor duurzame materiaalalternatieven. In totaal zijn zeven attributen gedefinieerd voor het experiment, waaronder de eerdergenoemde bouwcomponenten en een prijsniveau-attribuut. De attributen die worden gebruikt in het experimentele ontwerp zijn de materiaalopties van de drie materiaalprofielen. Als gevolg daarvan omvatten de zes bouwcomponentkenmerken elk een traditioneel, een circulair en een biobased alternatief als attribuutlevel, terwijl het prijsniveaukenmerk +0%, +7% en +14% attribuutlevel omvat. Met behulp van een fractioneel factoriaal ontwerp zijn 27 profielen gegenereerd om een gelijkmatige verdeling van de attribuutlevels over de keuzeprofielen te waarborgen. Het keuze-experiment is verspreid via een online enquête. Elke respondent is voorgelegd met acht keuzetaken, elk bestaande uit twee profielen en de optie "Geen van beide". Daarnaast bevatte de enquête vragen over sociaal-demografische kenmerken van de respondent en kenmerken van de huidige woning van de respondent. De enquête wordt afgesloten met zes uitspraken over milieubewustzijn en klimaatverandering, waarop de respondent zijn mate van overeenstemming aangaf op een 7-punt Likertschaal.

Er zijn 109 volledige en geldige reacties ontvangen op de enquête voor data-analyse. Uit de beschrijvende analyse van de sociaal-demografische kenmerken van de respondenten blijft dat de onderzoeksgroep niet adequaat de algehele Nederlandse bevolking vertegenwoordigde (getest tegen de WoON2021- of CBS-database). De onderzoeksgroep vertoonde geen overeenkomstige verdeling als de Nederlandse bevolking wat betreft geslacht, leeftijd, opleidingsniveau en huishoudsamenstelling. De verdeling van het huishoudinkomen kwam overeen met die van de Nederlandse bevolking. Ondanks het verschil met de Nederlandse bevolking blijft gegevensanalyse mogelijk. Toch wordt voorzichtigheid aanbevolen bij het generaliseren van de resultaten, vooral gezien het unieke milieubewustzijnsprofiel van de onderzoekspopulatie. Na een zelfevaluatie aan de hand van uitspraken over milieubewustzijn en klimaatverandering valt op dat 77,1% van de respondenten valt onder de categorie "hoog milieubewustzijn". Daarnaast is 21,1% ingedeeld als "beperkt milieubewustzijn", waarbij de overige respondenten "laag milieubewustzijn" hadden. Gezien de oververtegenwoordiging van respondenten met hoog en beperkt milieubewustzijn, moet voorzichtig worden omgegaan met generalisatie van de resultaten.

Het multinomiale logit (MNL) model duidt over het algemeen op een positieve houding ten opzichte van duurzame materiaal, met een duidelijke voorkeur voor biobased materialen. Daarnaast suggereert de analyse een negatieve voorkeur voor hogere prijsniveaus, wat de invloed van kosten op keuze-uitkomsten benadrukt. De stapsgewijze schatting van het MNL-model identificeert significante sociaal-demografische karakteristieken en de invloed van milieubewustzijn. Het mixed logit (ML) model geeft voorkeuren aan voor verschillende materiaaltypes, waarbij traditionele materialen de voorkeur hebben voor binnenmuren en gevelbekleding, circulaire materialen voor de fundering en de bouwstructuur, en biobased materialen voor raamkozijnen en dakbedekking. Heterogeniteit binnen voorkeuren wordt onthuld door het ML-model, met opvallende standaardafwijkingen voor vier biobased alternatieven (bouwstructuur, binnenmuren, gevelbekleding en dakbedekking), wat wijst op verschillende voorkeur ten opzichte van verschillende bouwcomponenten. Sociaal-demografische factoren spelen een cruciale rol, waarbij jongere, lager inkomen respondenten negatieve houdingen tonen ten opzichte van hogere prijsniveaus. Terwijl hoger inkomen, oudere individuen deze houding niet delen. Milieubewustzijn komt naar voren als een belangrijk karakteristiek dat de keuze beïnvloed, waarbij milieubewuste respondenten positieve voorkeuren tonen, vooral voor biobased materialen.

De algemene bereidheid om te betalen varieert tussen materiaalprofielen, waarbij circulaire materialen een gemiddelde waarde van 3,6% hebben, wat de traditionele niveaus overtreft. De biobased materialen tonen een waarde van 1,6%. Milieubewustzijn beïnvloedt de bereidheid om te betalen, waarbij zeer bewuste individuen een waarde van 6,3% laten zien voor biobased materialen. Geslacht heeft een beperkte invloed, waarbij de bereidheid om te betalen voor mannen wordt verlaagd naar 1,6%. Leeftijdsgroepen verschillen in voorkeuren, waarbij respondenten tussen 18 en 34 jaar hun bereidheid om te betalen voor alternatieve materialen licht verminderen. Dit wordt veroorzaakt door hun negatieve nut ten opzichte van de extra prijs, wat overeenkomt met de correlatie van deze groep met een maandelijks netto-inkomen van minder dan €2.000,-. Respondenten van 55 jaar en ouder geven de voorkeur aan de biobased (7,6%) boven de circulaire (-0,9%) bouwstructuur. Hogere inkomens (> €4.000,-) geven een negatieve voorkeur voor bepaalde alternatieven, wat leidt tot een lagere algemene bereidheid om te betalen. Het opleidingsniveau heeft een positieve invloed op de bereidheid om te betalen, waarbij masteropgeleide personen hogere voorkeuren tonen voor zowel circulaire (4,8%) als biobased (2,9%) alternatieven. De samenstelling van het huishouden heeft een marginaal effect en leidt tot bescheiden bereidheid om te betalen voor biobased alternatieven.

Het onderzoeken van de relatie tussen materiaalkosten en bereidheid om te betalen onthult een complex scenario. Over het algemeen worden verhoogde kosten niet volledig gedekt door bereidheid om te betalen. Het verschil tussen kosten en bereidheid om te betalen varieert van een dekkingstekort van 2,3% voor de circulaire bouwstructuur tot een aanzienlijk tekort voor duurdere materialen zoals circulaire gevelbekleding (verschil van 98,8%). De impact van sociaal-demografische kenmerken introduceert potentiële variaties in kostendekking. Specifiek vertonen zeer milieubewuste individuen een bereidheid om te betalen van 10,8% voor de biobased bouwstructuur, waarmee de extra 10,5% aan kosten effectief wordt gedekt.

Dit benadrukt de complexe aard van individuele voorkeuren en percepties met betrekking tot duurzame materialen, waarbij de bereidheid van mensen om te investeren in duurzame alternatieven afhankelijk is van directe ervaringen of sterke percepties van de duurzaamheid van de materialen. De studie benadrukt dat individuen een verhoogde bereidheid om te betalen vertonen voor materialen waarmee ze duurzaamheid associëren. Opvallend is dat materialen met een "duurzaam uiterlijk", zoals het groene dak, aanzienlijke bereidheid om te betalen vertonen. Echter, de algehele conclusie van de studie is dat, ondanks deze positieve associaties, de bereidheid om te betalen voor duurzame materialen de extra materiaalkosten verbonden aan circulaire en biobased alternatieven niet volledig compenseert. Deze complexiteit benadrukt de noodzaak van gerichte bewustwordingscampagnes en op maat gemaakte strategieën om de kloof te overbruggen tussen duurzaam gedrag en economische realiteiten op de markt voor bouwmaterialen.

Deze studie heeft beperkingen die voorzichtigheid vereisen bij het interpreteren van resultaten. De selectie van materiaalprofielen in het keuze-experiment vormt een uitdaging vanwege de subjectieve aard van het proces. De gekozen bouwcomponenten en materialen zijn gebaseerd op milieuprestaties en potentieel voor variatie, waardoor generalisatie beperkt is. De presentatie van materialen in het keuze-experiment kan vooroordelen introduceren, waarbij deelnemers specifieke kennis moeten bezitten. "Greenwashing" en hypothetische scenario's kunnen de vastgestelde waarden van de bereidheid om te betalen overschatten. De oververtegenwoordiging van milieubewuste individuen in de steekproef kan de generaliseerbaarheid van de bevindingen beïnvloeden.

De studie suggereert een bereidheid om te investeren in duurzame materialen, vooral die als milieuvriendelijk worden beschouwd. Ontwerpers en ontwikkelaars moeten hier rekening mee houden, maar er moet aandacht zijn voor mogelijke effecten van "greenwashing". Het vergroten van het bewustzijn bij consumenten over kenmerken van duurzame materialen is cruciaal. Het evenwicht tussen inspanningen om zowel energie- als materiaalgebonden emissies te verminderen, is essentieel voor duurzame bouw. Beleidsmakers zouden zich moeten richten op het bevorderen van duurzaamheidsnormen en materialen. Toekomstig onderzoek moet een gevarieerdere steekproef bevatten om de externe geldigheid van de studie te verbeteren en de toepasbaarheid op een breder publiek te vergroten.

Summary

The built environment stands out as one of the leading contributors to pollution on a global scale. It accounts for 38% of the total carbon dioxide (CO_2) emissions worldwide, with 11% directly accountable to material-related emissions. Recognizing the urgency of addressing climate change, the United Nations has established a goal that the global temperature increase should not exceed 2 degrees Celsius. Aiming to limit the temperature rise to a maximum of 1,5 degrees Celsius. In line with these global goals, the Netherlands implemented a climate plan in 2019. The plan outlines the goal to reduce CO_2 emissions by the year 2050 with 95% compared to the emissions of 1990. A crucial element in realizing this reduction is improving sustainability within the construction sector.

Over the past period, the construction sector has primarily focused on reducing emissions during the use stage of the building life cycle, referred to as energy-related emissions. The reduction of energy-related emissions of buildings has been achieved through improved insulation, the integration of solar panels, and improved building installations. However, a consequence of this is an increase in material-related emissions. These emissions originate from the production of construction materials and construction processes of a building. As a result, emissions at the start of a building its use stage have risen, and material-related emissions can now make up to 50% of the total emissions of buildings. To effectively address the overall environmental impact of the construction sector, more efforts are needed to the use of sustainable materials. A challenge is the generally perceived higher costs of sustainable materials, leading to more construction costs. To ensure that the development of houses in the Netherlands is sustainable, an understanding of the degree to which residential consumers attach importance to the use of sustainable materials when purchasing a home is required. This study aims to explore this aspect by determining the willingness to pay (WTP) of residential consumers for sustainable material alternatives. To come to that, the following research question has been constructed:

What is the willingness to pay for a sustainable material use in the Dutch multi-family owner-occupied housing sector, and to what extent is the willingness to pay influenced by material type used and socio-demographic characteristics of the residential consumer?

A literature review on building emissions serves as the basis for determining sustainable material usage. Subsequent literature review provides insight into the socio-demographic characteristics that influence the WTP for sustainability. After establishing sustainable material alternatives, specific material profiles are constructed, including the environmental performance and material costs of these materials. The material profiles are utilized to design a stated choice experiment (SCE) in which respondents express their preferences regarding housing options that vary in materialization and price level. Following the determination of respondents' preferences through the SCE, the analysis of the gathered data provides insight into individuals' preferences for sustainable material alternatives in housing and their WTP for these materials.

Material-related emissions are produced during all five life cycle stages of a building: the product stage, construction stage, use stage, end-of-life stage, and reuse stage. These emissions result from the production, construction, maintenance, and replacement of construction materials. With the improvement of the energy performance of buildings, material-related emissions have increased and now have a greater influence on the life cycle assessment (LCA) of buildings. Looking at the sustainable transition, one can classify sustainable material alternatives to traditional construction materials into two groups: circular and biobased construction materials. Biobased materials, including wood and other plant-based products, offer structural and thermal qualities while reducing reliance on carbon-intensive materials. Circular materials, such as recycled concrete and demountable modules, contribute to waste reduction and resource efficiency in construction.

A crucial part of the transition into a sustainable society and a sustainable built environment is understanding how individuals adapt to sustainable behaviour. Sustainability tends to be overlooked by a large part of the population due to perceived increased costs and limited understanding of its benefits. Overcoming the discrepancy between consumer desires and their understanding of sustainability poses a challenge, but it can be addressed through information campaigns, structural interventions, persuasive technology, and habit development. Consumer perception and knowledge of sustainability play a vital role in engagement and WTP for sustainable alternatives. Financial incentives, such as green mortgages, motivate homeowners to make

sustainable choices. Besides implying and promoting sustainable behaviour, it is also influenced by social norms and socio-demographic characteristics. Higher-income and higher achieved education level are characteristics that positively influence WTP for sustainable products or services. Looking at age, there is no consensus in the results from the literature. Although younger individuals are generally more environmentally conscious, external factors such as costs influence their willingness to pay. Gender and household composition can also affect engagement in sustainability, only the influence is probably to a lesser extent.

The construction sector is actively promoting sustainable behaviour by introducing sustainability benchmarks and certifications, both mandatory and voluntary. These benchmarks serve as guides and metrics for assessing the environmental performance of buildings, motivating designers and project developers to prioritize the construction of more sustainable structures. Eight environmental performance benchmarks are assessed in accordance with six criteria to identify the most suitable one to use as an indicator of environmental performance in this study. After assessing the benchmarks to six criteria, the "Milieuprestatie Gebouwen" (MPG) resulted as the indicator for environmental performance. The MPG is a building-specific indicator of environmental performance, calculated using the Environmental Cost Indicator (ECI) of the construction materials present in a building. In the further phases of this study, the ECI is used as the determination factor of the environmental performance of construction materials.

To define various sustainable material alternatives, three material profiles are constructed. These profiles are based on the three material types defined during the literature review on the sustainable transition and are as follows: traditional, circular, and biobased construction materials. Since a building comprises many components and materials, a selection has been made of six building components that are commonly present and allow for material variation: foundation, building structure, inner walls, façade cladding, window frames, and roof covering. For each building component, materials have been selected to represent the traditional, circular, and biobased profiles. Using the ECI values presented in GPR Materiaal software, the environmental performance of the materials is determined. The material costs are determined by using material costs documents of a project developer from Rotterdam. The analysis concludes that both circular and biobased material alternatives resulted in significant reductions in environmental impact, ranging from approximately -30% to -85%. However, the circular and biobased profiles showed increased material costs, with increased costs primarily falling within the range of +10% to +20% compared to the more cost-effective traditional profile. These additional material costs translate into an increased price for residential consumers, ranging from +7% to +14% in terms of selling prices, as material costs contribute to a portion of the overall construction costs.

The information gathered in constructing the material profiles is used in setting up a SCE, aimed at determining the WTP for the sustainable material alternatives. A total of seven attributes are defined for the experiment, these include the previously mentioned building components and a price level attribute. The attribute levels employed in the experimental design are the material options of the three material profiles. Consequently, the six building component attributes each comprises a traditional, a circular, and a biobased alternative as attribute levels, while the price level attribute includes +0%, +7%, and +14% attribute levels. Employing a fractional factorial design, 27 profiles are generated to ensure an even distribution of attribute levels across the choice profiles. The SCE is spread through an online survey, in which each respondent is presented with eight choice tasks, each consisting of two profiles and the option "None of the two". Additionally, the survey included questions on the socio-demographic characteristics of the respondent and housing characteristics of the respondent's current residence. The survey concluded with six statements on environmental awareness and climate change, to which the respondent indicated their level of agreement on a 7-level Likert scale.

The online survey is distributed via a social media platform (i.e. LinkedIn) and shared with the network of the researcher. Additionally, flyers are directly distributed to mailboxes in selected neighbourhoods in Eindhoven, Rotterdam, and ‘s-Hertogenbosch to facilitate a diverse but representative sample. After a period of five weeks in which the survey was online available, it received 109 complete responses which are valid for data analysis. A descriptive analysis of the socio-demographic characteristics of the respondents indicated that the research sample did not adequately represent the overall Dutch population (tested against the WoON2021 or CBS database). The research sample did not show the same distribution as the Dutch population in terms of gender, age, education level, and household composition. However, the distribution of household income aligned with that of the Dutch population. Despite the difference from the Dutch population, data analysis remains possible.

Nevertheless, caution is advised in generalizing the results, especially considering the unique environmental awareness profile of the research sample. Following a self-assessment using statements on environmental awareness and climate change, 77,1% of the respondents are categorized in the group with "high environmental awareness". Meanwhile, 21,1% are classified with "limited environmental awareness", leaving the remaining respondents with "low environmental awareness". Given the overrepresentation of respondents with high and limited environmental awareness, generalizing the results should be approached with caution.

The multinomial logit (MNL) model reveals an overall positive attitude towards sustainable material alternatives, with a distinct preference for biobased materials. Additionally, the analysis suggests a negative choice preference associated with increased price levels, underscoring the influence of cost on choice outcomes. The stepwise estimation of the MNL model identifies significant socio-demographic and environmental awareness interaction variables. The mixed logit (ML) model indicates preferences for different building components, with traditional materials preferred for inner walls and façade cladding, circular materials for the foundation and building structure, and biobased materials for window frames and roof covering. Heterogeneity within preferences is revealed through the ML model, with notable standard deviations for four biobased alternatives (i.e. the building structure, inner walls, façade cladding, and roof covering), suggesting variation in attitude towards biobased material alternatives. This variation may arise from the belief that these materials are of lower quality, less durability, and more maintenance involved. However, on the other side, there's an increase in perceived well-being and aesthetics. Socio-demographic factors play a crucial role. With younger, lower-income respondents express negativity towards higher price levels. While higher-income, older individuals do not share this attitude. Environmental awareness emerges as a key influencer, with environmentally conscious respondents displaying positive preferences for especially biobased materials.

The overall WTP varies across material profiles, with circular materials having an average WTP of 3,6%, surpassing traditional levels, while biobased materials show a WTP of 1,6%. Environmental awareness influences WTP, with highly aware individuals showing a 6,3% WTP for biobased materials. Gender has a minor impact, reducing the WTP for males to 1,6%. Age groups differ in preferences, with the respondents between 18 and 34 years old slightly reducing WTP for alternative materials. This is caused by their negative utility towards additional price, with aligns with the correlation of this group with a monthly net income of less than €2.000,-. Respondents aged 55 and older prefer the biobased (7,6%) over circular (-0,9%) building structure. Higher income earners (> €4.000,-) express a negative preference for certain alternatives, resulting in lower overall WTP. Education level positively influences WTP, with master-educated individuals showing higher preferences for both circular (4,8%) and biobased (2,9%) alternatives. Household composition has a marginal impact, leading to modest WTP for biobased alternatives.

Examining the relation between material costs and WTP reveals a complex scenario. Generally, increased costs are not entirely covered by WTP. The discrepancy between costs and WTP varies, ranging from a modest coverage shortage of 2,3% for the circular building structure to a substantial shortage for more expensive materials like circular façade cladding (difference of 98,8%). The impact of socio-demographic characteristics introduces potential variations in cost coverage. Specifically, highly environmentally aware individuals exhibit a WTP of 10,8% for the biobased building structure, effectively covering the additional 10,5% in costs.

This highlights the intricate nature of individual preferences and perceptions regarding sustainable materials, suggesting that people's willingness to invest in sustainable alternatives is dependent on direct experiences or strong perceptions of the materials' sustainability. The study emphasizes that individuals tend to display an increased WTP for materials they associate with sustainability. Notably, materials with a "sustainable appearance," such as the green roof, demonstrate significant WTP. However, the overall conclusion of the study is that, despite these positive associations, the WTP for sustainable materials does not fully offset the additional material costs linked to circular and biobased alternatives. This complexity emphasizes the need for targeted awareness campaigns and tailored strategies to bridge the gap between sustainable behaviour and economic realities in the construction materials market.

This study has limitations that warrant caution when interpreting results. The selection of material profiles in the choice experiment poses a challenge due to the subjective nature of the process. The chosen building components and materials are based on environmental performance and potential for variation, limiting generalization. The SCE's presentation of materials may introduce bias, requiring participants to possess specific knowledge. "Greenwashing" and hypothetical scenarios may inflate determined WTP values. The sample's overrepresentation of environmentally aware individuals may impact the generalizability of findings.

The study suggests a willingness to invest in sustainable materials, especially those perceived as environmentally friendly. Designers and developers should consider this but attention should be paid to potential "greenwashing" effects. Raising consumer awareness about sustainable material characteristics is crucial. Balancing efforts between reducing energy and material-related emissions is vital for sustainable construction. Policymakers should focus on promoting sustainability benchmarks and materials. Future research should include a more diverse sample to enhance the study's external validity and applicability to a broader population.

Contents

List of Figures

List of Tables

Terminology & Abbreviations

Benchmark	A standard to which buildings are compared or assessed
BENG	Bijna Energieneutrale Gebouwen: "Almost energy neutral buildings"
BREEAM	Building Research Establishment Environmental Assessment Method
C&DW	Construction & Demolition Waste
C2C	Cradle-to-Cradle
CBS	Centraal Bureau voor de Statistiek
CIP	Cast-In-Place
CLT	Cross-laminated Timber
CO_2	Carbon Dioxide
COP21	UN Climate Change Conference – Paris 2015
Costs – Material costs	Costs associated with acquiring materials and products for construction.
Costs – Construction costs	Costs throughout the full project development process, including costs associated with construction, planning, design, legal fees, and other costs.
DGBC	Dutch Green Building Council
DOI	Diffusion of Innovation Theory
ECI (MKI)	Environmental Cost Indicator: "Milieukosten Indicator" in Dutch
Embodied CO_2-eq.	The sum of all CO_2(-equivalent) emissions associated with a product's creation
Energy Label	Indicator of the energy efficiency of buildings
EPC	Energy Performance Utility
EPD	Environmental Product Declaration
ETS	EU Emission Trading System
GFA	Gross Floor Area
GPR	Gemeentelijke Praktijk Richtlijn: "Municipal Practice Guideline"
GWP	Global-warming Potential
IFEP	Integrated Framework for Encouraging Pro-environmental Behaviour
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
ML	Mixed Logit Model
MNL	Multinominal Logit Model

MPG	Milieuprestatie Gebouwen: “Environmental Performance Buildings”
NMD	Nationale Milieudatabase
NOVI	Nationale Omgevingsvisie: “National Strategy on Spatial Planning and the Environment”
Nul op de meter	Zero energy building
Paris Proof	Sustainability goal in line with COP21 goals
PCR	Product Category Rule
RCA	Recycled Concrete Aggregates
RUM	Random Utility Model
SCE	Stated Choice Experiment
SDG	Sustainable Development Goals
UoA	Unit of Analysis
WoON2021	Dutch housing & living survey (performed 2021)
WTP	Willingness to Pay

1. Introduction

This chapter introduces the background of sustainability in the real estate and construction sector. Especially focusing on the motivation to introduce sustainable real estate development, the parameters classifying sustainable real estate and the published literature into the WTP for sustainable real estate. Furthermore, the Dutch housing market is analyzed, and the current trends and developments are discussed. The chapter starts by elaborating on the background of the research and explaining the research aim. Next, the objective and research questions of the study are discussed. Additionally, the relevance of the study is mentioned as well as a brief outline of the thesis.

1.1 Background

1.1.1 Sustainability in Construction

Sustainability in construction has become a dominant theme in the current day. In the mid-90s and the early 2000s the rise of the theme “sustainable development” arose in the construction sector (Zhou & Lowe, 2003). The terms “social responsibility” and “corporate social responsibility” arose at organizations and companies during this period to pledge to the importance and protection of social and environmental interests (Lorenz & Lützkendorf, 2008). Besides the economic aspects of investments and developments, socially responsible investment strategies include the inclusion of ethical principles on environmental and social aspects. Pivo and McNamara (2005, p. 129) described social responsibility in correspondence to the real estate sector as socially responsible property investment which aims at “maximizing the positive effects and minimizing the negative effects of property ownership, management and development on society and the natural environment in a way that is consistent with investor goals and fiduciary responsibilities.” Indicating that the responsibility not only lies with the final owner of a property but also reflects on the developer and who manages it. The ability to minimize risks and improve financial performance is particularly compelling for actors when it comes to following socially responsible property investment approaches (Lorenz & Lützkendorf, 2008). Developing sustainable buildings requires developers and designers to balance decisions about materialization, structural systems, and functionality which influence economic, environmental, and social sustainability (AbouHamad & Abu-Hamd, 2019). The goal of sustainable development is further described by the World Commission on Environment and Development (1987): “Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.” This compares with the six principles of sustainable construction set up by Kibert, (1994) which are mainly focusing on minimizing consumption and/or maximizing reuse:

1. Minimize resource consumption;
2. Maximize resource reuse;
3. Use renewable or recyclable resources;
4. Protect the natural environment;
5. Create a healthy, non-toxic environment;
6. Pursue quality in creating the built environment.

These principles were set up to capture the essence of what the construction sector should undertake in the era in which environmental problems came at stake and recognized the important role of technological development in realizing sustainable development (Miyatake, 1996). Still, at the time in the 1990s and 2000s, developers were reluctant to develop sustainably because the positive long-term consequences did not yet outweigh direct higher material costs and more risk (Zhou & Lowe, 2003). In current times, it is estimated that the construction sector is globally responsible for circa 38% of the carbon dioxide emissions, of which 11% is accountable to material use (United Nations, 2020). To establish more sustainable development and achieve a sustainable world, the United Nations embraced 17 Sustainable Development Goals (SDGs) in 2015 as part of the global agenda for sustainable development (United Nations, 2015a). Among these goals are “Goal 11: Sustainable Cities and Communities” and “Goal 12: Responsible Consumption and Production”. Goal 11 focuses on inclusive, safe, resilient, and sustainable cities. Whereas Goal 12 focuses on sustainable consumption and production patterns. Both these goals have an influence on the built environment and the construction sector by forcing reuse and reducing consumption. In the end, this should result in a healthier and more sustainable world by decreasing the production of materials and decreasing emissions at all stages in a building its life cycle. Besides that, during the UN Climate Change Conference (COP21) in Paris in 2015, the parties agreed that the global average temperature increase should not go over 2 degrees Celsius, and efforts should be put in to limit the temperature increase to 1,5 degrees Celsius in relation to the pre-industrial levels (United Nations, 2015b). Following this, the Dutch climate plan was set up in 2019 and states a necessary reduction of 95% of the carbon dioxide (CO_2) emissions in 2050 in relation to 1990 should be met to ensure no exceedance of the 1,5 degrees Celsius increase (DGBC, 2023a; Ministerie van Economische Zaken en Klimaat, 2020).

Looking at the life cycle of a building, three types of emissions are possible to establish. First, there are the emissions accountable to the materials used in construction. Material-related emissions of buildings are those emissions during the production and construction process stage of a building its life cycle (Sobota, Driessen, & Holländer, 2022). Combined with the emissions from the maintenance, replacement, and the stage of discard and when possible, the recycle/reuse stage. The second is emissions created during the use stage of the life cycle and accountable to the building, defined as energy-related emissions. Those emissions are the ones created during the stage in which it is used by its occupants and are emissions produced by energy consumption, water, heating, and climate systems. The last category of emissions is user-related emissions produced by energy consumption due to cooking, household appliances, and other electrical appliances used by the user (Blom, Itard, & Meijer, 2011). User-related emissions are not further included in this study, as they are beyond the direct control and influence of project developers and the construction sector.

To improve the sustainability level of the real estate sector, several benchmarks have been introduced to assess and classify the environmental performance of buildings. The Dutch real estate market has developed several energy-efficiency benchmarks for residential real estate. For example, “Nul op de Meter” (Zero on the Meter), “Bijna Energie Neutrale Gebouwen” (BENG – Almost Energy Neutral Buildings) and “Energy-Neutral” (Milieu Centraal, n.d.). From January 2021 onwards, buildings have to meet the requirements of the BENG when applying for an environmental permit (RVO, 2023). Other labels and certificates have also emerged in the sustainable real estate and construction sector, covering topics such as biodiversity, water management, sustainable material use, health, etc. Commonly used for commercial properties, these labels and certificates are increasingly used for residential properties as well. Sustainability benchmarks such as “Gemeentelijke Praktijk Richtlijn” (GPR) are well known in the Dutch construction sector (GPR Software, 2023a). Whereas “Building Research Establishment Environmental Assessment Method” (BREEAM) and Leadership in “Energy and Environmental Design” (LEED) are more known in the international construction sector (DGBC, 2023c; RVO, 2010). Furthermore, the energy label is introduced to give transparency into the energy performance of dwellings (Brounen & Kok, 2011). Since 2008, it has become mandatory for houses constructed, sold, or rented to bear energy labels, ranging from the most energy-efficient rating of "A+++" to the least efficient "G" (Rijksoverheid, 2020; RVO, 2017). The introduction of the energy performance coefficient (EPC) into the energy label in 2012 established a minimum rating of "A" for newly constructed houses (Lente Akkoord, 2012). . The energy label serves as a certification required for the inclusion of a house in advertisements and accompanying documents during its sale or rental process (Brounen & Kok, 2011).

Ergo, the main focus over the past period regarding sustainable construction has been on energy efficiency. After the innovation and progress on “zero-energy” buildings, the more relevant it has become to also innovate on emission-free material, especially since the part of emissions taken on by building materials is relatively large and improving the energy efficiency often relates to an increase in the material use (Sobota et al., 2022). As Sobota et al. (2022) describe “time is an important factor to take into account” when looking at the emissions of a building, both the material-related and energy-related emissions. Energy-related emissions are emitted over the life cycle, so the damage done by emissions cannot be reflected in absolute amounts. Emissions from today cause more damage over a longer period of time than emissions from, for example, twenty years from now, because pollutants remain in the air for longer periods of time. Figure 1 visualizes the relation between material-related emissions and energy-related emissions. The graph shows the material-related emissions and the energy-related emissions, both over a total of X years and a total of Y tons of emission CO_2. The material-related emissions are all produced at the start of the life cycle (i.e. years = 0: completion construction process), the energy-related emissions are emitted gradually over the life cycle of the building. At the dashed line, the total of produced energy-related emissions is equal to the total of material-related emissions produced at the start of the life cycle. As compared to material-related emissions, energy-related emissions caused half the damage during the first X years of the life cycle (dotted line in the bottom graph). This is also known as the principle of “linear damage accumulation". Besides the greater impact of material-related emissions due to linear damage accumulation, there is a growing trend of increasing material-related emissions in the construction of houses. The contributing factor is the efforts that have been dedicated to improving the energy performance of houses. Due to this, more building materials are being used (e.g. more insulation, solar panels), which can result in material-related emissions accounting up to 50% of the total emissions in houses (Sartori & Hestnes, 2007; Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014). This means a significant increase in material-related emissions in comparison to the 10-20% share that was accountable for material-related emissions before the additional energy performance measures (Ramesh, Prakash, & Shukla, 2010). On that account, the reduction of material-related emissions at the constriction stage has a significant influence on the total reduction of damage done by emissions and is therefore of importance.

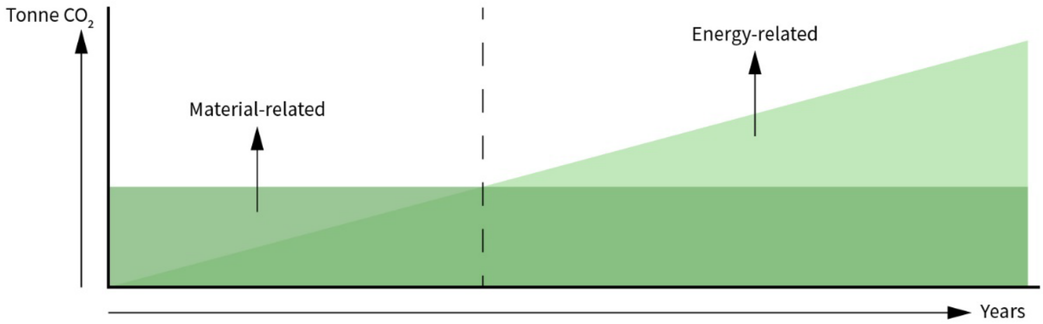


Figure 1 The effect of emissions over time: damage accumulation (adapted from Sobota et al., 2022).

As material-related emissions are increasing, the Dutch government has implemented a benchmark to evaluate the environmental performance of construction materials. Since 2018, the environmental performance related to the materialization of a building has been a mandatory inclusion in the application for an environmental permit and is defined in shadow costs, translated in the "Milieuprestatie Gebouwen" (MPG) (RVO, 2021). The MPG is an important measure of a building its sustainability by looking at the materialization. The more sustainable the material used, the lower the value of the MPG. A crucial point to keep in mind is that measures that are beneficial for the energy efficiency of buildings may be detrimental to their MPG and vice versa. As an example, thicker insulation or solar cells may improve energy efficiency but increases the value of the MPG. Since the 1st of July 2021, a maximal value of 0,8 (expressed in euros per m^2 GFA per year) is allowed for new dwellings in an environmental permit application (RVO, 2021).

Several market parties in the Netherlands want to increase the rate at which the Dutch built environment is becoming more sustainable. The "Dutch Green Building Council" (DGBC) has set up a parameter to test the emissions of a building in relation to the goals that were set during the COP21, named "Paris Proof" (Spitsbaard & Leeuwen, 2021). Limits for the embodied carbon per square meter GFA are set for several years to comply with the agreements and are therefore certified as Paris Proof. The basis for the calculation of the embodied CO_2-eq. for newly constructed buildings is an MPG calculation. The limits are specified in 2021 and divided per user type, Table 1 shows the Paris Proof limits.

Table 1 Paris Proof limits for new construction as set by Nibe and DGBC (Spitsbaard & Leeuwen, 2021).

Paris Proof limits	*Embodied carbon (kg CO_2-eq. per m^2 GFA)*			
New construction	*2021*	*2030*	*2040*	*2050*
Residential (Single-family)	200	126	75	45
Residential (Multi-family)	220	139	83	50
Office	250	158	94	56
Retail	260	164	98	59
Industrial	240	151	91	54

1.1.2 Dutch Housing Market

The Dutch housing market has been in transition over the past years. Since the bottom in the selling prices of houses in 2013, the highest increase in house prices was measured in the Netherlands in 2022 (CBS, 2023a). In

January of 2023, the prices of houses were 93% higher than the lowest point in 2013, the average transaction price of a house was in that month €424.681,-. One of the reasons for the high prices in the housing market is the discrepancy between supply and demand. There is a shortage of houses in the Netherlands, which was 279.000 in 2021 and is expected to grow till 2024 (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2021). Over the coming years, the goal is to develop 100.000 houses per year, reaching 900.000 new houses in 2030 (Actieagenda Wonen, 2021). This is a large challenge for the residential construction sector. The goal to build 100.000 houses per year will not be reached and the total construction of residential real estate is expected to decrease by 1,5% in 2023 and 2,0% in 2024 (EIB, 2023). Among others, the main reasons for the decrease in construction are the increased construction costs (Smit & Dirkse, 2022) and the influence of sustainability challenges, for example, the nitrogen crisis where building permits will not be issued due to the influence of the natural environment (Raad van State, 2022). The national government is pushing the sector to increase the production rate of houses, it provides subsidies (a total of 11 billion euros) for larger-scale residential development projects (Rijksoverheid, 2022). Efficient housing development is crucial for addressing the housing shortage. Nevertheless, it is important that housing development occurs sustainably to ensure resilience and long-term durability in the future.

The Dutch housing market can be roughly divided into three different groups looking at ownership. In 2022, 57,1% of the houses in the Netherlands were owner-occupied, meaning that they are privately owned by individuals for their own habitation (CBS, 2023b). 28,6% of the Dutch housing stock is owned by a housing corporation, so the rent is regulated by the liberalization limit and a maximum income. The remaining 14,1% of the stock is owned by either a private landlord or (institutional) real estate investors (for 0,2% of the housing stock the owner is unknown). Over the past decade, the share of privately rented houses has increased by 2,6%, whereas the percentage of owner-occupied houses has increased by 0,5% (CBS, 2023b). The percentage of social dwellings owned by a housing corporation has decreased. The trend where more houses are developed for the (private) rent sector is also visible in the number of licensed building permits in 2022. During the period 2019-2021, the ratio of licensed building permits between owner-occupied and rental houses was fairly stable at 65% owner-occupied and 35% rental houses (CBS, 2023c). In 2022, the division of licensed building permits was 47% for rental houses and 53% for owner-occupied houses. Even though the trend in the increase of private rental houses in the Dutch housing market has been going on for several years, the developments for the future are uncertain.

As the price increase in sale prices on the Dutch owner-occupied housing market is lowering (CBS, 2023a), investors want to withdraw the (remaining) surplus value by selling their houses. As a result of the new regulation affecting the mid-rent segment, renting out homes will probably become less profitable from 2024 onwards (Capital Value, 2023). Private investors have shown an interest in selling rental properties on the owner-occupied housing market. This combined with the increasing interest rate, the offer of houses in the owner-occupied sector has increased (Capital Value, 2023). Still, the discrepancy between demand and supply in the period 2023-2027 is expected to be the largest in the owner-occupied sector.

Generally speaking, the mentioned statements above are accountable for the whole of the Netherlands. However, in the Netherlands, there is a significant division between housing markets (i.e. division between areas: urban areas and outer-urban/rural areas) concerning for example dwelling type. In the Netherlands, 36,2% of the housing stock is an apartment, so a multi-family building (CBS, 2022a). Looking at the four largest municipalities in the Netherlands, this division is significantly different and is the share of multi-family houses significantly higher: Amsterdam (88,1%), Rotterdam (74,5%), Den Haag (78,8%), and Utrecht (57,5%). In recent years, there has been a shift in the development of new houses. The share of newly constructed multi-family houses is increasing and will increase more over the coming years (Bisschop & Waal, 2023). About half of the new houses developed in the period 2018 to 2020 were single-family homes, this was 45% in 2021. Judging by the construction plans, based on environmental permits, for 2023 and 2024, the percentage of multi-family apartments in development will increase to 45% and 52% respectively. Figure 2 visualizes the division in developed houses over the past years and the prediction for the coming year. This is in trend with the vision of the Dutch government on the development of the Dutch built environment (stated in the 'Nationale Omgevingsvisie' (NOVI)). There the preference is stated that densification of urban areas is preferred over the development outside of the urban tissue in green/rural areas (Ministerie Binnenlandse Zaken en Koninkrijkrelaties, 2020). This policy will increase the number of multi-family buildings in urban areas and the total share in the Netherlands.

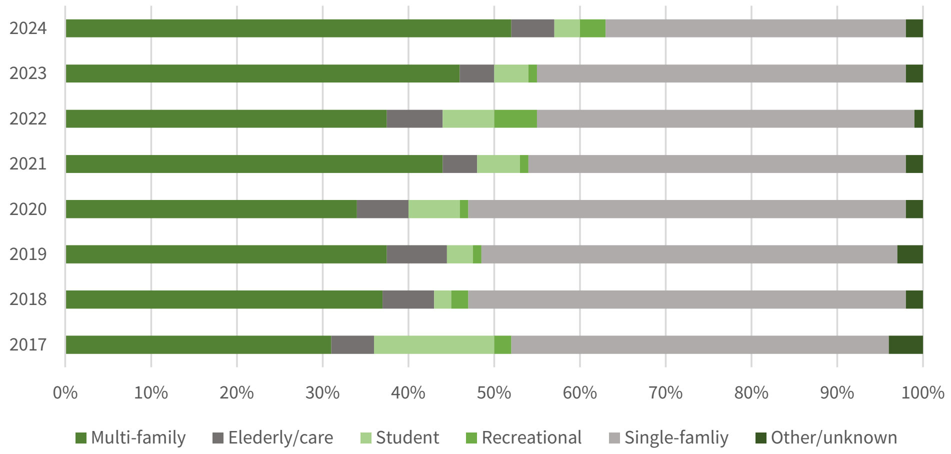


Figure 2 Share of developed new houses per type (adapted from Bisschop & Waal, 2023).

The stage of life, along with personal characteristics and preferences, influences people's housing demand. Since the share of apartments in the Netherlands is growing and is for that reason becoming more important in the Dutch residential real estate sector, the general residential profile of a person living in an apartment is described here. The Dutch housing survey (WoON2021), a large-scale national research into the living situation, housing costs, moving wishes and households in the Netherlands (most recently performed in 2021), concluded the same trend in multi-family development as described above. The share of owner-occupied apartments has relatively doubled in the last thirty years (Stuart-Fox, Kleinepier, Ligthart, & Blijie, 2022). In the WoOn2021 research, the desired housing type per household group is researched. The analysis reveals that households without children tend to show a preference for multi-family houses. This is visible in Table 2, which details the desired housing types per household group. Within this data, three specific groups stand out with a notably high inclination toward multi-family houses. These groups comprise couples aged 65 years and older, one-person households aged 65 years and older, and one-person households aged 35 years and younger (Stuart-Fox et al., 2022).

Table 2 Desired housing type of actively seeking home buyers by household type (Stuart-Fox et al., 2022).

	One parent household	*Couple with kids*	*Couple 65+ yr.*	*Couple 35 – 64 yr.*	*Couple <35 yr.*	*One person household 65+ yr.*	*One person household 35 – 64 yr.*	*One person household <35 yr.*
Single-family	70%	92%	34%	71%	69%	14%	50%	37%
Multi-family	30%	8%	66%	29%	31%	86%	50%	63%

The preferred housing type is also dividable in a preference for owner-occupied or rental houses. The demand for owner-occupied multi-family houses is the highest for couples with an age over 65 years old (32%). This is visible in Figure 3, where the dark grey bar represents the share of multi-family owner-occupied houses that are in demand by the stated target group. Next to couples of 65 years and older, the preference for an owner-occupied multi-family house is relatively high for one-person households in the age under 35 years old and between 35 and 64 years old (both 20%). As an additional point to both of these statements, it's worth noting that these groups express an equal or greater preference for a rental apartment compared to an owner-occupied one. See Figure 3 for the division for all household composition and housing types. Generally, it can be concluded from this that there are two main groups of people living in multi-family buildings. These are either one-person households or couples with an age of 65 years old and higher (Stuart-Fox et al., 2022).

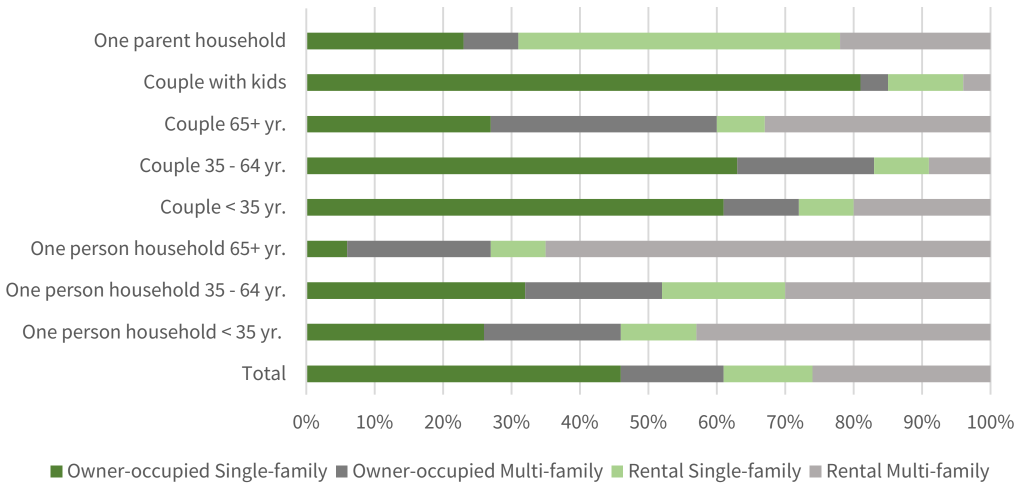


Figure 3 Desired housing type of actively seeking home buyers (adapted from Stuart-Fox et al., 2022).

1.2 Research Aim

1.2.1 Problem Outline

Several studies have concluded that the WTP for a house increases if environmental performance during the use stage of the building is better and therefore is classified as energy efficient. According to Brounen & Kok (2011), the lower energy costs during the lifetime of a house by improving energy efficiency causes the transaction price of a house to rise at the sale. Judge et al. (2019) concluded that people are willing to pay more for a very low-energy house, especially those who recognize the importance of sustainability and environmentally friendly behaviour. Besides that, they concluded that WTP is influenced by the familiarity of sustainability benchmarks, as seen with the energy label's mandatory inclusion in house advertisements and documentation. A study by Tan (2011) performed in Malaysia showed that people are willing to pay more for a house situated in a neighbourhood where sustainability and environmental quality are central concepts. Published literature also indicates that people are willing to pay for environmental attributes, such as water-reduced taps and solar energy, because this reduces operating costs (Mandell & Wilhelmsson, 2011). Besides the economic benefits of sustainable housing, due to reduced operating costs and increased valuation, the living environment is often also improved, what increases its valuation (Zalesjska-Jonsson, 2014; Zhou & Lowe, 2003; Noiseux & Hostetler, 2010; Judge, Warren-Meyers, & Paladino, 2019).

Studies into the WTP for sustainable housing conclude several personal characteristics that influence the mentioned WTP. First, multiple studies have concluded (e.g. Judge et al., 2019; Mandall & Wilhelmsson, 2011) that the WTP is higher when one is more environmentally aware. People who identify themselves as “green consumers” and/or have “environmental concerns” are more willing to pay for sustainable measures in housing than people who do not associate themselves with the environment. Besides that, Mandall & Wilhelmsson (2011) also concluded that households with a higher income are more willing to pay for a sustainable house in comparison to households with a lower income. Additionally, Li, Long & Chen (2018) concluded that people with a higher education level have a higher WTP for a sustainable house. They state that people with a lower education level are more susceptible and have a lower WTP. The characteristic age is an interesting factor when looking at the WTP for sustainability. Literature has indicated that younger people are more concerned with environmental issues (Suki, 2013). This relates generally speaking to their objective to adopt environmentally friendly behaviour and therefore they should have a higher WTP for environmentally friendly products (Royne, Levy, & Martinez, 2011). However, due to limited financial strength, the relation between WTP and intention to implement sustainable measures has been demonstrated to be moderated by age, as well as the impact of subjective norms and environmental concerns (Prete, et al., 2017).

The aforementioned literature focuses on WTP for energy-related sustainability measures, the WTP for the implementation of sustainable materials in housing is undelighted and research into this is not known to the researcher. So, it should also be stated that the personal characteristics mentioned above that influence the WTP for sustainable housing relate to research where sustainability is defined as energy efficient. The direct influence of sustainable material use on overall construction cossts is also not clear. In the real estate sector, there is a general opinion that sustainability does mean increased material costs (Dobson, Sourani, Sertyesilisik, & Tunstall, 2013). Nasereddin and Price (2021) concluded that sustainable construction projects tend to have 2% to 7% higher overall construction costs than buildings with lower sustainability ambitions. Of which the additional investments are partly derivable to installations and materials that improve energy performance. Due to the unawareness of sustainable materialisation on construction costs, the sustainability ambitions of project developers are not clear or substantiated. To get insight into the mentioned, this study aims to define the relation between sustainable residential development and the WTP for sustainable materialization. The sustainable materialization are based on real material costs, to get insight into the relation between the costs and the WTP. The following problem statement is constructed:

> *There is no consensus among real estate developers as to whether it is viable for them to follow current regulations or pursue higher sustainability goals, which will also come with more sustianability regulations. The degree to which residential consumers attach importance to the use of sustainable materials when purchasing a home and their willingness to pay for additional sustainability measures are unknown. As long as this insight is lacking, resources (e.g. money and time) and development opportunities for more sustainable housing development could be wasted.*

1.2.2 Scope

Since every country handles development projects differently and every housing market is shaped differently per country, this study will only focus on the Netherlands. Furthermore, this study focuses on the residential owner-occupied real estate market in the Netherlands, which remains the largest housing sector in the country. Dwellings in this market can be categorized into single-family homes (ground-level residences) and multi-family homes (apartments). The impact of sustainability measures on the prices of housing is not homogeneous overall housing segments, there is a differentiation between different housing types and housing characteristics (Marmolejo-Duarte & Chen, 2019). This in combination with the vision of the Dutch government on the development of the Dutch built environment to prefer the densification of urban areas over development outside of the urban tissue in green/rural areas (Ministerie Binnenlandse Zaken en Koninkrijkrelaties, 2020), has resulted in the decision that this study will only focus on multi-family houses (apartments). Furthermore, this study only focuses on the WTP for newly constructed multi-family buildings and not on renovation or redevelopment projects.

1.2.3 Research Objective & Question

To gain insight into the WTP for sustainable material use by residential consumers, the following research question is formulated:

> *What is the willingness to pay for a sustainable material use in the Dutch multi-family owner-occupied housing sector, and to what extent is the willingness to pay influenced by material type used and socio-demographic characteristics of the residential consumer?*

To answer the main research question, a number of sub-questions are constructed. This sub-question each answers a critical part to answer the main research question. The sub-questions are stated as follows:

1. *What is sustainable material use in multi-family housing and how can this be defined?*
2. *To what extent is the willingness to pay for sustainable material use influenced by the type of material?*
3. *To what extent is there a relation between socio-demographic characteristics of the residential consumer and the willingness to pay for sustainable material use in a multi-family house?*

The first sub-question gives insight into the definition of sustainable material use in the residential construction sector. It will make clear how sustainable material use can be assessed in the housing sector, which should result in an indicator to test the sustainability of different types of materials used. The second sub-question should make clear if the WTP is influenced by, and if so to what extent, specific materials used. Lastly, the third sub-question gives insight into the possible relation between socio-demographic characteristics and the WTP for sustainable material use.

1.3 Academic and Societal Relevance

The Netherlands is dealing with a housing shortage, and numerous dwellings need to be constructed over the coming years with an emphasis on efficiency and sustainability. In the past decade, the focus has been on reducing energy-related emissions by implementing materials and installations that enhance energy performance. Improving energy performance reduces operating costs for residential consumers, resulting in a WTP for energy performance measures. However, this has led to increased material usage and, consequently, a rise in material-related emissions. The lack of research on the relation between WTP for a sustainable house and materialization might be attributed to the absence of direct financial incentives for individuals to buy a sustainable house based on material considerations. As the imperative to enhance the sustainability of the built environment grows, it becomes crucial to shift attention toward decreasing material-related emissions through the use of more sustainable materials. Understanding the WTP for sustainable materials allows the residential real estate sector to assess the feasibility of sustainable housing projects. By comparing the additional costs associated with sustainable materials to the price individuals are willing to pay, developers can make informed decisions about the viability of such projects. This information is essential for balancing sustainability goals with economic considerations, ensuring the long-term success and affordability of sustainable housing initiatives.

Despite the obligation to assess the environmental performance of construction materials in the application for an environmental permit through the MPG, the significance of sustainable material use has not yet been fully embraced by developers and designers. The benchmark for sustainable material use remains relatively easy to attain (Sobota et al., 2022). However, as the benchmark becomes stricter (e.g., MPG < 0.5) (W/E Adviseurs, 2023a), the environmental impact is poised to play a more significant role in the design and development process of buildings, necessitating a thorough understanding of the impact.

The WTP for a sustainable house concerning material use adds to the scientific scope of WTP and sustainability. While recent literature has extensively examined WTP for energy-efficient houses, there is a lack of research on WTP and sustainable material use. Moreover, published literature has predominantly focused on ground-bound single-family houses, leaving a gap in understanding the influence of sustainability on WTP in the academic world, particularly in multi-family buildings.

1.4 Research Design

The research is divided into five parts: literature review, the experimental design, the experiment itself, the data analysis, and the conclusion. In the first part, existing relevant literature is examined to specify key concepts and to define research variables. In the literature review, sustainability in the real estate sector is assessed. This is to get insight into building emissions, the perception of sustainability, and sustainable transition in the construction sector. The information from the literature review should form the basis of the determination of sustainable material use. Next to that, this should give insight into the socio-demographic characteristics that influence WTP for sustainability. Specific sustainable material profiles are set up to be able to define the variables which are used in the choice experiment. These profiles are set up based on an analysis of a method to determine sustainability.

The results of the choice experiment make it possible to answer the sub-questions. Furthermore, the determination of the WTP for a sustainable dwelling concerning material use is possible and should, therefore, answer the main research question. Besides answering the main research questions, the discussion is formed including recommendations for future research. The full research design is graphically visualized in Figure 4.

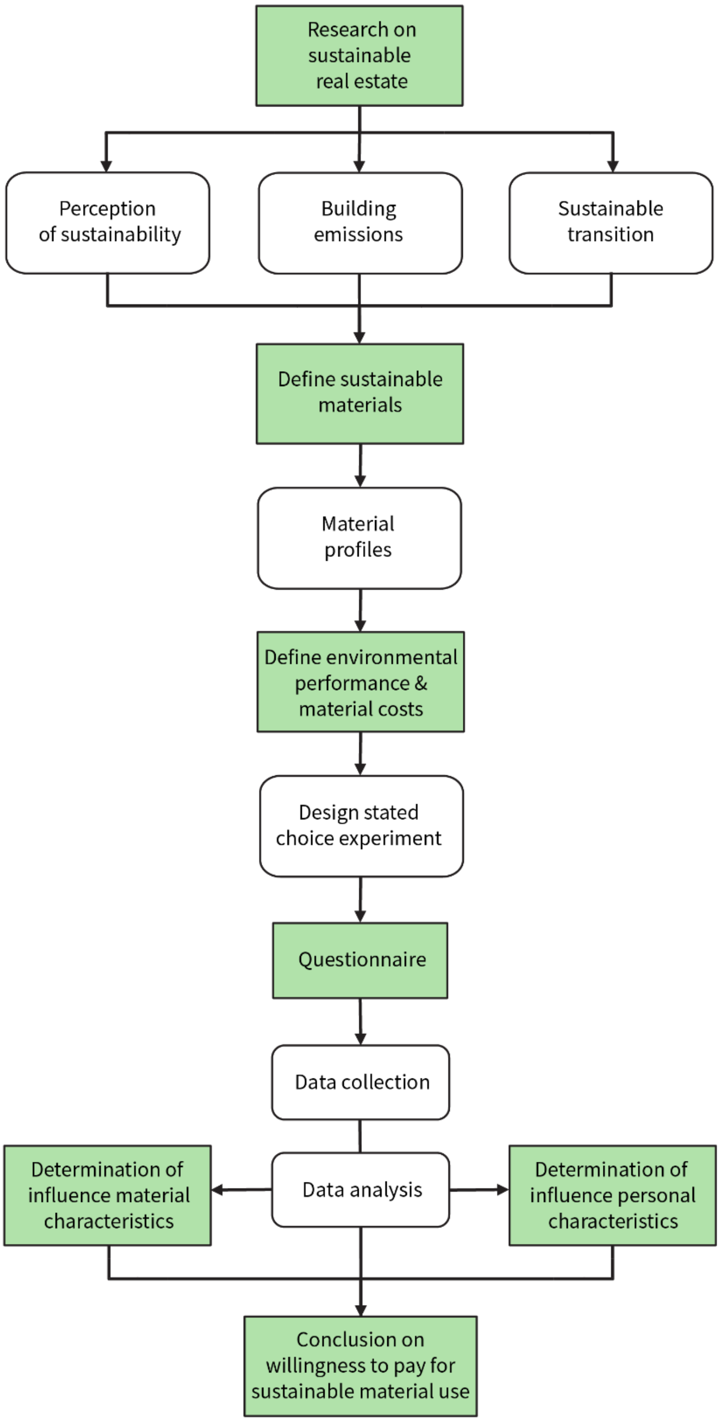


Figure 4 Research Design.

1.5 Reading Guide

This study is structured as follows. Chapter 2. Building Emissions delves into the life cycle and emissions of buildings. It distinguishes between material- and energy-related emissions and explores the sustainable transition, including traditional, biobased, and circular materials. Chapter 3. Sustainable Behaviour focuses on factors that influence individuals' sustainable behaviour and how this can be influenced. In this chapter, special attention is paid to socio-demographic characteristics that influence WTP for sustainable alternatives. Chapter 4. Environmental Performance follows, introducing an environmental performance benchmark that is used in further analysis. Criteria and results of the benchmark are discussed, along with the determination method, and consideration about data availability. In Chapter 5. Material Profiles, different material profiles are concluded each focussing on a specific material characteristic. For several building components, material alternatives are determined with the corresponding environmental performance and associated material costs. It continues with Chapter 6. Research Methodology presents detailed information about the research method. It includes the conceptual model, experimental design, and the used analysis models. Chapter 7. Data Description offers insights into the gathered research data and describes the data in correspondence to the Dutch population. Furthermore, it describes the data recoding before analysis. In Chapter 8. Results, the results of the data models are presented and described, including the results of the analysis into WTP for the sustainable material alternatives. Finally, the report concludes in Chapter 9. Conclusion & Discussion. Summarizing the key findings of the research and the discussion points that have arisen during the research. Furthermore, this chapter also includes the limitations and recommendations of this study.

2. Building Emissions

An understanding of the building life cycle is crucial for understanding the environmental impact of construction. This chapter provides an overview of the building life cycle, emphasizing the significance of material-related emissions in the construction sector. Connected to that, the two building-related emissions, namely material and energy, are compared and their influence is explained. Furthermore, the sustainable transition in the Dutch construction sector at this moment is discussed, focusing on the introduction of sustainable materials.

2.1 Building's Life Cycle & Emissions

Building emissions are produced over the full life cycle of a building. The life cycle of a building can be divided into five different stages: product stage, construction process stage, use stage, end-of-life stage, and reuse stage (Birgisdottir & Rasmussen, 2016 & Sobota et al., 2022). The life cycle stages can be described as follows:

- *Product stage*
  The product stage refers to the processes involved in producing the construction products used in the construction: the supply of raw materials, the transportation to the production site, as well as the final product production.

- *Construction stage*
  In the construction process stage, the construction products are transported from the manufacturer to the construction site and installed as a part of the finished building.

- *Use stage*
  As part of the use stage, construction products are maintained, replaced, and repaired in order to ensure their continued performance. In addition, energy and water consumption related to the building's operations are included.

- *End-of-life stage*
  The end-of-life stage is scenario-based. In terms of the end-of-life stage, one refers to the deconstruction of a building and the subsequent reprocessing of its materials or components before continuing to use them for other purposes.

- *Reuse stage*
  As part of this scenario-based stage, the gains and drawbacks of reusing and recycling construction products/materials are calculated. In accordance with European standards, contributions from the reuse stage must be considered separately.

Emissions of a building are determined by looking at all emissions in the life cycle of a product used in the building, established by a life cycle assessment (LCA). Rather than focusing on factors related to the completed building, the life cycle approach involves factors throughout the building's lifespan (Birgisdottir & Rasmussen, 2016). In the LCA, all the emissions related to material, product, and energy are taken into account, this for example also includes emissions due to transport. Figure 5 shows the defined building-related emissions over the different life cycle stages of a building. The life cycle stages are subdivided, and the emission causes are indicated.

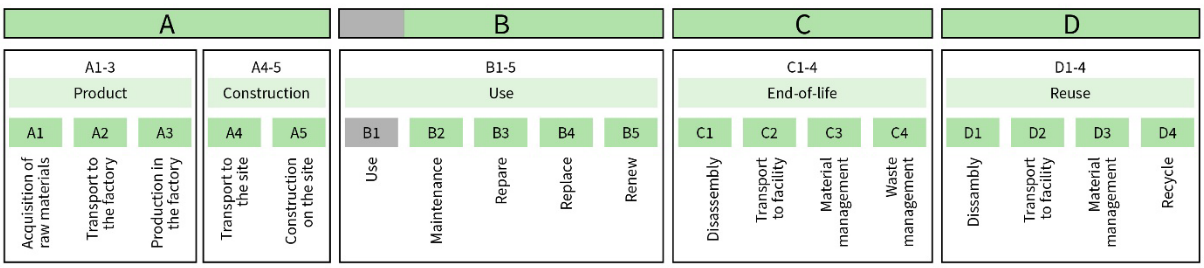


Figure 5 The life cycle stages of a building and the defined emission types (adapted from EN 15804, 2019).

The LCA provides an overview of the impact a building has on the environment at different stages of its life cycle (Birgisdottir & Rasmussen, 2016). Figure 6 illustrates an example of LCA results translated in global warming potential (GWP) [1] for three types of buildings, divided over the life cycle stages. The traditional bar shows the GWP of a building for which no extra energy performance or material efficiency measures are taken. When including more energy-efficient installations or materials (e.g. better insulation) it is visible that the GWP at the product stage increases. The amount of material and the increase in pollution per material result in more emissions at the start of the life cycle. Due to the energy performance measures, the use stage decreases drastically. When also implementing sustainable materials, as shown in the material efficiency bar, the GWP of the product stage decreases drastically when combined with the reuse stage. In combination with energy efficiency measures and sustainable materials, the total GWP decreases.

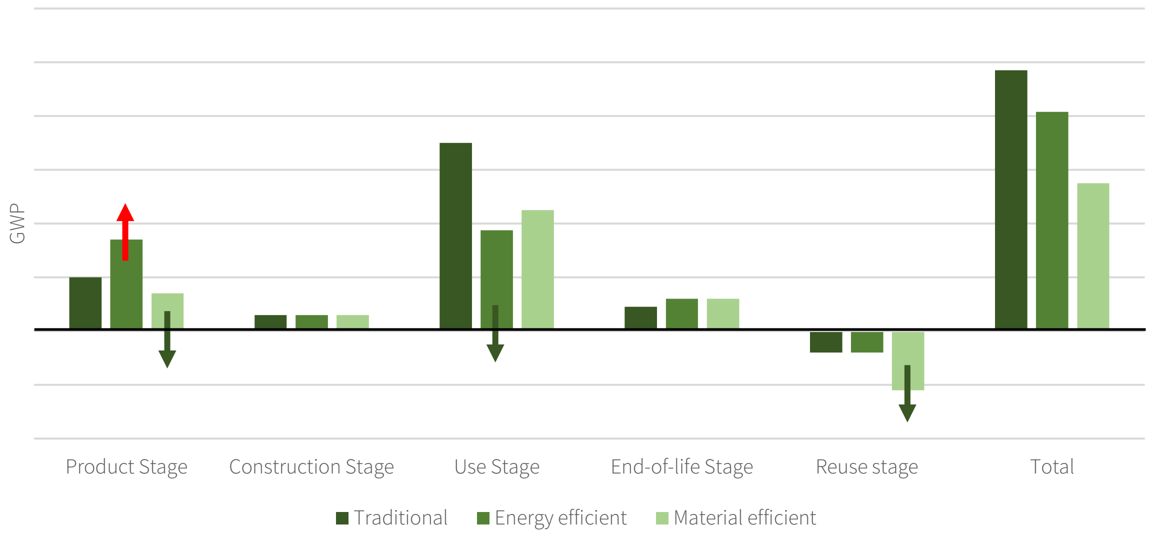


Figure 6 Division of a possible GWP per life cycle stage for three building types.

2.2 Material- Versus Energy-Related Emissions

The analysis of the emissions in the LCA makes it possible to divide the emissions into energy-related emissions and material-related emissions, the latter are commonly referred to as "embodied" impacts (Birgisdottir & Rasmussen, 2016). In Figure 5 the material-related emissions produced in the life cycle stages are visible (A1-A5, B2-B5, C1-C4 & D1-D4) (Sobota et al., 2022). The energy-related emissions are those emissions produced during the use stage (B1) by for example heating and cooling a building. In the past, environmental impacts from energy use have typically had the largest influence on a building's LCA results (Birgisdottir & Rasmussen, 2016). However, with the expectation of reduced operational energy use and the shift towards renewable energy sources in the future, the significance of embodied impacts from construction products is expected to increase proportionally in the overall LCA assessment of a building.

This indicates that the role of material-related emissions is getting increasingly important in the lifetime assessment of building emissions. Ramesh et al. concluded in 2010 that approximately 10-20% of the total building emissions is accountable to material-related emissions, emitted during the production, construction, and reuse stage. However, since effort has been put into improving the energy performance of houses, more building materials are used, which can result in the role of material-related emissions in low-energy houses up to 50% (Sartori & Hestnes, 2007; Cabeza et al., 2014). This is also concluded by recently published research into the emission of newly constructed houses in the Netherlands. In 2021, a newly constructed house produced on average approximately 5 kg of CO_2 emissions per square meter per year of energy-related emissions (W/E Adviseurs, 2023b). The material-related emissions of the same newly constructed houses were in 2021 approximately 340 kg CO_2 per square meter at completion of the construction stage. Meaning that after 68 years the energy-related emissions are equal to the material-related emissions at the start of the use stage. In

[1] Global Warming Potential (GWP) is a metric used to quantify the impact of greenhouse gases on global warming over a specific time horizon, usually 100 years. It measures the potential of a greenhouse gas, relative to carbon dioxide, to trap heat in the atmosphere and contribute to climate change (EPA, 2023).

comparison, the life span of a building is often set at 75 to 100 years (Birgisdottir & Rasmussen, 2016). Renewal and renovation are not considered in these calculations, meaning that the share of material-related emissions is even larger. The material-related emissions emitted during the renewal and renovation process can take up to 35% of the total material-related emissions, mainly related to the replacement and maintenance of building elements (Sobota et al., 2022). Indicating that a significant portion of the total building emissions is accountable to material emissions.

2.3 Sustainable Transition

Society, including the Dutch residential construction sector, is promoting and encouraging a sustainable transition to lessen the negative effects on the environment and to reduce climate change. Numerous causes, such as stricter legislation, increased awareness of climate change, and rising demand for environmentally friendly and energy-efficient buildings, are causing this development. Instead of building with CO_2 intensive materials like concrete and cement, a transition is starting to take place to materials with significantly lower or even positive effects on CO_2 concentrations in the atmosphere (Bronsvoort, Veldboer, Slaa, & Kaptein, 2020). In the literature, two primary sustainable material alternatives are commonly discussed, namely, circular materials and biobased materials (e.g. Oorschot, et al., 2023; Arnoldussen, et al., 2020). Both categories focus on reducing the amount of unusable waste and creating a cycle of materials, classified as the biological cycle for biobased materials and the technical cycle for circular materials (C2C Products Innovation Institute, 2021). Figure 7 visualizes both cycles. The technical cycle is based on the disassembly of products and the use of the parts to produce new products, which results in circular products. The biological cycle is based on the biological degradation of products, resulting in biological nutrients which organisms can use to grow. Meaning that a cycle occurs from biobased products. These two material groups are described further in this section and examples of these products as used in the Dutch construction sector are provided. Before, the two stated material groups are described, the traditional and common construction methods for Dutch multi-family buildings is explained.

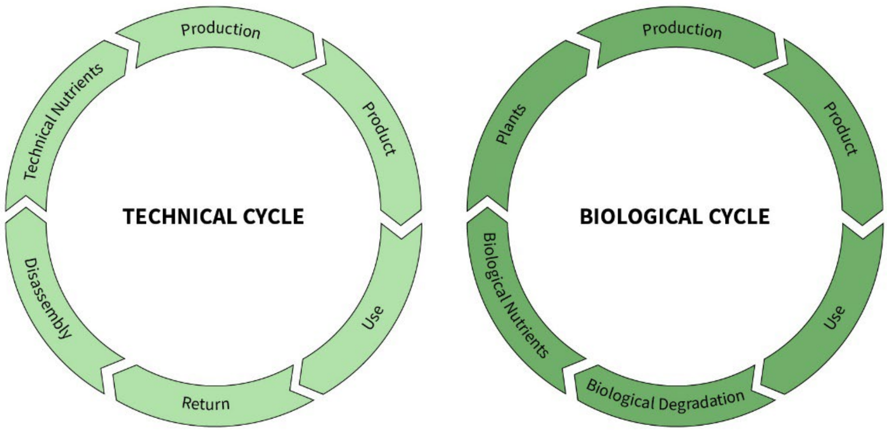


Figure 7 Technical and biological product cycles (adapted from C2C Products Innovation Institute, 2021).

2.3.1 Traditional Materials

In this study, when the term "traditional materials" is used, it refers to construction materials that have been widely used in the Dutch construction sector over the past decades. An examination of the Dutch construction building constructed up until 2014, has led to 14 product types which are most used in the Dutch construction sector (concrete, steel & iron (+ other), stone (+ other), wood, insulation, glass, sand, gypsum, ceramics, plastics, paper, bitumen, copper, and other) (Arnoldussen, et al., 2020). From these materials, concrete is significantly the most used product used in the construction of houses in the Netherlands. For multi-family buildings, 85% of the total mass of materials is accountable to concrete. Besides concrete bricks (4%), wood (3%), and steel (4%), are also frequently used.

So, the Dutch construction sector makes use of stoney materials like brick, cement, and concrete (Arnoldussen, et al., 2020). These materials are CO_2 intensive to produce and therefore have a negative effect on the environment. One common construction method for multi-family buildings in the Netherlands is using cast-in-place (CIP) concrete. This method involves pouring concrete directly into molds or formwork on-site (Liu, Zhang,

& Zhang, 2020). It allows for flexibility in shaping and sizing, making it suitable for complex and custom structures. CIP concrete offers strength, flexibility, durability, and fire resistance, making it a popular choice for high-rise buildings and foundations.

2.3.2 Circular Materials

Next to the significant portion of the emissions worldwide due to the production of construction materials (globally 11% of the CO_2 emissions (United Nations, 2020)), the construction sector is globally also responsible for 35% of the total waste production (Solís-Guzman et al., 2009). To reduce material-related building emissions and the total construction and demolition waste (C&DW) generated, while maintaining the continuous flow of productions and materials, policies are pushing for a circular economy model. The approach of the circular economy aims to effectively repurpose resources, resulting in a decrease in the reliance on new materials and minimizing environmental consequences (Ghaffer, Burman, & Braimah, 2020). Circular construction materials can be based on the principle of demounting and reusing materials without degradation of the quality (e.g. modular systems, façades, and window frames), this principle is referred to as circular design (C2C Products Innovation Institute, 2023). Another option is circular sourcing, which means using C&DW in new materials (e.g. fragmented glasses and wood in insulation).

The amount of concrete waste generated on construction sites can vary from 40% to 85% of the total waste, depending on the nature of the project (Monier, Mudgal, Hestin, Trarieux, & Mimid, 2011). This makes concrete an effective and interesting materials to reuse, resulting in circular sourcing. It is possible to reuse concrete waste in a variety of applications by recycling it. For unbound applications such as filling road sub-bases or as recycled concrete aggregates (RCA), recycled concrete can be effectively used. However, using recycled materials in such low-value applications, recycling can be stated as downcycling, meaning that recycled materials are used for applications of lower value than their original uses (Allwood, 2014). Modern technologies have made it possible to recycle concrete in high-quality applications. By separating the components of used concrete, new, circular concrete consisting of 40-80% recycled material can be produced (New Horizon, 2023). The effort that is required for production and the limited availability of circular concrete compared to traditional concrete makes it that circular concrete has at present approximately 20% higher material costs (Arnoldussen, Endhoven, & Lange, 2023). Regarding the proportion of concrete in the overall construction costs, this leads to an increase of approximately 8% in the total construction costs of a multi-family building.

Besides the use of C&DW, modern construction methods have embraced prefabricated modules as a waste-reduction technique. Waste can be minimized, and resource efficiency can be enhanced through the use of prefabricated modules. As a result of prefabrication, more than 80% of total construction waste can be avoided (Gálvez-Martos, Styles, Schoenberger, & Zaschmar-Lahl, 2018). Prefabrication plays a crucial role in facilitating the integration of circular design principles in construction. However, a key determinant of a thriving circular construction industry is standardization (Geldermans, 2016). For instance, while prefabrication can reduce material waste, it does not align with circular design principles if the components cannot be disassembled. Standardization, for example with dry connections, which means avoiding adhesive-like substances to connect materials, becomes essential for enabling the disassembly and reuse of these elements without degradation of the quality. Innovative materials that implement this principle are, among others, click-on systems for façade bricks and detachable aluminium frames for inner walls (Oorschot, et al., 2023).

2.3.3 Biobased Materials

In the Netherlands, the goal is to construct 80% of the new houses using biobased materials by 2030 (Bronsvoort et al., 2020). Biobased materials are a class of materials derived partially or entirely from biomass sources (Yadav & Agarwal, 2021). These materials can be categorized into two broad groups: emerging and conventional biobased materials (MaterialDistrict, 2014). Emerging biobased materials are a result of ongoing research and development, driving innovation within the field. Within this study, these kinds of materials will not be considered, only conventional biobased materials are incorporated in this study. Conventional biobased products and materials are typically biodegradable and manufactured from animal or plant-based sources. Examples of conventional biobased construction materials are wood, paper, hemp, and bamboo. Several conventional biobased materials are already common in the Dutch construction sector. Examples of these are wooden façade cladding, fiber boards, and wooden window frames (Oorschot, et al., 2023). Besides those and many more biobased materials, there are several emerging implications of biobased materials as insulation, such as hemp, straw, and flax (Bronsvoort et al., 2020).

As mentioned, concrete is the primary construction material, and it is therefore important to find a more sustainable alternative. Wood plays a significant role in that transition to constructing with biobased materials, due to its structural and thermal qualities (Pajchrowski et al., 2014). A common timber construction material in the Western world is cross-laminated timber (CLT). The structural simplicity of its orthogonal and laminar structure makes it useful as a large-scale wall and floor component, as well as a linear timber member capable of bearing out-of-plane loads as well as in-plane loads (Brandner et al., 2016). In comparison to a CIP-reinforced concrete structure, the construction cost of building with CLT is approximately 15-40% higher, largely dependent on the geographical region and the availability of CLT (Vos, Yildiz, Jackson, & Berg, 2021; CKC Structural Engineers, 2018). Despite initially higher costs, wood is light, accurate, and workable, allowing for potential savings. An estimated 20% higher cost is charged when a concrete or steel building is simply converted to a solid wood building. In contrast, if you take into account the properties of solid wood from the beginning of the design process, the cost price may be reduced. When the cost price is optimized in such a situation, it is about 5% higher (Vos et al., 2021). Incorporating a shorter construction time and possible savings on the foundation has not yet been done. Policymaking at both the Dutch and European levels guarding that timber is priced competitively compared to traditional, carbon-intensive materials, for example by establishing a CO_2 tax.

2.3.4 Feasibility of the Sustainable Transition

In sustainable construction, biobased and circular materials offer viable alternatives to traditional construction materials. However, it's important to recognize that the technical feasibility of implementing these materials can vary significantly from one product to another. Consequently, the integration of highly innovative circular and biobased materials, while environmentally promising, can be costly and experimental at this stage, posing challenges for large-scale implementation (Synchroon, 2023). Nevertheless, the sector is looking for materials which it can adapt to in a more efficient matter, by for example comparing the environmental performance (CO_2 reduction) to the technical feasibility (see Figure 8). Besides that, governmental regulations arise that push and motivate the construction sector to develop more environmentally friendly, with as examples the following two. MPG regulation maximizes the environmental impact of construction projects, likely pushing architects and constructors towards options with minimal environmental consequences (Sobota et al., 2022). Additionally, the Dutch CO_2 tax and the increasing price of the EU Emissions Trading System (ETS) will make CO_2 intensive building materials more expensive, with reinforced concrete costs potentially rising by up to 30% and certain types of cement by 115% (Bronsvoort et al., 2020).

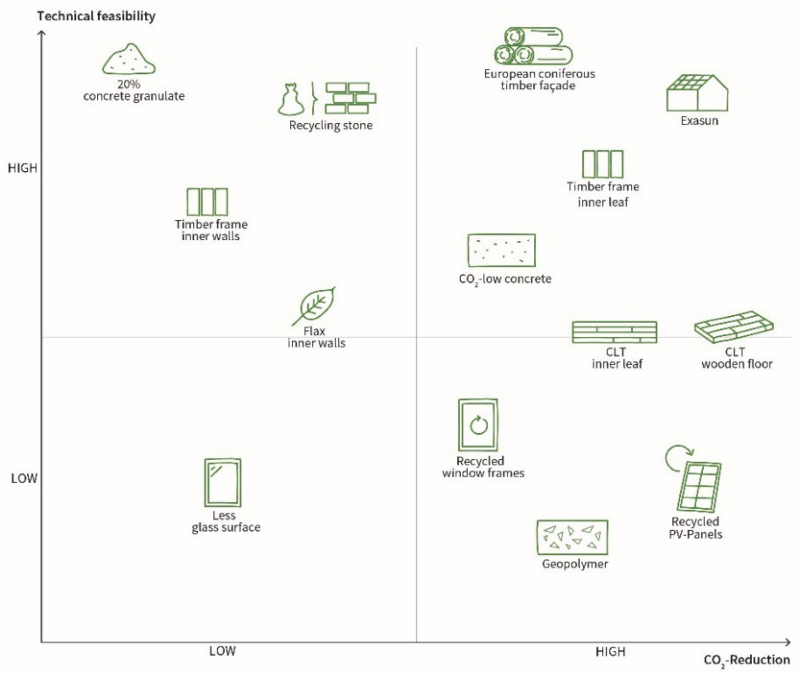


Figure 8 CO_2 reduction of materials related to the technical feasibility (adapted from Synchroon, 2023).

2.4 Conclusion

This chapter provided an overview of the building life cycle and its environmental impact, with a particular focus on material-related emissions. It is emphasized that material-related emissions play a significant role in the overall emissions of a building throughout its life cycle, produced during the product, construction, use, end-of-life, and reuse stages. The analysis of emissions in life cycle assessment (LCA) allows for the differentiation between energy-related emissions and material-related emissions. While energy-related emissions have traditionally had a larger influence on LCA results, the increasing focus on improving the energy performance of buildings has shifted attention towards the significance of material-related emissions. Recently published literature has indicated that material-related emissions can account for up to 50% of the total produced building emissions. The sustainable transition in the Dutch construction sector is driven by factors such as stricter legislation, increased climate change awareness, and the demand for environmentally friendly buildings. Circular and biobased materials are two promising alternatives for achieving a sustainable transition. Circular materials, such as recycled concrete and prefabricated modules, contribute to waste reduction and resource efficiency in construction. Biobased materials, including wood and other plant-based products, offer structural and thermal qualities while reducing the reliance on carbon-intensive materials. A challenge lies in the technical and financial feasibility of implementing innovative biobased and circular construction materials fully in the development of housing.

3. Sustainable Behaviour

The concept of sustainable behaviour refers to intentional actions taken to minimize one's negative impact on the built and natural environments (Kollmuss & Agyeman, 2010). The decision-making process behind sustainable behaviour is influenced by various factors. These include individual goals and values, social norms, emotions, the symbolic significance associated with the behaviour, and financial incentives. This chapter focuses on the factors influencing sustainable behaviour, both personal factors and external factors. Understanding these factors is vital for grasping the intention of people to make sustainable choices, for promoting environmentally conscious behaviour and encouraging individuals to make sustainable choices. The chapter starts with describing individuals' decision-making concerning sustainable behaviour. This is followed by the factors that can promote sustainable behaviour, both by increasing knowledge and awareness, and with financial incentives. Besides promoting sustainable behaviour, sustainable behaviour can also be implied. Policies introduced to imply sustainable behaviour are stated. Following this, this chapter will describe socio-demographic characteristics that influence WTP for sustainability.

3.1 Promoting Sustainable Behaviour

Understanding the decision-making processes of individuals is important when seeking to influence their behaviour. By gaining insight into the factors that shape their choices and actions, more effective strategies to encourage desirable behaviours and promote positive change can be developed. This knowledge provides an understanding of how to influence human decision-making and guide individuals towards making sustained and sustainable decisions.

Individuals are influenced by the behaviour and attitude of others, and conformity to social norms can drive them to adopt sustainable practices. The steps in which people adopt to sustainable behaviour can be described using the Diffusion of Innovation theory (DOI). Rogers (2003) described five steps in which people adapt to technology and innovations:

1. *Knowledge*
   Individuals learn about the new behaviour or innovation and gain a basic understanding of it. Media, educational initiatives, and information campaigns are frequently used to spread this knowledge.

2. *Persuasion*
   Individuals are influenced to adopt a positive attitude and show interest in the new behaviour. They become aware of the advantages and potential effects of the innovation and are interested in actively seeking related information.

3. *Decision*
   Individuals assess the potential advantages, disadvantages, and effects of implementing the new behaviour. They decide whether or not to adopt the behaviour by weighing the benefits against any potential risks or obstacles.

4. *Implementation*
   Individuals start putting the new behaviour into practice as soon as they decide to do so. In this step, the behaviour is actively practised and integrated into the person's routines or daily activities.

5. *Confirmation*
   The confirmation step focuses on how people assess the new behaviour. They evaluate whether the behaviour satisfies their needs, conforms to their expectations, and generates the desired results. Positive experiences and reinforcement during this step contribute to the continued adoption and diffusion of the behaviour.

When specifically looking at sustainable behaviour, Lindenberg & Steg (2007) constructed an Integrated Framework for Encouraging Pro-Environmental Behaviour (IFEP). The framework suggests that there are three different types of goals that influence one's behaviour, these are hedonic goals, gain goals, and normative goals. For this, they state the following definitions:

> *Hedonic goals lead individuals to focus on ways to improve their feelings in a particular situation, such as avoiding effort, seeking direct pleasure or seeking excitement. Gain goals prompt people particularly to be sensitive to changes in their personal resources, such as money and status. Normative goals lead people to focus on the appropriateness of actions and make them especially sensitive to what they think they ought to do, such as contributing to a clean environment or showing exemplary behaviour. (Steg, Bolderdijk, Keizer, & Perlaviciute, 2014, p. 104)*

When examining pro-environmental behaviour, individuals can be driven by various motives. Some may engage in such behaviour for hedonic reasons because it brings enjoyment. Others are motivated by gain, as it can lead to cost savings, such as reduced energy expenses. Alternatively, people may engage in pro-environmental behaviour for normative reasons, driven by their belief that protecting the environment is the morally right thing to do. However, pro-environmental behaviour introduces a conflict between normative goals on one side and hedonic and gain goals on the other (Lindenberg & Steg, 2007). This conflict arises because individuals need to sacrifice personal benefits, including time, money, pleasure, or convenience. Steg et al. (2014) have identified two fundamental strategies for promoting pro-environmental behaviour in light of this conflict. The first method involves reinforcing normative goals, thereby reducing the relative influence of hedonic and gain goals. This serves to lessen the prominence of the conflict between normative goals and the other two. The second approach focuses on mitigating the conflict between normative goals and hedonic/gain goals by altering the actual or perceived outcomes of pro-environmental behaviour. These strategies encourage individuals to prioritize the environmental consequences of their actions, thereby diminishing the significance they attribute to hedonic and gain considerations. This, in turn, encourages pro-environmental behaviour, even when such actions may entail personal costs.

Looking at one's personal values, the same values are in place as the goals. Pro-environmental behaviour is influenced by four categories of personal values. These are altruistic values, which involve concern for the well-being of others; biospheric values, which encompass worry for nature and the environment itself; egoistic values, which involve consideration of the costs and benefits involved; and hedonic values, which relate to concern for one's feelings (Groot & Thøgersen, 2019). Emotions play a role in sustainable behaviour since they can generate pleasure, satisfaction, or meaningfulness (Taufik & Venhoeven, 2019). Social norms also have a significant impact on sustainable behaviour. These norms reflect what is typically done or accepted within a particular community or society (Keizer & Schultz, 2019).

By understanding these psychological motivators and the social contexts that influence sustainable behaviour, it becomes applicable to encourage and persuade individuals to make environmentally conscious decisions regarding material usage in housing. This can be achieved by enhancing normative goals and strengthening biospheric values, which involves increasing environmental awareness and knowledge. This process motivates individuals with a better understanding of the significance of environmentally responsible actions, ultimately motivating them to align their behaviour with these norms. The following section will elaborate on methods to enhance knowledge and environmental awareness, along with their influence on pro-environmental behaviour. Additionally, financial incentives are discussed that can be employed to promote pro-environmental behaviour, reducing the personal sacrifices individuals may need to make.

3.1.1 Increasing Sustainable Behaviour

Encouraging sustainable behaviour can be achieved through various strategies. Validated approaches are information campaigns combined with structural interventions (Abrahamse & Matthies, 2019). Policy measures and information campaigns can create environmental awareness and justify sustainable economic policies and interventions by governments (Mandell & Wilhelmsson, 2011). Reward and penalty systems can also be employed, although the emphasis should be on promoting inner motivation rather than relying solely on external rewards (Bolderdijk, Lehman, & Geller, 2019). Persuasive technology, such as smart systems that promote energy efficiency, can contribute to pro-environmental behaviour by raising awareness and intervening when individual choices negatively impact the environment (Midden & Ham, 2019). Habits also play a role in pro-environmental behaviour. These automatic cognitive structures link situational cues to behavioural patterns, leading to unconscious behaviour (Klöckner & Verplanken, 2019). For example, turning off lights when leaving a room can become habitual behaviour. By employing these strategies, individuals can enhance their environmental awareness.

3.1.2 Financial Incentives

The low-cost theory concerning sustainable behaviour suggests that individuals are more likely to engage in pro-environmental behaviour when the costs associated with that behaviour are low (Diekmann & Preisendörfer, 2003). According to the low-cost theory, people are more likely to adopt and maintain sustainable behaviour when it is cost-effective, requires minimal effort or resources, and matches people's lifestyles. This can include matters like recycling, using energy-saving appliances, using less water, or making use of public transportation. People are more likely to engage in sustainable behaviour when the perceived costs, both financial (i.e. the up-front cost of purchasing sustainable products or technology) and non-financial (i.e. time, effort, inconvenience, or changes to regular routines), are minimized. Based on the low-cost theory, interventions often concentrate on the removal of barriers and the creation of favourable circumstances in order to promote sustainability. This can involve initiatives such as providing financial incentives and offering subsidies or rebates for sustainable products (Bolderdijk, Lehman, & Geller, 2019).

An example used in the Dutch real estate sector to promote sustainable housing is the “green mortgage”. Green mortgages are designed to provide financial benefits to homeowners who have energy-efficient and sustainable homes (Veul, 2022). These mortgages typically offer lower interest rates or additional loan options to motivate homeowners to invest in energy-saving measures and sustainable features for their properties. The main goal of green mortgages is to encourage homeowners to make sustainable choices and contribute to reducing emissions and energy consumption in the housing sector. By offering financial incentives, such as reduced interest rates, banks and financial institutions aim to make sustainable housing more affordable and accessible to a wider range of homeowners (Veul, 2022). The financial benefits of green mortgages can include lower interest rates, extended loan terms, or increased borrowing capacity. Homeowners can use these benefits to invest in sustainable upgrades, such as installing solar panels, improving insulation, or adopting energy-efficient heating and cooling systems. By making these investments, homeowners can reduce their energy costs, increase the value of their property, and contribute to a more sustainable built environment. To qualify for a green mortgage in the Netherlands, homeowners need to meet certain sustainability criteria, which vary among different lenders and mortgage providers. Most of the large mortgage providers (banks) in the Netherlands base their sustainability discount on a mortgage on the energy label, on average ranging from -0,10% to -0,15% (ABN AMRO, 2023; ASN, 2023; ING, n.d.; Rabobank, 2023; Triodos Bank, 2023).

The criteria of mortgage providers are based on factors such as energy performance certificates. Furthermore, several banks deliver a more sustainable mortgage for specific sustainability measures, with lower interest rates or more loan value. Besides that, Triodos Bank also provides a sustainability mortgage for “biobased houses”. This is based on the MPG value of the house, with a maximum of 0,45 (Triodos Bank, 2023). This mortgage gets a discount on the interest rate of -0,30% compared to the null value of energy labels B, C & D. A monetary benefit as the green mortgage based on the MPG value of a house can serve as incentives and triggers for individuals to embrace sustainable practices in their homes. By offering financial benefits and incentives, as substantiated by the low-cost theory, homeowners are motivated to make sustainable improvements and adopt sustainable measures (Diekmann & Preisendörfer, 2003). This not only reduces environmental impact but also empowers individuals to actively contribute to a greener future, which creates environmental awareness.

3.2 Implying Sustainable Behaviour

Apart from people’s decision-making, sustainable behaviour can also be implied. This mostly happens in the form of standards and benchmarks to which products or services should comply with. In the Dutch real estate sector, various sustainability benchmarks and certification systems are introduced which compel individuals and developers to construct more sustainable real estate. The benchmarks serve as guidelines and measurement tools to assess the environmental performance of buildings. The Dutch government has initiated benchmarks that are mandatory for obtaining an environmental permit, including the Energy Label, BENG (Nearly Energy-Neutral Buildings), and MPG (Environmental Performance of Buildings) (RVO, 2023). Furthermore, the sector and environmental organizations have introduced benchmarks such as Paris Proof (DGBC, 2023b) and BREEAM (DGBC, 2023c) among others. These benchmarks play a vital role in promoting sustainable practices and shaping the development of sustainable buildings throughout the Netherlands. By establishing clear standards and targets, these benchmarks not only serve as a regulatory framework but also motivate stakeholders to adopt sustainable approaches in building design, construction, and operation. They provide a roadmap for achieving energy efficiency, reducing environmental impact, and enhancing overall sustainability in the built environment. By integrating these benchmarks into the planning and decision-making processes, individuals, businesses, and policymakers are compelled to prioritize sustainability and make conscious choices that align with these standards.

In current times, awareness about sustainable energy performance has arisen. Warren-Myers, Judge, & Paladino (2018) studied the perception of sustainability in housing by consumers. Sustainability measures in housing such as LED lighting, energy-efficient features, and increased insulation were seen as the most common responses (Warren-Myers et al., 2018). Energy efficiency has been prioritized by consumers and therefore been incorporated by real estate developers. This is due to its quantifiable and measurable impact, making it possible to perform a cost-benefit analysis on kilowatt hours, carbon emissions, and overall costs (Warren-Myers et al., 2018). These concrete factors have served as driving forces behind the development of energy efficiency measures in housing combined with a certification system. In the Dutch real estate sector, energy performance is certified with an "Energy Label" (Rijksoverheid, 2020). Regulations like the energy label have standardized the adoption of energy-efficient measures. The real estate sector has embraced the significance of energy efficiency and recognized the inherent value in implementing such practices (Pitt & Sherry, 2014). In the Western world today, there is a widespread community understanding that buildings should adhere to sustainable energy efficiency standards (Iwaro & Mwasha, 2010). The awareness about energy efficiency is the result of the obligation to include energy labels in the sale, resale, and rental of properties and the direct positive impact on consumers due to decreased operational costs (Brounen & Kok, 2011). This has consequently fostered a willingness among consumers to invest in quality outcomes, thus supporting the industry's efforts. This means that certification like an energy label results in an increase in the property's sales value (Brounen & Kok, 2011; Warren-Myers et al., 2018). So consumers experience a direct financial benefit from sustainable energy performance and adapting to sustainable energy use, which creates WTP.

3.3 Willingness to Pay for Sustainability

The perception and knowledge of sustainability by consumers play a significant role in the engagement to sustainable development and the WTP for sustainability measures. In the 2000s and early 2010s, various studies have demonstrated that consumers' engagement in sustainability initiatives was hindered by the lack of information, awareness and knowledge, coupled with unknown cost implications (e.g. Warren-Myers, Carre, Vines, & Wakefield, 2012; Crabtree & Hes, 2009; Dalton, Horne, & Maller, 2008). Only in higher socioeconomic classes of society the implementation of sustainable measures and the embracement of sustainable products is concluded to be structurally present (Eves & Kippes, 2010; Hurth, 2010). This has been substantiated by published literature into the WTP for sustainability. Mandell & Wilhelmsson (2010) concluded that people with a higher income level have a higher WTP for sustainability measures in housing. Besides that, a higher education level is generally seen as a personal characteristic that increases environmental awareness and has a positive influence on the WTP for sustainability in relation to people with a lower education level (Li, Long, & Chen, 2018). Additionally, pro-environmental behaviour can have symbolic significance in such communities, due to normative goals, allowing individuals to demonstrate their identity and belief in a sustainable environment (Gatersleben & Werff, 2018).

A factor that has been a point of interest during the first period of research into the engagement to sustainability is the relation with gender. It has been stated during that time that women had more belief than men concerning consequences for people and the biosphere (Stern, Dietz, & Kalof, 1993), as a consequence of their biological ability to reproduce and thus their linkage to nature and the feeling of responsibility for its conservation (Meinzen-Dick, Kovarik, & Quisumbing, 2014). This statement has been argued since gender is not the only driver for intrinsic motivations, attitudes, desires, and preferences. The same discussion is present in literature about household composition in regard to having children or not. The discussion relates to the "legacy hypothesis" – also referred to as "parental roles hypothesis" (Davidson & Freudenburg, 1996) and "parenthood status" (Blocker & Eckberg,

1997) – the birth of a child increases environmental concern, driven by a consideration of the legacy parents are leaving for their child(ren) in relation to environmental and life quality (Thomas et al., 2018). This also relates to the influence of gender, where the environmental concern increases for women and less for men (Hamilton, 1985; Davidson & Freudenburg, 1996). However, more recent published literature has shown that the influence of having children is limited on the increase in environmental concern, factors as, for example, overall environmental awareness, education level, and socio-economic class have more impact (e.g. Poortinga, Milfpmt, & Sibley, 2020; Thomas et al., 2018). Looking at age, there is also a difference in literature and the conclusion of the WTP for sustainable products. It has been concluded that younger people are more often environmentally aware than people in older age classes (Suki, 2013). However, the financial strength of younger people is often not in relation to their WTP, so there is willingness but no financial possibility to fulfil the WTP (Royne, Levy, & Martinez, 2011).

As mentioned above and also described in Section 3.1.1 Increasing Sustainable Behaviour, sustainable behaviour is influenced by the overall environmental awareness of individuals. For that reason, environmental awareness can be seen as the main driver for sustainable acceptance, resulting in positive environmental behaviour, leading to a higher WTP for sustainable measures and products (Judge et al., 2019; Mandall & Wilhelmsson, 2011).

3.4 Conclusion

The embracement of sustainability by the full society is associated with challenges, primarily due to the perception of its increased costs and a limited understanding of its benefits. The challenge lies in bridging the gap between consumer desires and their understanding of sustainability. Sustainable behaviour can be encouraged through information campaigns, structural interventions, persuasive technology, and the development of habits. The perception and knowledge of sustainability among consumers are also crucial for their engagement and willingness to pay (WTP) for sustainability measures. In the past, a lack of information and awareness hindered consumers' involvement in sustainability initiatives, but the introduction of sustainability benchmarks and certifications has helped to promote sustainable practices. These benchmarks, both mandatory and voluntary, provide guidelines and measurement tools for assessing the environmental performance of buildings. Energy efficiency, in particular, has gained prominence due to its quantifiable impact and cost-effectiveness, resulting in the incorporation of energy-efficient measures and certifications such as energy labels. Financial incentives, such as green mortgages, have emerged as a means to stimulate sustainable housing. By providing financial benefits, banks and financial institutions encourage homeowners to make sustainable choices and contribute to a more sustainable built environment.

Besides the incentives and measures that are taken to promote sustainable behaviour, there are still socio-demographic characteristics of individuals that influence sustainable behaviour and the WTP for sustainable products. Individuals with a higher income and/or education level have a higher WTP for sustainable products. Besides those, environmental awareness is one of the key characteristics that positively influence WTP for sustainability. The main driver for environmental awareness is the gain in environmental knowledge, achieved through campaigns and social values. Age is an interesting socio-demographic characteristic when looking at the WTP for sustainability. Overall, younger people are more environmentally aware but their WTP is influenced by external factors such as costs. Gender and household composition can have an influence on WTP for sustainability, due to the wishes for a healthy future. However, literature does not conclude to one consensus on this influence and varying results are shown between studies. For this reason, these socio-demographic characteristics will still be considered in this study.

Overall, by understanding the characteristics influencing WTP for sustainability, promoting sustainability benchmarks and certifications, and offering financial incentives, it is possible to encourage sustainable material use and environmentally conscious behaviour.

4. Environmental Performance

To classify sustainable material use in this study, an environmental performance benchmark that certifies sustainable material use is selected to employ as a definition of sustainable material use in the residential construction sector. This chapter starts with the classification of eight different sustainability benchmarks on several criteria which are of importance for this study. Following this, the benchmark which results as most sufficient for the research is explored and the determination method is explained.

4.1 Environmental Performance Benchmark

Several benchmarks which assess the environmental performance of buildings are classified into six criteria. Assessing the benchmarks according to predefined criteria allows for the evaluation and comparison of the benchmarks to determine the most appropriate benchmarks (Dean, 2022). Firstly, the specific criteria which are used to assess the benchmarks are described. Research into environmental performance benchmarks in the real estate sector resulted in eight benchmarks that are used to certify the sustainability of buildings (as mentioned in Section 1.1.1 Sustainability in Construction and 3.3 Implying Sustainable Behaviour). These eight benchmarks emerged as frequently used and referenced when examining the sustainability of the real estate sector. The assessment of the criteria is used to select the benchmark that aligns with the research objectives and provides insights into environmental performance.

4.1.1 Criteria Environmental Performance Benchmark

A total of six criteria have been selected to which the environmental performance benchmarks are assessed. These criteria are selected to ensure accuracy between the chosen sustainability benchmark and the aim and structure of this study. This for example relates to the availability of the benchmark in the Netherlands, the applicability to newly constructed residential buildings and the assessment of material-related emissions. The criteria and the alternative to which the benchmark should correspond to be valuable for this study are explained below:

- *(Inter)national*
  Sustainability is an important topic all over the world. However, in different places, people can have different interpretations of sustainability. To assess sustainability in the Dutch housing sector, the definition of sustainability should meet Dutch standards. For that reason, a Dutch (national) environmental performance benchmark is preferred over an international benchmark.

- *Building Type*
  Buildings can be divided into several types, e.g. residential, commercial, industrial, etc. This study only focuses on residential buildings. For that reason, the environmental performance benchmarks should be applicable to residential buildings. Consequently, the criteria building type is divided into two options: residential and utility (all non-residential building types).

- *Scale Level*
  Within the built environment, it is possible to define several scale levels. In some literature (e.g. Tan (2011)) whole neighbourhoods are defined as sustainable. There are benchmarks that assess a full area when classifying sustainability. This study focuses on the individual dwellings of residential consumers. For that reason, the environmental performance benchmark chosen for the analysis should also focus on the building level and not on the area/neighbourhood level.

- *Emission Type*
  Three types of emissions are defined by looking at buildings and their use of them. Energy-related emissions are those emissions which are emitted by heating or cooling the building. User-related emissions are the emissions derivable to the use of household and electrical equipment. For example, washing machines, lighting, computers, etc. Material-related emissions are emitted by all the materials used in a building during the full life cycle. This study focuses on sustainable material use. The environmental performance benchmarks should therefore certify the sustainability of the materials used in buildings, and thus assess material-related emissions.

- *Life cycle Stage*
  Material-related emissions are emitted during the full life cycle of a building. To assess material-related emissions sufficiently, the environmental performance benchmarks must include all life cycle stages in the certification.

- *Standard / Voluntary*
  There are environmental performance benchmarks that are mandatory in the environmental permit procedure, as well as benchmarks that are voluntary and can be requested to certify a building. The voluntary benchmarks have more rigorous criteria and exceed the environmental performance requirements imposed by the government for mandatory benchmarks. Due to the obligation of an environmental benchmark, it is more commonly used, and data is easier to obtain than a voluntary benchmark.

4.1.2 Result Environmental Performance Benchmark
Table 3 shows the sustainability benchmarks and their respective scores on the criteria. In Appendix A the nine environmental performance benchmarks and an explanation of the score per criteria are given. Based on the assessment, the MPG benchmark is considered the most suitable for testing the sustainability of residential buildings with regard to material use. Since the MPG is compulsory in the environmental permit procedure for all residential construction projects in the Netherlands, there is a larger sample of MPG reports available than the other benchmarks. This positively influences the process of the research.

Table 3 Characteristics of environmental performance benchmarks.

Benchmark	*(Inter) national*		*Building type*		*Scale level*		*Emission type*			*Life cycle stage*					*Norm*	
	National	International	Residential	Utility	Area	Building	Operational-related	User-related	Material-related	Product	Construction	Use	End-of-life	Reuse	Standard Norm	Voluntary Certificate
Energy Label[a]	X		X	X		X	X					X			X	
BREEAM[b]		X		X	X	X	X		X	X	X	X	X	X		X
LEED[c]		X	X	X	X	X	X		X	X	X	X	X	X		X
BENG[d]	X		X	X		X	X					X			X	
MPG[e]	X		X	X		X	X		X	X	X	X	X	X	X	
GPR Gebouw[f]	X		X			X	X		X	X	X	X	X	X		X
Paris Proof[g]	X		X	X		X	X		X	X	X	X	X	X		X
C2C[h]		X	X	X		X			X	X	X		X	X		X

[a](Rijksoverheid, 2020). [b](DGBC, 2023c). [c](RVO, 2010). [d](RVO, 2022). [e](RVO, 2021). [f](GPR Software, 2023a). [g](DGBC, 2023b). [h](Milieu Centraal, 2019).

Additionally, the MPG includes the entire life cycle of the materials used in construction, making it a reliable indicator of material sustainability in buildings. Other benchmarks, such as the Energy Label and BENG, only assess energy efficiency and are thus not relevant to this study. While BREEAM and LEED do assess material use, they do not do so exclusively, which can lead to inaccurate results. Moreover, these benchmarks, along with several others, are not standard norms but buildings are certified on a voluntary basis when they exceed certain performance benchmarks. Due to this, the cases from the Dutch residential real estate sector are too limited. The same counts for Cradle to Cradle Certified and Living Building Challenge. Although Paris Proof appears to be a sufficient indicator for testing sustainable material use in residential construction based on the criteria, it is a relatively new benchmark in the construction sector, and the certification process for buildings as Paris Proof is not yet clear within the industry (Tuinenga, Plas, & Huijbers, 2022). This results in a limited number of cases in the Netherlands and is therefore insufficient for this study. GPR Gebouw has become a more common building quality indicator. The GPR Gebouw classification assesses a building based on five criteria, namely energy, environment, health, quality of use, and future proof (GPR Software, 2023a). The topic environment covers the sustainability of the materials used and it uses an MPG calculation to come to a scoring. For that reason, it is superfluous to use the GPR Gebouw assessment instead of the MPG scoring.

4.2 Environmental Performance Building

In order to motivate and push the construction sector to use more sustainable materials, the Dutch government introduced the MPG. The MPG is obliged to include in every environmental permit application for newly constructed houses or offices (larger than 100 square meters). The MPG defines the environmental performance of a building in a 1-point score per square meter, stated as shadow costs (in € / m² GFA / year) (RVO, 2021). The maximum value for the MPG is in the Netherlands in 2021 set at 0,8 (RVO, 2021). The MPG is determined by summing up the environmental impact of the materials used over the lifetime of a building and dividing by the gross floor area (GFA in m², determined in accordance with NEN2580) allocated to the residential and office function (Stichting Nationale Milieudatabase, 2020a).

$$MPG = (ECI \times amount) / (GFA \times lifespan) \quad [1]$$

$$Units: € / m^2 / year = (€ / (m^2, m \text{ or } \#) \times (m^2, m \text{ or } \#)) / (m^2 \times year)$$

In the determination of the MPG, the environmental impact of a certain material is defined by the environmental cost indicator (ECI, 'Milieukostenidicator' (MKI) in Dutch). The ECI quantifies the environmental cost throughout a material's entire life cycle, including production, transportation, use, and disposal (Quist, 2023). Sustainable materials, including recycled, renewable, and biobased resources, typically demonstrate lower environmental costs owing to reduced energy consumption, decreased emissions, and minimized waste generation (Stichting Nationale Milieudatabase, 2020b). For each environmental effect, these have been estimated and include the anticipated social costs incurred by society if the occurring effect must be avoided, along with the current and regular solutions. Some examples of the costs that are involved are raising dykes because of climate change, reducing maximum speed for lowering nitrogen emissions or treating skin damage caused by UV radiation because of ozone layer depletion. Taking into account all of the environmental effects, the ECI, which is expressed in € / unit (unit is often in square meters, meters, or amounts), is calculated as the shadow cost of that material. The lower the value of the ECI, the less harmful the material is to the environment.

In the following section, the determination method of the environmental impact of construction materials is described. The assessment factors to define the ECI are explained, which is used further in this study.

4.2.1 Determination Method

The basis of the determination method is the European norm EN 15804:2012+A2:2019 developed for the Environmental Product Declaration (EPD), which is complemented to fulfil the environmental performance of buildings, ground, road, and water works in the Netherlands (Stichting Nationale Milieudatabase, 2022). A revision was made to EN 15804 in 2019, making it possible to align the determination method with the LCA methodology of the Product Environmental Footprint (PEF). The determination method serves as a product category rule (PCR) to the LCA, which is performed to formulate an EPD. To compare environmental performance, defined for materials in an EPD, across building materials and products, it is important that the EPDs are collected and checked. The 'Nationale Milieudatabase' (NMD) is responsible in the Netherlands for ensuring the verifiability of the environmental data entered by the producer and the clarity of its use in the calculation of environmental performance (Stichting Nationale Milieudatabase, 2020a). Three categories for construction materials are defined by the NMD and used in the calculations for environmental performance, these categories are based on the availability and validity of data (Sobota et al., 2022):

- *Category 1:*
  Based on data provided by manufacturers and checked by recognized LCA experts.

- *Category 2:*
  Based on data from industry umbrella organizations and supplier groups, independent of specific manufacturers. Checked by recognized LCA experts and representatives of the Dutch market.

- *Category 3:*
  Generic data, independent of manufacturers, uncontrolled and based on averages. 30% additional environmental impact is applied to that specific element as a margin of error to the estimated impact (Stichting Nationale Milieudatabase, 2022).

In order to arrive at unambiguous environmental performance calculations for buildings, the determination method, calculation rules, NMD, and process database are combined to form a coherent whole. As shown in Figure 9, the determination method serves as a PCR for drawing up EPD's and as a rule for determining the calculation instruments.

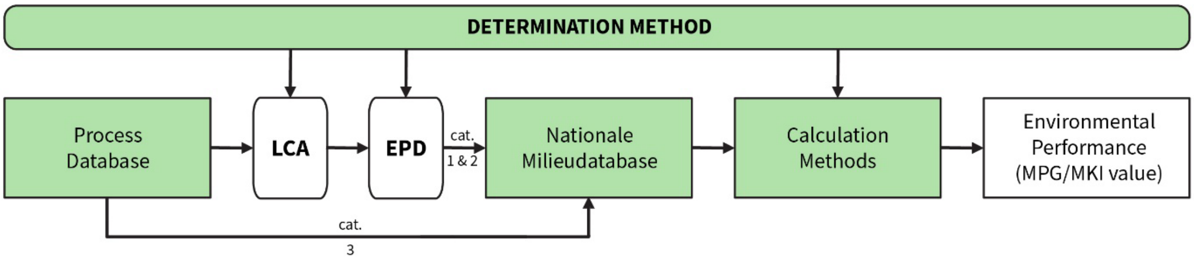


Figure 9 Determination method MPG (Stichting Nationale Milieudatabase, 2022).

A life cycle assessment is defined to determine the environmental impact of construction materials. A set of emission elements is determined that need to be included and valued in the LCA (Stichting Bouwkwaliteit, 2011). These emission elements refer to emissions into the air, water, ground, and emissions for which there are environmental regulations for producing construction materials, products or elements. The emissions are currently tested via 11 impact categories[2] each with its own weight. The life cycle stages, for which the impact categories need to be included in the LCA are product stage (A1-A3), construction stage (A4-A5), use stage (B1-B5), end-of-life stage (C1-C4), and reuse stage (D1-D4) (Stichting Nationale Milieudatabase, 2022). Per the life cycle stage there are multiple components that need to be included in the assessment.

Figure 10 visualizes a process tree as used in the LCA with the indicated material and emission flows as stated in the determination method. These components are used in composing as well as in testing the LCA for the purpose of an EPD. The impact categories recalculated into a monetary value (unit: € / kg equivalent), combining these values of one material results in the ECI. Due to the similar unit of the ECI, it is possible to compare the environmental impact of different materials (Hillege, 2022).

[2] The impact categories: depletion of abiotic resources, depletion of fossil energy carriers, climate change, ozone layer degradation, photochemical oxidant formation, acidification, fertilization, human toxicological effect, ecotoxicological effects on freshwater, seawater, and terrestrial.

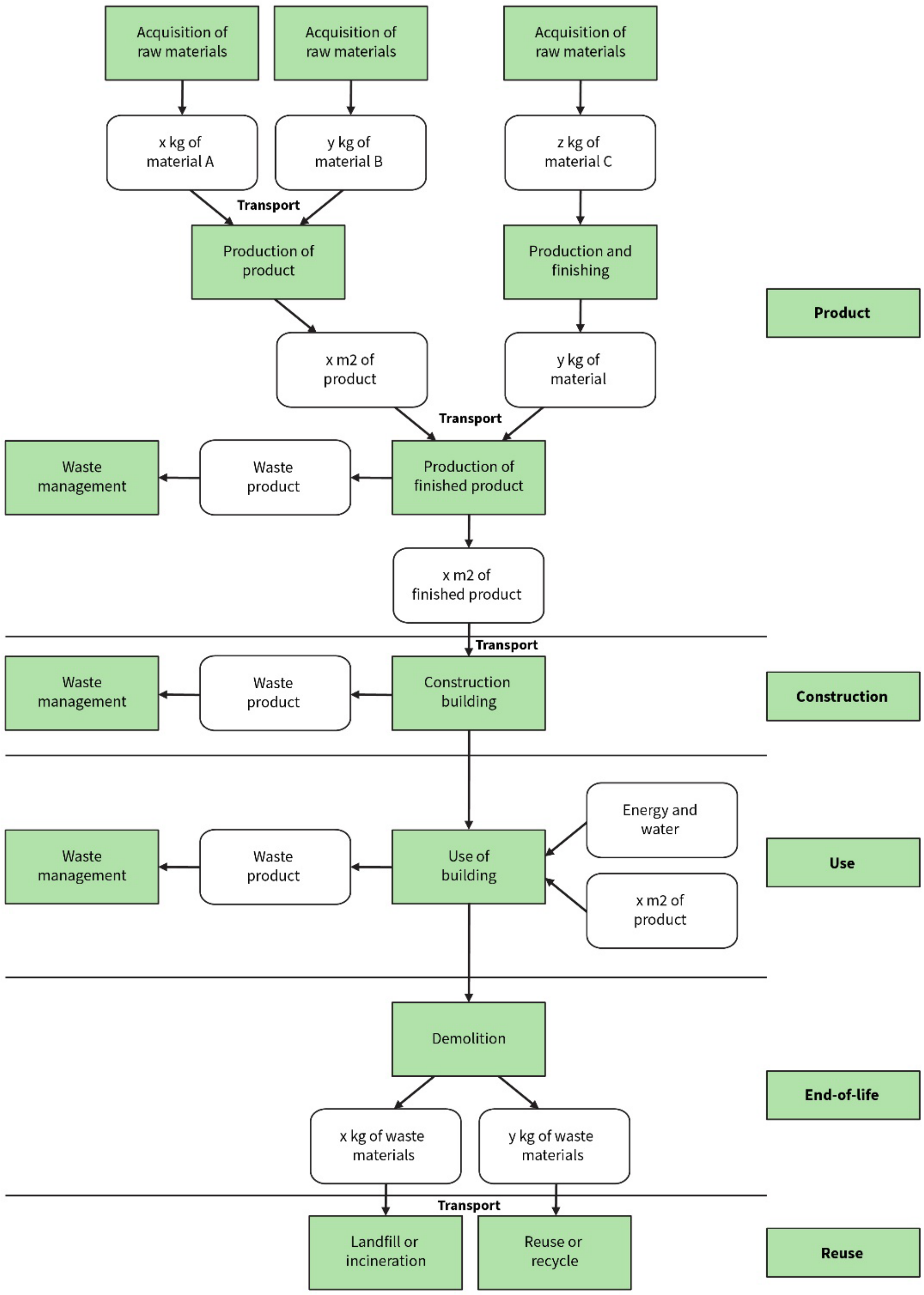


Figure 10 Process tree containing the stages of the life cycle (adapted from Stichting Bouwkwaliteit, 2011).

4.2.2 Data Availability

As described, the database of the NMD includes the product cards of construction materials, which describe the LCA concluding the ECI (Stichting Nationale Milieudatabase, 2022). In this study, use will be made of the GPR Materiaal software tool (after this: GPR), which incorporated the database of the NMD. GPR is developed by W/E Adviseurs in the Netherlands and is validated by the Stichting Nationale MilieuDatabase for performing environmental performance calculations (GPR Software, 2023c). GPR calculates the environmental performance according to the current determination method of the 'Milieuprestatie Gebouwen en GWW-werken' version 3.0 and includes the current database of the NMD 3.0 (GPR Software, 2023c). GPR software is only available in Dutch. Materials names in this report are translated to English as representative as possible, snapshots from the software are not translated. Figure 11 shows a snapshot of the software interface where the building is divided into several main components. Figure 12 shows a snapshot of the software interface where a specific material for a building component (in this case constructive flooring) can be chosen with all the available information given.

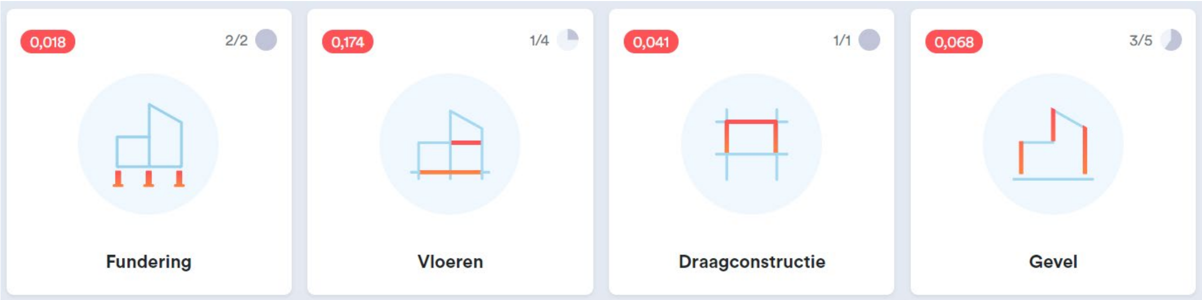


Figure 11 Snapshot from the GPR Materiaal software (GPR Software, 2023b).

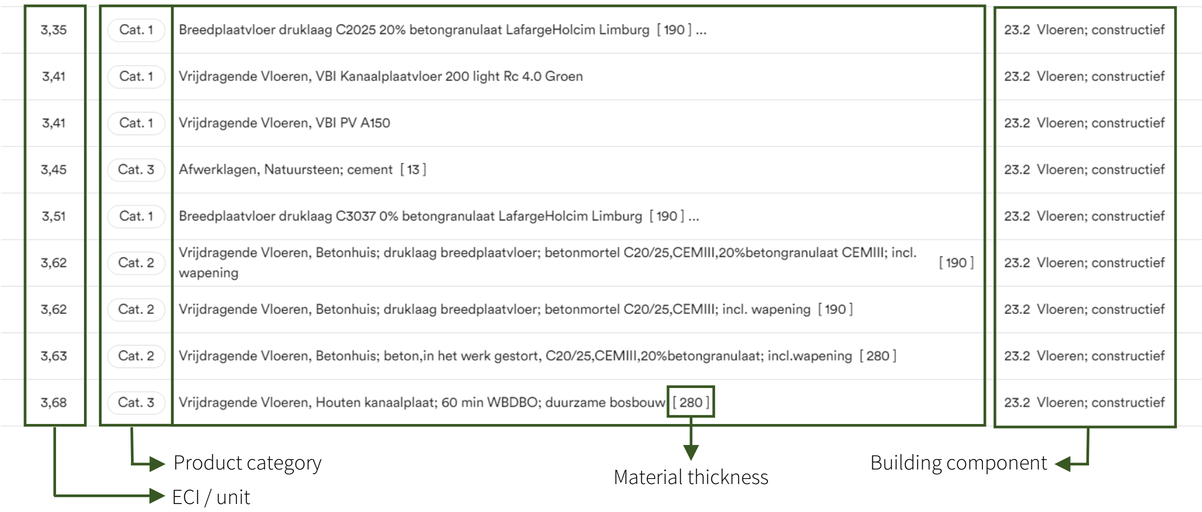


Figure 12 Snapshot of GPR Materiaal with material options and information indicated (GPR Software, 2023b).

4.3 Conclusion

This chapter examined environmental performance benchmarks in the real estate sector, with a focus on sustainable material use in residential construction. Through an assessment on six criteria, the “Milieuprestatie Gebouwen” (MPG) benchmark resulted as the most suitable benchmark to use as the definition of sustainable material use due to its mandatory status, life cycle evaluation, and widespread availability in the Netherlands. The MPG is a building-specific value of environmental performance, determined with the material-specific environmental cost indicator (ECI). The ECI, which is incorporated into the “Nationale Milieudatabase” (NMD), sets the basis for assessing the environmental performance of construction materials and will consequently serve as an indicator of environmental performance in the following part of this study.

5. Material Profiles

This chapter presents various material profiles that facilitate the assessment of both the environmental impact and material costs associated with buildings on different levels. It starts by establishing an understanding of building components and the elements that make up those components. Once the building components are defined, materials are selected in accordance with three different material profiles. Each of these material profiles is distinguished by a particular material characteristic. Subsequently, the environmental impact and material costs for each material profile are outlined. This aims to make it clear what influences variations in building materialization on both environmental performance and costs.

5.1 Building Components

To analyze the material composition of a building, it needs to be divided into its basic components, which together form the whole building. These components serve distinct functions, have varying lifespans, possess different characteristics, and are composed of diverse materials. In this section, the building components are identified based on general architectural and construction norms and aligning with the relevance of this study's objectives.

Brand (1994) defined the building components by his shearing layers concept. According to him, the building consists of several layers, namely structure, skin, services, and the space plan. These layers are divided into a number of components that form the whole of the building. The structure is constructed by the foundation and the load-bearing elements. The skin consists of the façade and the roof. Installations and other systems make up the services of a building. The interior layout of a building, including walls, doors, and stairs, forms the space plan. These components are used as a basis for the determination of the building components used in this study. The components can once again be divided into several elements. In Table 4 the building layers are divided into components, with a stated definition, to which some elements are added. It must be stated that more elements can be defined that form the components, but for the scale of this study, the stated elements are the most relevant.

Table 4 Building components, definitions and elements.

Layer	*Component*	*Definition*	*Element*
Structure	Foundation	The supporting structure below the ground floor or surface of a building (Cornell University, 2005).	Piles Basements
	Load-bearing vertical	The vertical (walls and/or columns) of a load-bearing structure (Punmia & Jain, 2005).	Walls Columns
	Load-bearing horizontal	The horizontal elements of a load-bearing structure which divide levels (Punmia & Jain, 2005).	Floors/slabs Beams
Skin	Façade open	The open outer skin of a building filled with windows and/or doors (ETH Zürich, 2018).	Windows Doors
	Façade closed	The closed outer skin of a building cladded aesthetically (ETH Zürich, 2018)	Inner leaf Façade cladding
	Roof	The covering forming the top of a building (Cambridge University Press & assessment, 2023).	Covering Ballast
Services	Installations	A system or equipment with a mechanical/technical purpose (Universidad Europea, 2023).	Electrical Water & heath
Space Plan	Built-in	Non-structural elements inside a building (inner walls, doors, etc.) (Punmia & Jain, 2005).	Inner walls Inner doors (+ frames)

The NMD makes use of the same division of building components in their database as stated in Table 4. The NMD has made an assumption to which degree the building components have an influence on the scoring of the MPG. By analyzing published MPG calculations, the percentual contribution of materials in the building components to the score of the environmental performance of a building with a residential function could be established, these contributions are visible in Table 5 (Stichting Nationale Milieudatabase, 2020a). As visible, the installations are the largest influential factor on the environmental performance of a house. In the calculations, the performance of the installations is not taken into account, but the environmental impact is based on the LCA of the materials used for producing the installations. So an installation that improves the energy performance of a building does not directly have a positive impact on the environmental performance. On the contrary, most installations which have a significant positive influence on the energy performance have a significant negative impact on the environmental performance (RVO, 2021). For example, PV panels improve energy efficiency but have a negative impact on the MPG. Due to the significant variations in the impact of installations based on factors such as the type of installation and the contrast between energy performance and environmental performance, this study excludes installations from its scope and so will not be considered further on.

Table 5 Share building components in MPG[3] (Stichting Nationale Milieudatabase, 2020a).

Building Component	*Regular*	*Zero-energy*
Foundation	7%	5%
Horizontal structure	16%	13%
Vertical structure	7%	11%
Facades	18%	13%
Roofs	6%	4%
Installations	33%	45%
Built-in	13%	9%

Optimizing the environmental performance, therefore creating a more sustainable building regarding material use, is most efficient by improving those components of a building that have a more significant influence on the environmental performance. Still, when making a house as environmentally friendly as possible, all materials should be taken into consideration. In this study, due to the scale of the research, not all elements and materials can be considered. A selection is made and is further discussed in Section 5.2 Material Profiles.

5.2 Material Types

To gain insight into the impact of different material types on the environmental performance and the material costs of houses, three materials profiles are defined. These three profiles are based on the material types as described in Section 2.3 Sustainable Transition and have one material characteristic as the main concept. The profiles are distributed nominally rather than arranged in a direct hierarchical order. This means that a material does not necessarily have a lower environmental impact when it changes profiles. However, there are differences in levels, which makes it possible to compare materials between profiles per building component. The definitions of the material characteristics of the profiles are stated as follows:

1. *Traditional*
   Traditionally, the Dutch construction sector makes use of stony materials like brick, cement, and concrete. These materials are CO_2 intensive to produce and therefore have a negative effect on the environment.

2. *Circular*
   Circular construction materials can either be based on the principle of demounting and reusing materials without degradation of the quality or using construction and demolition waste in new materials. The use of circular materials aims to effectively repurpose resources, resulting in a decrease in the reliance on new materials and minimizing environmental consequences.

3. *Biobased*
   Biobased materials are a class of materials derived partially or entirely from biomass sources. Biobased materials are a natural and renewable material source, decreasing the reliance on non-renewable resources.

The building components listed in Table 4 form the basis for selecting materials within the scope of this study. To maintain a manageable scope, focus is laid on one specific element for each building component. This means that for the foundation, the piles are taken into consideration. The horizontal and vertical load-bearing structures

[3] It's important to recognize that various design choices can impact the extent to which building components influence environmental performance. This are gross floor area, number of stories, story height, façade area, and share of open parts in the façade (see Appendix B for an explanation of the influences).

are constructed out of the same material. For that reason, these components can also be combined and referred to as "Building Structure". For the open façade, the window frames are taken into consideration since the most variation is possible between the different material profiles. The façade cladding is considered looking at the closed façade, also because the most variation in materialization between the profiles is possible for this component. For the roof, the ballast and covering are considered as one in this study. The inner walls (i.e. room and dwelling dividing walls) are considered for the built-in.

Materials that align with the building components and the profile's characteristics are selected for each material profile. The materials selected as traditional materials, are in this study materials that are commonly used in the Dutch construction sector over the past decades and/or are materials with a higher environmental impact. Circular and biobased material alternatives are selected based on their alignment with the characteristics of material profiles and their practical suitability in the construction sector (e.g. resulting in concrete piles at the biobased profile). It is essential to note that the chosen building components and materials do not constitute a full building but rather represent a selection of diverse materials. As previously mentioned, this selection is driven by considerations of presence and potential variations within the construction of buildings. The GPR software is employed to facilitate this material selection process. The software enables the identification of materials commonly used in the construction sector that closely match the profile's characteristics. See Table 6 for the material profiles with the selected materials per component.

Table 6 Material profiles including the material per building component.

Building Component	*1. Traditional*	*2. Circular*	*3. Biobased*
Foundation	CIP screw pile	Cir. Concrete prefab pile	Concrete prefab pile
Horizontal structure	Wide slab	Cir. prefab elements	CLT elements
Vertical structure	CIP columns & walls	Cir. prefab columns & walls	CLT columns & walls
Built-in (Inner walls)	Gypsum blocks	Flax wall elements	Timber frame
Façade (Cladding)	Masonry brick	Click brick	Wood
Façade (Window frames)	Aluminium	Recycled PVC	Wood
Roof covering	Grit ballast	Recycled bitumen	Green roof

5.3 Environmental Performance

The environmental impact is determined using the ECI from the NMD database which is accessed via GPR software. The materials are selected which match the characteristics of the profile. There are multiple categories in which a material type can be categorized, as explained in Section 4.2.1 Determination Method. Per building component and material profile, it can differ to which product category the selected material belongs. Appendix C includes an overview of all the exact materials selected from the GPR database. Based on the characteristics of the profiles it is expected that the environmental performance, measured by the ECI, will decrease for both profile 2 and profile 3 when compared to profile 1. This decrease is observed across most building components, although the extent of the decrease varies depending on the specific component. Furthermore, it varies whether the circular profile or the biobased profile achieves the lowest ECI for each building component. Table 7 provides the ECI of the selected materials per profile and building component.

Table 7 ECI per profile including the difference of profiles 2 & 3 in comparison to profile 1.

	Profile 1	*Profile 2*		*Profile 3*	
Building Component	*ECI*	*ECI*	*Δ%*	*ECI*	*Δ%*
Foundation	30,92	4,00	-87,1%	12,19	-60,6%
Horizontal structure	6,47	1,76	-72,8%	1,20	-81,5%
Vertical structure	13,72	1,76	-87,2%	1,43	-89,6%
Built-in (Inner walls)	2,94	1,97	-33,0%	1,94	-34,0%
Façade (Cladding)	4,32	1,16	-73,1%	0,65	-85,0%
Façade (Window frames)	5,44	1,56	-71,3%	3,78	-30,5%
Roof covering	1,95	0,64	-67,2%	3,29	68,7%

Figure 13 visually represents the difference in the cumulative ECI scores of the material profile levels. It is evident that the traditional profile results in the highest environmental cost indicator per square meter when considering the specified building components and materials from Table 6. In contrast, the circular and biobased profiles present significantly lower ECI values, indicating an environmentally friendlier alternative. The range in which the ECI value decreases for the circular profile ranges from -33,0% till -87,2%. For the biobased products, the reduced range varies from -30,5% to -89,6%, with one outlier for the Roof covering with increases of 68,7%. This outlier is explained further in this section.

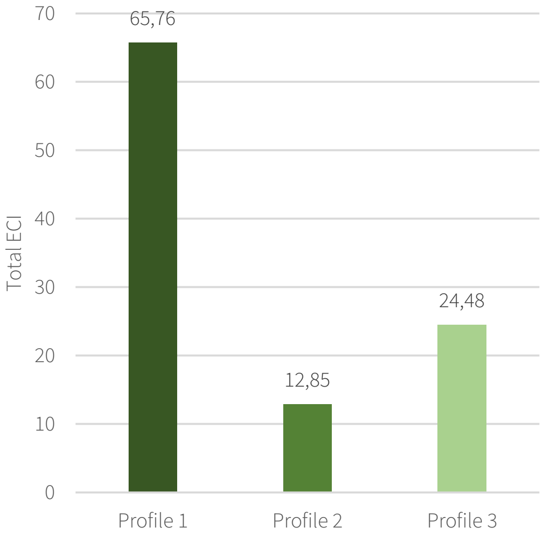


Figure 13 Sum of the ECI values per level.

Figure 13 distinctly highlights the differentiation between the traditional profile in relation to the circular and biobased profile. Also visible is that, with the materials chosen in these profiles, the circular profile results in a lower total ECI value compared to the biobased profile. This discrepancy relates to the material choices, consequently, the overall ECI can vary between the two profiles with different types of circular and biobased materials. Additionally, the biobased profile registers a higher value primarily due to the choice of roof covering materials. Profile 1 includes a grit ballast roof covering, while profile 3 holds a green ballast roof covering. The green ballast roof covering necessitates additional elements, particularly for drainage systems, resulting in more material per square meter and thus a higher ECI. To provide visual clarification of this statement, Figure 14 presents simplified roof covering details, highlighting in blue the presence of additional elements (i.e. additional drainage and filter) and thus the increased material required for the green roof. Since the use of a green roof is not precisely a biobased product, but more has a biobased appearance, the ECI value of the roof is left out of further consideration.

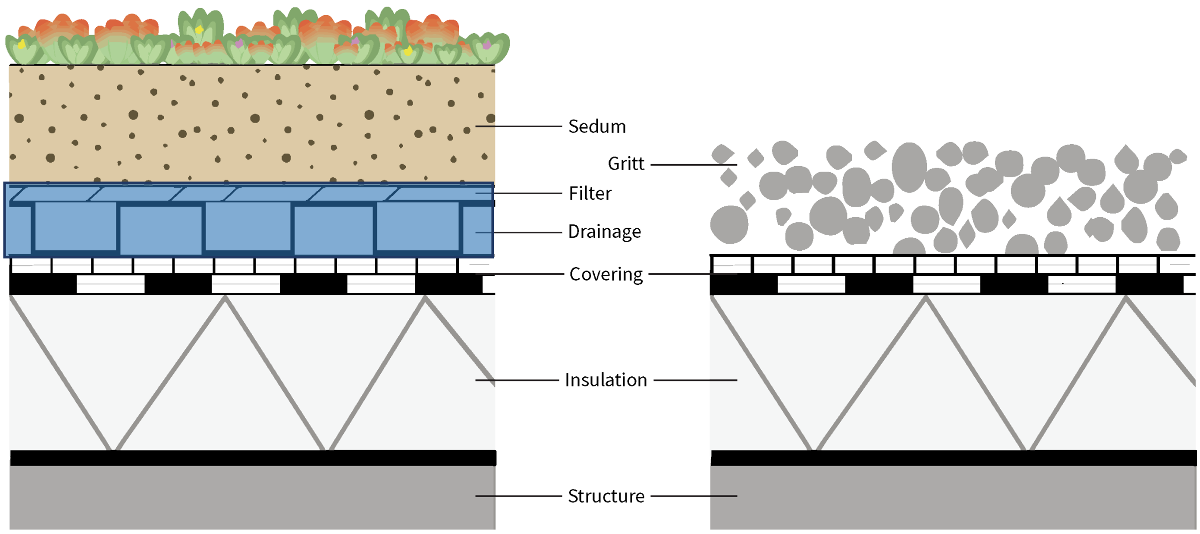


Figure 14 Simplified detail roof covering. Left: Sedum roof. Right: Grit roof (adapted from Groenblauw, n.d.).

5.4 Material Costs

The material costs are determined using data from a Dutch residential project developer (i.e. VORM). The data are based on realized residential construction projects which resulted in mean material costs for each component of a building (VORM, 2023a). Building components that are most comparable with the materials selected from the GPR software are selected to determine the material costs. For materials that are not present in the data, literature sources are used to determine the material costs. The latter is the case for the materials of the horizontal and vertical structures for circular and biobased profiles, which are circular concrete and CLT.

Concerning the circular profile, the material costs of the circular concrete need to be determined to be able to compare it to the other profiles. "Urban Mining Concrete 50" is selected as a circular alternative to regular concrete. This concrete is produced by making use of modern technologies, making it possible to separate the components of demolition waste concrete and use this to produce new circular concrete (New Horizon, 2023), as also discussed in Section 2.3.2 Circular Materials. It is stated that on average circular concrete is 10% more expensive than regular concrete (Planbureau voor de Leefomgeving, 2021). In the comparison of the material profiles, circular concrete is stated with 10% higher material costs in relation to the material costs of the concrete used in the traditional profile. The material costs of CLT are variable in the way it is implemented in a building. As discussed in Section 2.3.1 Biobased Materials the additional material costs due to the use of CLT can be 5-40% higher depending on the stage in which it is implemented in the design process of a building and the geographical location combined with the availability of materials (Vos et al., 2021; CKC Structural Engineers, 2018). This study focuses on new construction houses, making it possible to adopt a wooden structure early on in the design process. Furthermore, the geographical location of the Netherlands is beneficial for the use of CLT in construction (CBI, 2017). Taking these aspects into consideration has led to the decision to add an additional 15% material costs to the CLT structure in comparison to the concrete structure of the traditional profile.

Table 8 provides the material costs for the selected materials per profile and building component. Figure 15 illustrates the variance in the total material costs per square meter among the various material profiles. The traditional profile results as the most cost-effective alternative. In contrast, the circular profile results in an overall additional material costs of 21,0%, and the biobased profile has an overall increase in material costs of 15,3% when compared to the traditional profile.

Table 8 Material costs per profile including the difference of profiles 2 & 3 in comparison to profile 1.

Building Component	*Profile 1* *€/m²*	*Profile 2* *€/m²*	*Δ%*	*Profile 3* *€/m²*	*Δ%*
Foundation	146,60	161,26	10,0%	162,97	11,2%
Horizontal structure	114,06	125,47	10,0%	131,17	15,0%
Vertical structure	180,50	198,55	10,0%	207,58	15,0%
Built-in (Inner walls)	57,47	64,42	12,1%	93,76	63,1%
Façade (Cladding)	146,60	338,25	130,7%	175,00	19,4%
Façade (Window frames)	347,48	310,59	-10,6%	314,99	-9,4%
Roof covering	68,58	86,14	25,6%	138,00	101,2%

In line with the information provided in Section 2.3 Sustainable Transition, it is clear that generally, the construction expenses for circular and biobased materials are higher compared to those of traditional construction materials. However, there are some exceptions to this statement. The first building component where the circular and biobased options offer more economical alternatives is the window frames. The traditional profile includes aluminium window frames, which are the highest-priced option among the three, followed by the biobased and circular profiles. Moreover, noticeable differences are observed in the façade cladding. The most economical choice among the three material profiles is profile 1, a masonry wall. There is a significant difference in cost per square meter with the "Click Brick" system used for profile 2, which allows for dry stacking of brick walls and demounting without damaging the bricks (Wienerberger, 2023). This results in this system being more than twice as expensive as the traditional profile and almost twice as expensive as the biobased profile. Excluding the outliers and expectations, looking at the average difference in material costs between the traditional profile and the circular/biobased profile falls in the range of +10% to +20%.

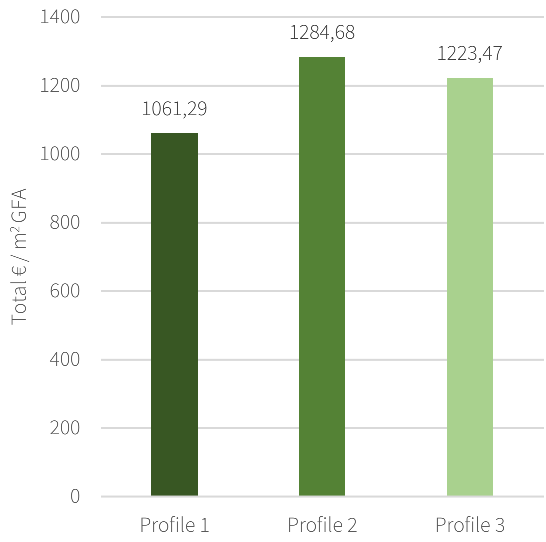


Figure 15 Sum of the material costs per level.

5.4.1 Additional Consumer Costs

One should recognize that an increase in material costs does not yield a directly proportional increase in the selling price of a house. The difference between the material costs and the selling price arises from the complex composition of the overall construction costs. The overall construction costs consist of a large number of different cost items, of which the most significant are material costs, professional fees, levies, insurance, risk settlement, and more (IGG Bouweconomie, 2023). The material costs account for the largest share of the overall construction costs, the remaining share is defined as the “additional costs”. Generally, the material costs (i.e. material costs including labour costs) make up to 70% of the overall construction costs (EIB, 2011). The analysis reveals that, on average, there is an increase in material costs ranging between +10% and +20% for buildings constructed using circular and biobased materials compared to the traditional profile. A rise in the material costs as stated contributes to a proportional but slightly moderate increase in the selling price, estimated to fall within the range of +7% to +14%. This situation highlights the relation between material costs and the calculation of selling price.

5.5 Conclusion

This chapter gives insight into the environmental performance and costs of different materials used in construction. Three material profiles – traditional, circular, and biobased – are defined, and materials are selected in accordance with relevant building components: foundation, building structure, inner walls, façade cladding, window frames, and roof covering. Each profile has its own specific material characteristics and differences in environmental impact and costs. Environmental performance is defined using the environmental cost indicator (ECI) from the NMD. The analysis of the environmental performance revealed that both circular and biobased profiles showed positive shifts in environmental impact, marked by substantial ECI reductions ranging from approximately -30% to -85%. In contrast, the circular and biobased profiles entailed marginally higher material costs, with increases mostly in the range of +10% to +20%, respectively, in comparison to the more cost-effective traditional profile. These additional material costs can result in increased costs for consumers, ranging from +7% to +14% in terms of selling prices, since the material costs account for a part of the overall construction costs.

6. Research Methodology

To move forward with the sustainable transition, the use of sustainable materials in housing holds a significant position. The goal is to reduce emissions and mitigate the impacts of climate change, incorporating sustainable practices into the construction and design of residential properties becomes crucial. To ensure the efficiency of the sustainable transition, the preferences and behaviour of people should be known. Choice modelling serves as a valuable tool in the field of sustainable housing, allowing insights into human behaviour and determine individuals' WTP for sustainable materials. By presenting individuals with different scenarios and options, researchers can analyse their choices and preferences, shedding light on the factors that influence decision-making. Through choice modelling, one can assess the relative importance individuals place on sustainable materials in housing and estimate their WTP for such features. In this chapter, the research method, namely a choice model, is explained. It starts with the setup of the conceptual model. Followed by the explanation and the design of the choice experiment. Finally, it is explained how the data is collected and analysed.

6.1 Conceptual Model

The conceptual model, visualized in Figure 16, presents an overview of various characteristics that influence the WTP for sustainable materials in a multi-family house. The Unit of Analysis (UoA) in this model is identified as the "residential consumer". Published literature, discussed in Section 3.3 Willingness to Pay for Sustainability, indicates that several key socio-demographic characteristics can influence the WTP for sustainability. The socio-demographic characteristics for which the influence on the WTP for sustainability is more discussed in published literature are education level, household income, and environmental awareness. Age is a characteristic which has influence, but also relates to factors such as financial strength. The influence of gender and household composition differs in literature, with recent publications indicating that the influence is limited. However, the mentioned characteristics are included in this study to see their influence on the WTP for sustainable materials in housing. The relation between these socio-demographic characteristics and the WTP is influenced by the interaction variable, which is defined as the building component. This interaction variable operates at two levels: environmental performance and price level associated with different materials used in the building components. The conceptual model provides a framework for understanding how the socio-demographic characteristics of residential consumers interact with the building component to influence the WTP for sustainable materials.

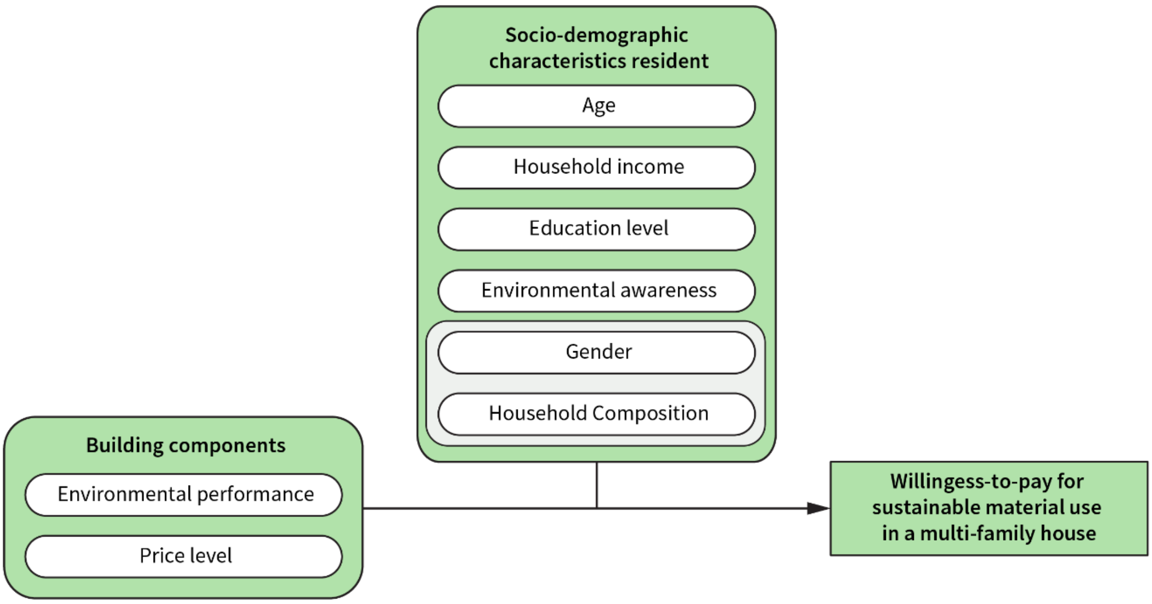


Figure 16 Conceptual model.

6.2 Stated Choice Model

In the academic world, there are several experiments and research models to test one's preferences. Correlating to the conceptual model and the goal of this study, a stated choice experiment (SCE) is used in this study. A SCE is a method used to understand people's preferences and decision-making by presenting them with hypothetical scenarios and asking them to make choices among different options (Hensher, Rose, & Greene, Applied Choice Analysis, 2015). The set-up of an SCE consists of several steps to construct a sufficient experiment to reveal the preferences and decision-making behaviour. Figure 17 shows the steps schematically after which the method and information needed for each step, including the decisions that have been made, are explained.

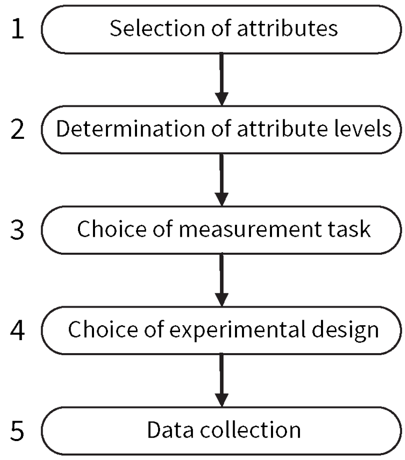


Figure 17 Steps for constructing a stated choice experiment (Molin, 2011).

6.2.1 Attributes

The first step of constructing a SCE is the identification of the attributes. Defining the attributes can be based on literature research, preliminary research, or the experience of the researcher himself (Molin, 2011). The attributes should align with the research objectives and be relevant to the decision context. All possible attributes that can have influence on the decisions should be identified. Nonetheless, there are a few criteria to which one can judge and assess the attributes to define the most important attributes for the research (Louviere & Timmermans, 1990): 1) Which distinctive attributes can be disregarded to maintain a collection that is relevant to the majority of individuals? 2) Which attributes can be preserved, combined, or reformulated to ensure that the set of attributes remains concise and avoids unnecessary repetition, making the experiment manageable? 3) Are the selected attributes adequately specific to provide managers or planners with insights into the outcomes of policy or planning measures? 4) Do the used terms of the attributes align with the respondents' cognitive representations of the alternatives they can choose from? To keep the experiment manageable but definable, up to 10 attributes are typically defined (Hensher et al., 2015). The attributes for the SCE are stated as follows, after which it is explained how they are defined:

1. *Foundation*
2. *Building Structure*
3. *Inner Walls*
4. *Façade Cladding*
5. *Window Frames*
6. *Roof Covering*
7. *Price Level*

Attributes 1 to 6 are a translation of the building components as stated in Chapter 5. Material Profiles. These building components have a substantial impact on the overall environmental performance of buildings. Therefore, it can be concluded that these attributes are valid and relevant to the majority of individuals in multi-family housing. As mentioned in Section 5.2 Material Profiles, it is possible to combine the horizontal and vertical structure into the attribute "Building Structure", due to the same material characteristics. The defined attributes represent a unique aspect of sustainable materials in housing. Including these attributes in the SCE, makes it likely that the resulting data will provide valuable insights into the outcomes of policy or planning measures related to sustainable materials in multi-family housing. Furthermore, the attributes are general building components, making it possible for respondents to understand the alternatives and the information given. Besides attributes 1 to 6 which are related to the building components, there is attribute 7 which is the price level. As described in Section 5.4 Material Costs the use of circular and biobased materials can result in an increase in the total construction costs. This is translated to an additional price for the consumer in the SCE, as explained in Section 5.4.1 Additional Consumer Costs. By introducing the "price level" attribute, it is possible to observe how respondents make trade-offs between the cost of sustainable housing and the perceived benefits of sustainable materials presented to them in the choice sets.

The environmental performance of the house is not included as an attribute in the SCE. As explained in Section 5.2 Environmental Performance, the environmental performance is dependent on the material types of the building components, which are now categorized as attributes 1 through 6. Given that environmental performance is strongly dependent upon the type of materials and is challenging to quantify as independent values, it has not been considered as a summarizing variable. The variation in environmental performance across levels is communicated to participants before the experiment. Consequently, participants are informed about these differences and therefore are taken into consideration. However, these differences will not be treated as separate variables correlated with the attributes. A more detailed explanation of information presented about the environmental performance during the survey is provided in Chapter 6.3 Survey Design.

6.2.2 Attribute Levels

Secondly, the attribute levels should be identified. Each attribute should have multiple levels that represent different options or characteristics. The attribute levels can either represent quantitative attributes (e.g. price 100 euros, 200 euros, etc.) or qualitative attributes (e.g. colour) (Hensher et al., 2015). Here a distinction can be made between nominal and ordinal attributes. For nominal attributes, it is important that the attribute levels are concluded from an in-depth study. With ordinal attributes, it can be assumed that there is some natural order among the levels. The number of attribute levels can differ per attribute and is normally limited between two and four levels (Molin, 2011).

Table 9 Defined attributes & attribute levels.

	Attribute	*Attribute Levels*
1	Foundation	1. Traditional: Cast-in-place concrete screw pile
		2. Circular: Circular prefab concrete pile
		3. Biobased: Prefab concrete pile
2	Building Structure	1. Traditional: Cast-in-place concrete walls & floors
		2. Circular: Prefab circular concrete walls & floors
		3. Biobased: Cross-laminated-timber walls & floors
3	Inner Walls	1. Traditional: Gypsum blocks
		2. Circular: Flax Wall elements
		3. Biobased: Timber frame
4	Façade Cladding	1. Traditional: Masonry brick
		2. Circular: Click Brick (dry masonry)
		3. Biobased: Wood
5	Window Frames	1. Traditional: Aluminium
		2. Circular: Recycled PVC
		3. Biobased: Wood
6	Roof Covering	1. Traditional: Gritt
		2. Circular: Recycled bitumen
		3. Biobased: Green
7	Price Level	1. No additional costs
		2. +7% additional costs
		3. +14% additional costs

In this study, the attribute levels are related to the material profiles as described in Chapter 5. Material Profiles. Attributes 1 to 6 each have three attribute levels (i.e. traditional, circular, and biobased) with a specific material type as stated in Table 9. The seventh attribute is the price level. Differences in material use lead to differences in the total material costs of a house. In chapter 5.4 Material Costs an analysis is done into the material costs of the materials as presented in the material profiles. To exclude correlation between the attributes, the price level is not included as a summary variable determined by the levels of attributes 1 to 6. The decision has been made to define three levels which give a representative additional costs due to the use of traditional, circular or biobased materials. As explained in Section 5.4.1 Additional Consumer Costs, the additional material costs are translated into an addition to the selling prices. This results in the following levels: "No additional costs", "+7% additional costs", and "+14% additional costs".

6.2.3 Measurement Task

The next step is the choice of the measurement task, which relates to the type of response requested from the respondents. Typically, three distinct measurement tasks are identified (Molin, 2011). First, the ranking task asks the respondents to arrange the set of profiles in order of their overall preference. Secondly, in a rating task respondents use a rating scale to indicate their strength of preference for each profile. Ensuring that a rating task also captures the relative preference between profiles, while a ranking task only captures a preference order. Lastly, a widely recognized measurement task that closely resembles the behaviour of decision-makers is the choice task. Respondents are presented with two or more choice sets and are required to indicate the most preferred profile. Due to the setup of the experiment, one additional step is necessary to construct the choice experiments, namely, to identify the choice sets. Since the choice task most accurately resembles the behaviour of decision-makers in the real estate market (Molin, 2011), this study makes use of the choice task for decision-making.

6.2.4 Experimental Design

The fourth step is the choice of the experimental design. As described, respondents will have the choice task between choice sets, these choice sets need to be identified. To define the choice sets, there is the possibility to make use of one of the experimental designs (Molin, 2011): full-factorial designs, fractional-factorial design, and comprehensive design. When a full-factorial design is used, the number of profiles would have been too large to present to respondents. This would have been an unlabelled experiment making the number of choices set in the experiment to have been equal to L^H (Hensher et al., 2015), in this study equal to 3^7 = 2.187 profiles. For that reason, the SCE as constructed in this study will make use of a fractional-factorial design. In a fractional-factorial design, the attributes and their levels are translated in a design through orthogonality, meaning that there is no correlation between the attributes and all the attribute levels appear an equal number of times over the design (Hensher et al., 2015).

In a fractional-factorial design, a matrix is used to determine how attribute levels should be combined to create profiles. Each attribute is assigned to a column that corresponds to a specific set of numbers, with (0, 1, 2) corresponding to a third-level attribute (Molin, 2011). See Table 10 for an example of assigning numbers to the attribute levels. Level 1 becomes 0, level 2 becomes 1, and level 3 becomes 2. Each row in the matrix (of which the first three rows are shown in Table 11 as an example) represents a distinct profile, combining different attribute levels according to the assigned numbers in the columns. The fractional-factorial design used in this study is based on the orthogonal basic plans designed by Addelman (1962). Taking the number of attributes and their levels into consideration, resulted in the use of Basic Plan 6 and brought the number of profiles to 27. Appendix D shows the orthogonal design where the attribute levels per choice profile are defined.

Table 10 Example of numbering the attribute levels for the orthogonal fractional-factorial design.

	Attribute	*Attribute Levels*	*Assigned number*
1	Foundation	1. Traditional: Cast-In-Place Concrete Screw Pile	0
		2. Circular: Cast-In-Place Circular Concrete Screw Pile	1
		3. Biobased: Prefab Concrete Pile	2

Table 11 Example of an orthogonal fractional-factorial design to define the profiles.

Profile	*Attribute #1*	*Attribute #2*	*Attribute #3*	*Attribute #4*	*Attribute #5*	*Attribute #6*	*Attribute #7*
1	0	0	0	0	0	0	0
2	0	0	0	0	1	1	2
3	0	0	0	0	2	2	1

Presenting all 27 profiles in different choice tasks to each of the respondents would make the SCE too elaborate. For that reason, each respondent is presented with 8 choice tasks, each including 2 profiles and the option "None of the two". Including the option "None of the two" in a SCE allows respondents to indicate that they do not prefer either of the presented options. It provides more accurate insights into real preferences since respondents are not forced into making a decision and so effectively reduces hypothetical bias (Ladenburg, Olsen, & Nielsen, 2007).

6.2.5 Sample Size

To ensure the statistical reliability and meaningful analysis of data collected in a SCE, an appropriate sample size should be determined. The minimal sample size can vary based on factors such as the complexity of the experiment design, the number of attributes and levels, and the statistical analysis techniques utilized (Bekker-Grob, Donkers, Jonker, & Stolk, 2015). The rule of thumb presented by Orme (2010) includes the number of respondents (n), the number of tasks (t), the number of alternatives per task (a), and the number of analysis cells – the maximum number of levels in an attribute – (c) to determine the minimum sample size:

$$\frac{n\,t\,a}{c} \geq 500 \;\Rightarrow\; n \geq \frac{500\,c}{t\,a} \qquad [2]$$

In the SCE in this study, the number of tasks (t) is equal to 8, the number of alternatives in a choice set (a) is equal to 2, and the number of analysis cells (c) is equal to 3. Substituting these numbers in Equation 2, results in a minimal sample size of 94 respondents. Nevertheless, it is positive to aim for a large sample size to increase the statistical strength. It is crucial to recognize that sample size alone does not solely determine statistical reliability. The quality of the data, representativeness of the sample, and validity of the experimental design are also integral in ensuring accurate and robust results.

6.3 Survey Design

The SCE, described in the previous chapter, is conducted using an online survey. This section of the thesis outlines the design of the survey. To gain information from the respondents the survey starts with supplementary questions concerning socio-demographic characteristics and housing characteristics. Followed are the choice tasks as discussed in detail in Section 6.2.4 Experimental Design. Before the choice tasks are given, the respondents are presented with additional information needed to understand how to perform the choice tasks. The additional information presented is discussed in Section 6.3.3 Choice Tasks & Information. The survey ends with several statements about environmental awareness to which the respondent has to fill in the level to which he/she agrees. The reasoning behind and the setup of the questions are described in this section. The complete survey (including an exemplar choice task) can be found in Appendix E.

6.3.1 Socio-Demographic Characteristics

In order to conduct effective market research and formulate effective policies, understanding the factors that influence individuals' WTP is essential. Several socio-demographic characteristics have been identified as potential drivers of WTP for sustainability, including age, gender, educational level, household income, and household composition. Questions on these socio-demographic characteristics are included in the survey in order to make it possible to research the relations between those characteristics and WTP.

Furthermore, the data from the questions on socio-demographic characteristics is used to validate the representativeness of the obtained sample compared to the Dutch population as a whole. By doing this, it becomes possible to determine whether the sample is a true reflection of the Dutch population, allowing for an assessment of the generalizability of any drawn conclusions.

6.3.2 Housing Characteristics

Incorporating questions about housing characteristics, such as current housing type, number of bedrooms, construction year, dwelling size, and rent or owner-occupied status, into the survey may offer the opportunity to filter respondents' data based on housing type, provided a sufficient amount of data is collected. Additionally, it can provide valuable insights into the research sample, potentially enhancing the understanding of the target population and contributing to the validity of the research findings.

6.3.3 Choice Tasks & Information

Within the SCE, definitions are used that the respondents might not be familiar with. For that reason, the respondents are informed of the definition used in the SCE before they are presented with the choice tasks. The goal of the experiment is explained, followed by the definition of “environmental impact”, “traditional construction”, “circular construction”, “biobased construction”, and “price level”. The definitions provided to the respondents are visible in the survey as stated in Appendix E. Additionally, a sheet is provided with visualizations of the different materials per profile and building components (see Figure 18). These visualizations will give people with less knowledge about the construction sector a better understanding of the differences between the materials presented. Furthermore, each of the building components is explained, including the differences between various materials. The visualizations could be opened in a separate screen throughout the whole SCE. The definitions of the building components, as stated in Appendix F, opened when hoovering over a specific component with one’s mouse.

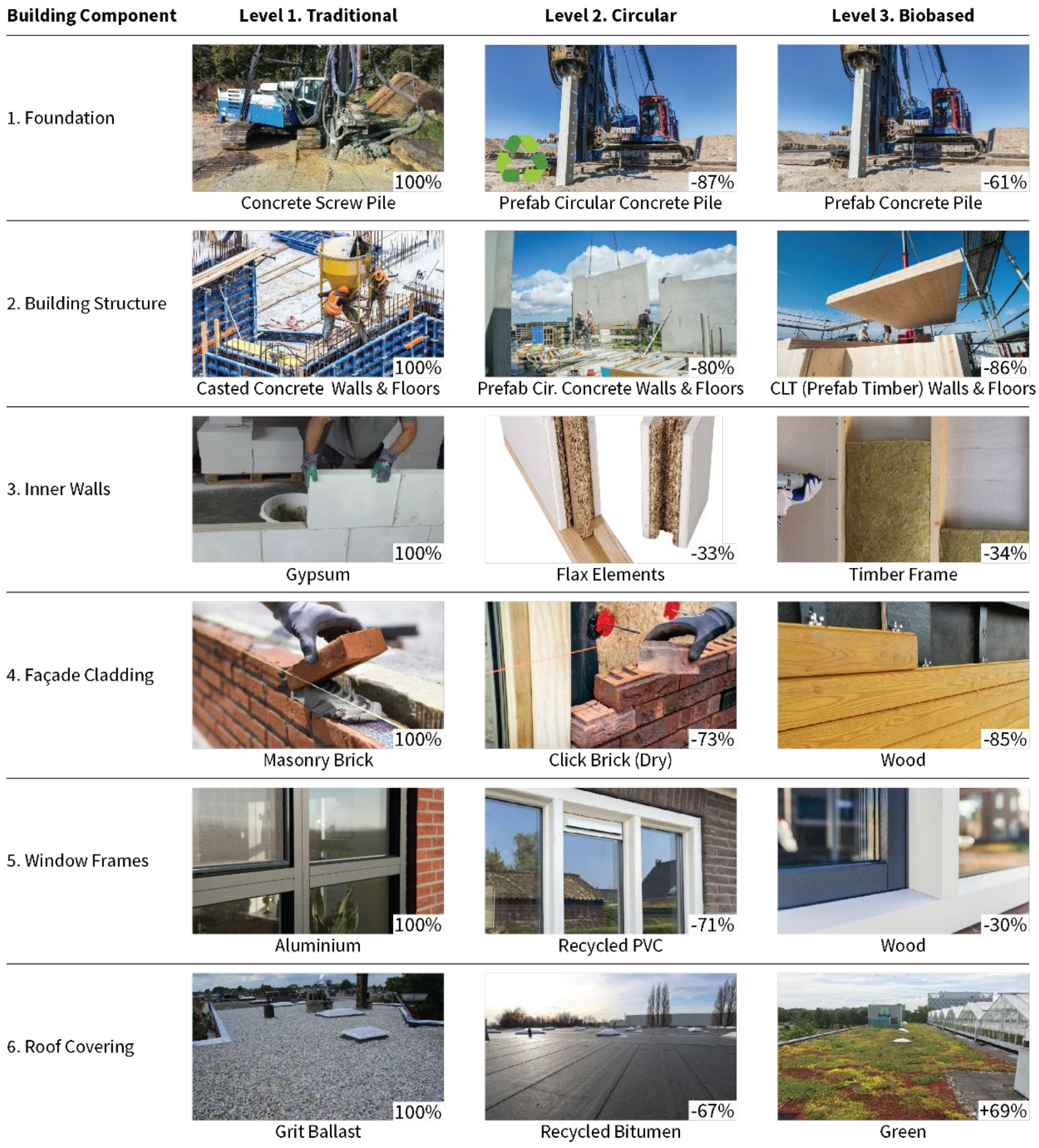


Figure 18 Overview of the building components and materials as presented in the survey.

6.3.4 Environmental Awareness

The level of environmental awareness of people is one of the characteristics that influence one's WTP for sustainability and sustainable measures in housing. To determine the environmental awareness level of the respondents of the survey, the opinion of people is asked concerning several statements. These statements reflect on climate change and environmental problems. Respondents are asked to indicate their level of agreement with the statements on a 7-level scale of agreement proposed by Likert (1932):

1. Strongly disagree;
2. Disagree;
3. Somewhat disagree;
4. Neither agree nor disagree;
5. Somewhat agree;
6. Agree;
7. Strongly agree.

The Likert-scale is common in survey research and useful when measuring unobservable individual characteristics with no objective measurement, such as attitudes and opinions (Likert, 1932). To gain insight into the environmental awareness of the respondents, a total of six statements are presented to the respondents. Each statement assesses a single aspect of climate change or the environment to receive accurate results. Research by Özden (2008) is used as a reference for the statements, with additions made specifically related to this study. Some of the statements have a negative attitude towards the environment and others have a positive attitude towards the environment. The mixture of attitudes within the statements helps to leave out biasedness and checks whether respondents respond reliably and consistently (Kreitchmann, Abad, Ponsoda, Nieto, & Morillo, 2019). The following statements are presented to the respondents:

1. I believe that climate change is exaggerated.
2. I believe that human activities are the main cause of climate change.
3. I believe that climate change will have serious negative consequences.
4. I believe that each of us can make a contribution to environmental protection.
5. I am NOT willing to make sacrifices in order to protect the environment.
6. I am willing to pay extra for sustainable products/measures.

6.4 Data Collection

Respondents for the SCE are gathered through various means to ensure a representative sample of individuals. The strategy encompasses several channels to maximize participation and diversity within the target group. The first method of creating a wide reach of the survey is sharing it via social media platforms (e.g. LinkedIn) and the personal network of the researcher (i.e. colleagues and acquaintances). Additionally, flyers are directly distributed to mailboxes in selected neighbourhoods in Eindhoven, Rotterdam, and 's-Hertogenbosch to ensure a diverse but representative sample. This also improves engagement with individuals who might prefer traditional communication channels or have limited online presence. The combination of the reach of digital platforms, direct networking, and the impact of physical flyers, ensures that the SCE accurately represents the individuals of the target group.

The survey was online from Thursday the 14^{th} of September 2023 till October 22^{nd}. A total number of 193 respondents started the survey, of which only 110 respondents completed the full survey. The majority of the uncompleted respondents stopped at the start of the SCE (55 respondents, 28%). The remaining 28 respondents (14,5%) who did not complete the survey either stopped during the SCE or at the start of the environmental awareness statements. Several factors could be stated as reasons to stop, including the possibility that the terminology used to explain the stated choice tasks is too difficult. That the SCE is too complex or that the survey is too long. It's important to note that only those respondents who successfully completed the survey are included in the data analysis.

6.5 Data Preparation

Before valid data analysis is possible, the research data needs to be cleaned and recoded. Data cleaning includes the removal of respondents who completed the survey but where the data includes inconsistencies. After checking the data, only 1 respondent needed to be removed from the research data. This respondent is removed since it filled in all questions homogeneously. Removing this respondent brings the total number of respondents valid for data analysis to 109. Which exceeds the minimum required sample size as discussed in Section 6.2.5 Sample Size.

Data preparation is needed to conduct a statistical analysis of the data. Attributes used in the survey and which are included in the data analysis are categorical variables. Recoding is needed on these attributes for them to be included in the regression model. In the context of recoding attributes, there are two options to consider: dummy coding and effect coding (Hensher et al., 2015). Effect coding offers advantages over dummy coding when performing and interpreting multinominal logit models. Dummy coding compares the utilities to the base level of an attribute. Due to this, it is less clear what the effects are of each attribute level. On the contrary, effect coding compares the levels to the grand mean, allowing the possibility to define the effects of each attribute level. For the stated reason, effect coding is selected as the method used in the data analysis. The traditional level is represented by the base level coding [-1, -1], the circular level by [1, 0], and the biobased level by [0, 1]. This same coding order is applied to code the price levels 1 through 3. An overview of the effect coding for the attribute levels is provided in Appendix G.

Additionally, the data exported from LimeSurvey, is structured in the so-called “wide format”. NLOGIT, the software in which the data is analyzed, makes use of the “long format” data structure. Wherein a single respondent is not represented within a single row but is delineated by multiple rows. In this format, each row corresponds to a choice alternative. Consequently, the data structure is converted into the “long format” using Python code. Appendix H includes all the Python code used to recode the data.

6.6 Determining Willingness to Pay

The SCE as described collects data that gives insight into an individual’s preferences between alternatives. To determine the significance and the strength of the preferences, expressed in utilities, the data needs to be analysed using discrete choice models. In this section, the theoretical explanation of the choice data analysis is explained.

6.6.1 Utility Theory

In choice analysis, utility theory is often used to construct models that predict how individuals will choose among different alternatives. One of the most common models derived from utility theory is the Random Utility Model (RUM), which assumes that individuals make choices based on a combination of deterministic factors (attributes of the alternatives) and random factors (individual-specific taste variations and unobserved factors). The basic idea is that individuals assign utilities to the different attributes of each alternative and then choose the alternative that provides the highest overall utility.

Within an SCE, there are observed and unobserved effects, this means that the utilities are not necessarily directly measurable, but the model needs to predict the choice probabilities based on the differences in utilities. Utility (U_{iq}) is formed from two components: structural utility (observable) denoted as V_{iq}, and random utility (unobservable) referred to as the error term ε_{iq}. Here, $\boldsymbol{iq}$ signifies a particular alternative $\boldsymbol{i}$ and decision maker $\boldsymbol{q}$ (Hensher et al., 2015).

$$U_{iq} = V_{iq} + \varepsilon_{iq} \qquad [3]$$

$$U_{iq} = Utility\ value$$
$$V_{iq} = Structural\ utility\ (observed)$$
$$\varepsilon_{iq} = Random\ utility\ (unobserverd)$$

The calculation of utility primarily involves the observable structural component, as the unobservable random utility is considered a stochastic error component. Hensher et al. (2015) provide the definition of the structural utility as follows:

$$V_{iq} = \sum_{n} \beta_n * X_{inq} \quad [4]$$

$$V_{iq} = Structural\ utility\ (observed)$$
$$\beta_n = Weight\ of\ attribute\ n$$
$$X_{inq} = Score\ of\ alternative\ i\ on\ attribute\ n\ for\ individual\ q$$

6.6.2 Multinominal Logit Model

The multinomial logit (MNL) model is a statistical method used to research and predict the decisions people make when given a variety of options (Labbé, Laporte, Tanczos, & Toint, 1998). This model is helpful for assessing scenarios when people must choose one option from a variety of available alternatives. In essence, the MNL supports understanding the likelihood that a person will select a particular option from a list of options. Each alternative's varied characteristics are considered, and their impact on the decision-making process is quantified. The MNL's core assumption is that people make rational decisions by weighing both the positive and negative aspects of each alternative and choosing the one that maximizes their predicted utility. The logit function is used in the model to connect these probabilities of selection to the characteristics of the alternatives. It enables one to gain insight into the variables that affect respondents' decisions and generate predictions about their likely choices based on these variables. Equation 5 shows this translated into a formula (Labbé et al., 1998):

$$P_{iq} = \frac{expV_{iq}}{\sum_{i} \exp\ (V_{i'q})} \quad [5]$$

$$P_{iq} = Probability\ of\ alternative\ i\ for\ indivual\ q$$
$$V_{iq} = Observed\ component\ of\ alternative\ i\ for\ individual\ q$$
$$V_{i'q} = Observed\ component\ of\ the\ number\ of\ alterives\ in\ the\ choiceset$$

6.6.3 Mixed Logit Model

The mixed logit (ML) model, a type of random utility model, is employed to analyse choices made by a sample of respondents, each facing a selection of diverse alternatives. This model posits that respondents select their preferred alternative based on the one that offers the highest utility (Hensher & Greene, 2003).

The ML model addresses three key limitations that standard multinominal logit models exhibit. These include that mixed logit models accommodate random variations in individual preferences, permit unrestricted patterns of substitution between alternatives, and account for correlations in unobserved factors over time (Train, 2009). In this study, the ML model is employed to analyse the random variations in individual preferences, excluding the other two functions from consideration. The ML model is a flexible model that is capable of approximating any random utility model (McFadden & Train, 2000). The significance of mixed logit models lies in the ability to consider the heterogeneity within the respondent population. The model assumes that parameters differ from one individual to another. In essence, the ML model asserts that each individual possesses a unique interaction of systematic and random components for each alternative in their choice set. Consequently, the model is often viewed as a more realistic representation compared to other discrete choice models (Hensher & Greene, 2003).

6.6.4 Goodness-of-fit

McFadden's R-squared test is used to assess model performance. This assessment focusses on the measurement of goodness-of-fit, achieved through an analysis of the log-likelihood value derived from the model under investigation and that of a null model. Dividing the log-likelihood value of the estimated model by the log-likelihood value of the null model and subtracting that number from 1 results in the R-squared value (McFadden D. , 1974). In practice, a model's goodness-of-fit is deemed acceptable within the range of 0,2 to 0,4, considering the R-squared Adjusted value. Significantly higher values, exceeding 0.5, are typically considered unrealistic for behavioural experiments (Domencich & McFadden, 1973).

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \quad [6]$$

$$\rho^2 = Rho\ Square$$
$$LL(\beta) = Log - likelihood\ of\ estimated\ model$$
$$LL(0) = Log - likelihood\ of\ null\ model$$

The McFadden R-squared equation, denoted as Equation 6, naturally incorporates the concept of R-squared growth when new variables or attributes are introduced. Nevertheless, the introduction of additional variables does not always lead to an enhancement of the model's performance. Therefore, to account for the increase in R-squared driven solely by the addition of variables, an adjusted R-squared must be computed, as defined in Equation 7 (Long & Freese, 2001):

$$\rho^2 adjusted = 1 - \frac{LL(\beta) - K}{LL(0)} \quad [7]$$

$$\rho^2 adjusted = Adjusted\ Rho\ Squared$$
$$K = Number\ of\ estimated\ parameters\ in\ the\ model$$

6.6.5 Willingness to Pay

An output of choice models is the WTP for specific attributes. The measurement of WTP among the attributes in monetary terms is achieved by calculating the ratio of utility to cost attributes (Hensher et al., 2015). Equation 8 and Equation 9 are used to calculate the WTP as an additional percentage of the base price. Through the calculation of the difference in utility between the base and additional price level, one can determine the utility per percentage of the price. Implementing this in Equation 8, where the division of the utility difference between the base level of an attribute and a particular attribute level (k) enables the determination of the WTP % for attribute level (k) in comparison to the base level of that specific attribute.

$$U_{\%} = \frac{U_0 - U_X}{X} \quad [8]$$

$$U_{\%} = Utility\ per\ percentage$$
$$U_0 = Utility\ at\ 0\%\ additional\ costs$$
$$U_X = Utility\ at\ X\%\ additional\ costs$$

$$WTP_k = \frac{\beta_k - \beta_0}{U_{\%}} \quad [9]$$

$$WTP_k = Willingess\ to\ pay\ for\ attribute\ level\ (k)$$
$$\beta_k = Marginal\ utility\ for\ attribute\ level\ (k)$$
$$\beta_0 = Marginal\ utility\ for\ the\ base\ attribute\ level$$

6.7 Conclusion

In order to address the research questions, data is collected and will undergo analysis. A stated choice experiment (SCE) is constructed including 7 attributes with each 3 levels to define choice preferences. The SCE is included in a research survey combined with closed-end questions (personal and housing characteristics) and statements about environmental awareness. In the survey, each respondent receives 8 randomly selected choice tasks, including two profiles and a neither option. A total number of 183 respondents started the survey of which 110 completed the survey. Removing incorrect responses resulted in a total number of 109 respondents which can be included in the data analysis, exceeding the minimal of 94 responses. The data form the survey formatted using wide format effect coding, making it suitable to use in the NLOGIT software. Logit models are applied to estimate the choice preferences of the respondents, ultimately determining their willingness to pay (WTP) for the sustainable material alternatives.

7. Data Description

A total of 109 respondents completed the survey, allowing valid data analysis. This chapter includes a descriptive analysis of the collected data. The descriptive analysis begins with a visualization of the data distribution. Alongside the SCE, the survey included questions regarding the socio-demographic characteristics of the respondents. The chapter includes an assessment of the respondents' representatives in comparison to the Dutch population. The research survey concluded with several statements about the environment and climate change, to which respondents had to indicate their level of agreement. The final section of this chapter presents the results derived from these statements.

7.1 Data Distribution

Figure 19 visualizes the distribution of the respondents across the Netherlands. As explained in Section 6.4 Data Collection, flyers are distributed over several multi-family complexes in Eindhoven, Rotterdam, and 's-Hertogenbosch. The map shows a higher response rate in these locations compared to most other regions in the Netherlands. Besides these three cities, respondents' residential areas are more scattered over the Netherlands, with a higher representation in the province of Noord-Brabant. The Dutch population is not fully represented by the respondents.

Figure 19 Distribution of the respondents (adapted from CBS, 2022b).

7.2 Socio-Demographic Data

To check the research sample in comparison to the Dutch population, chi-square goodness-of-fit tests are performed for socio-demographic characteristics. The chi-square goodness-of-fit test statistically determines the representativeness of an observed sample to the expected sample. A part of the socio-demographic data used to determine the expected sample came from the WoOn2021 database. The WoON2021 database is the result of research done by the Dutch government into the living situation, living wishes and general information of Dutch households (Stuart-Fox et al., 2022). The database includes 46.700 individuals and is representative of the Dutch population. For socio-demographic data that is not included in the WoON2021 database or where the division of answer options is not the same as in the survey of this study, data is used from the Dutch Bureau of Statistics

(CBS). The databases are used to compute the expected frequencies for the socio-demographic characteristics, forming the basis for the chi-square goodness-of-fit tests. Notably, the graphs presented in this section show the distribution in percentages, only for improved visualization.

7.2.1 Gender

The gender distribution of the survey respondents does not align with the distribution of the Dutch population. The significant difference is confirmed by the chi-square goodness-of-fit test. The chi-square (χ^2) has a value of 11,68. This means that with a degree of freedom of 1 and a critical value of 3,84 (University of Queensland, n.d.), the null hypothesis can be rejected. Figure 20 visually illustrates the contrast between male and female respondents in the research sample compared to the expected sample, which is derived from data provided by CBS (CBS, 2023d). The discrepancy can partly be explained by the distribution of the survey. The survey was promoted at a large project developer and within the professional network of the researcher. Given that the construction sector is still relatively male-dominated, it likely contributed to the higher participation of male respondents. Additionally, it's noteworthy that within the survey, the option "Other / I prefer not to say" is provided for the gender question, but none of the respondents selected this option.

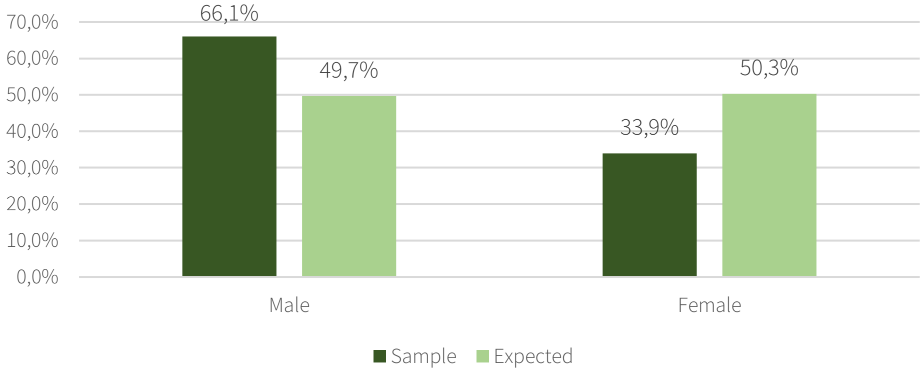


Figure 20 Gender distribution.

7.2.2 Age

Figure 21 shows the distribution of the age of the respondents in years. The expected age distribution data is sourced from the CBS (CBS, 2023d). Visible is the large overrepresentation of respondents between the ages of 18 and 34 years, and a considerable underrepresentation of respondents aged 65 years and older. The other age groups (between 35 and 64 years old) are also underrepresented in the research sample. The overrepresentation of individuals aged 34 years and younger can potentially be attributed to the researcher's personal network, through which the survey was distributed. Or by the respondents' affinity with technology. The survey was shared via social media platforms such as LinkedIn and Instagram, where the researcher has a predominantly "younger" network. Furthermore, the flyers distributed at multi-family buildings contained a QR code for survey access, which may have been more appealing to individuals aged 34 or below. A chi-square goodness-of-fit test resulted in a chi-square value of 44,65. This value compared to a critical value of 12,59 validates the statistical difference, indicating that the sample does not accurately represent the Dutch population.

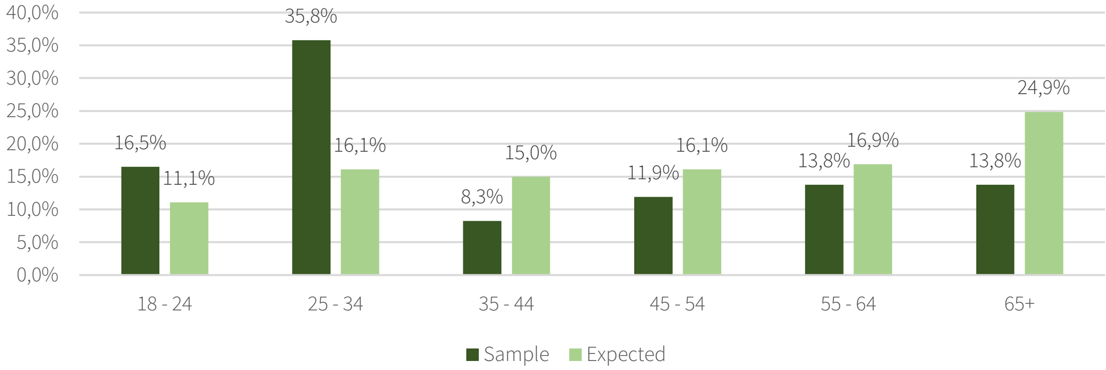


Figure 21 Age distribution (Years).

7.2.3 Education Level

The data used to come to the expected education level is derived from the WoON2021 database. The difference between the observed and expected sample is significant, confirmed by a chi-square goodness-of-fit test. The chi-square (χ^2) resulted in a significantly higher value than the critical value, which means the null hypothesis can be rejected. Figure 22 visualizes the discrepancy between the observed sample and the expected sample for education level. Higher achieved education levels, both HBO-, WO-Bachelor and HBO-, WO-Master, Doc/PhD are both significantly overrepresented in the research sample. All other levels of education are significantly underrepresented in the research sample. Meaning that the research sample is not a valid representation of the Dutch population. When drawing conclusions from the research, it is important to take the overrepresentation of highly educated individuals into account for possible generalization of the research results.

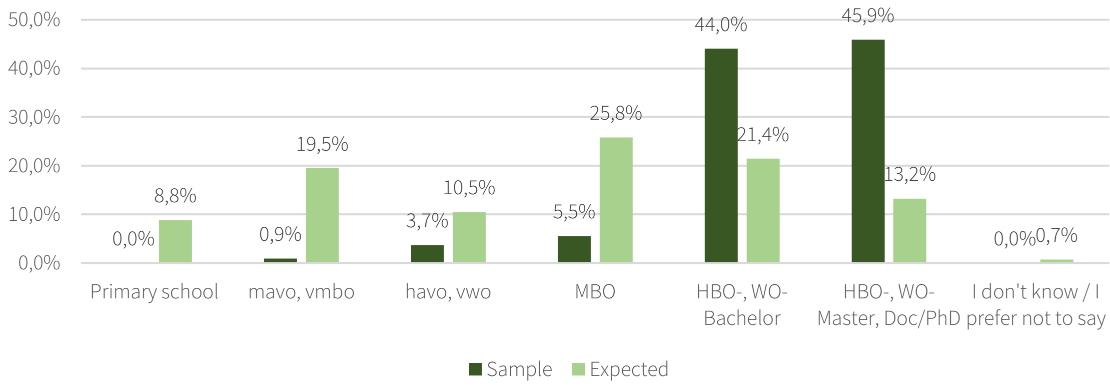


Figure 22 Education level distribution.

7.2.4 Household Composition

Figure 23 visualizes a notable discrepancy between the research sample and the Dutch population (WoON2021 database). There is an overrepresentation of couples without children and people co-living. Conversely, there is a substantial underrepresentation of couples with children living at home. This discrepancy can be attributed to the specific research focus, which involves distributing flyers at multi-family buildings, in line with the research focus. The household compositions overrepresented in the research sample are those that are primarily resident in multi-family buildings. Subsequently, the underrepresentation of couples with children is a direct consequence of the sampling approach, which did not follow the same housing types as the Dutch population.

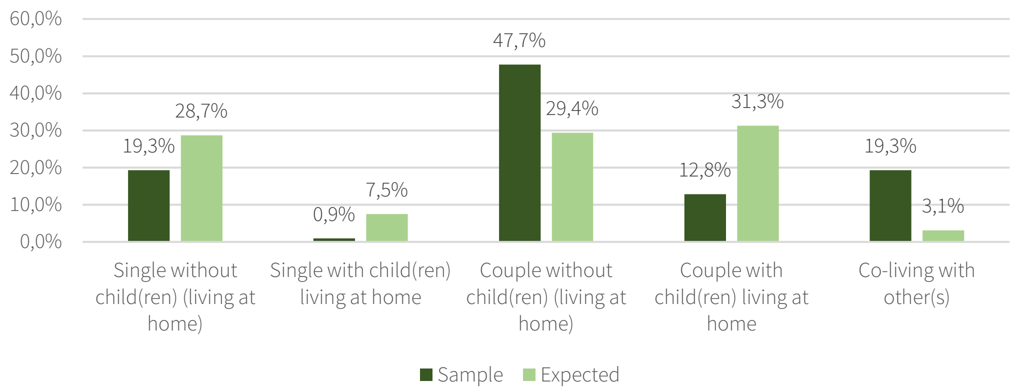


Figure 23 Household composition distribution.

7.2.5 Household Income

Comparing the respondents who indicated their monthly net income in the survey to the Dutch populations (WoON2021 data), the sample is representative. The goodness-of-fit test has a chi-square statistic of 2,76, which is lower than the critical value at a degree of freedom of 3 and a significance level of 0,05. However, it is important to note that the inclusion of respondents that chose the option "I don't know / I prefer not to say", results in the whole research sample not being representative compared to the Dutch population. Figure 24 visualizes the income distribution of the research sample and the expected observations in relation to the Dutch population.

Figure 24 Household net income distribution (€ / month).

7.2.6 Conclusion

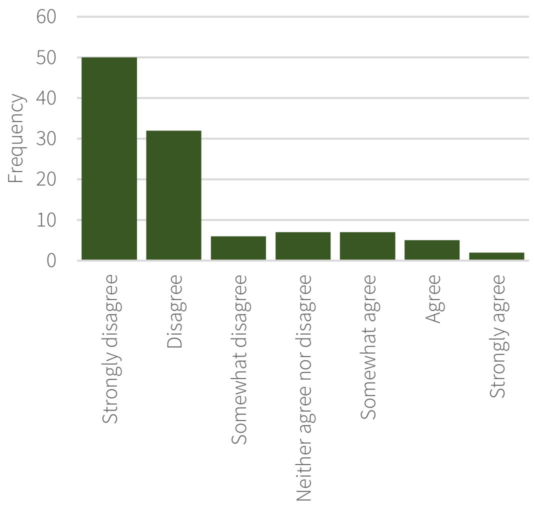
The descriptive analysis on the basis of socio-demographic characteristics has resulted in a conclusion that the research sample is not a representative match on the characteristics gender, age, education level, and household composition. Chi-square goodness-of-fit tests concluded the significant difference between the sample and the expected group when looking at the Dutch population. Only the household income of the respondents is in line with the Dutch population. The method in which the survey is distributed probably influenced the representativeness of the research sample. These findings underline the importance of acknowledging the limitation of the research sample and the potential impact on generalizability of the further results.

7.3 Environmental Awareness

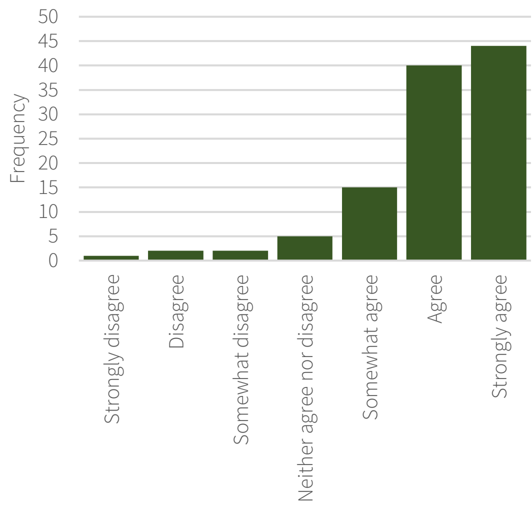
As explained in Section 6.3.4 Environmental Awareness, the survey included six statements about the environment and climate change to test the environmental awareness of the respondents. Respondents are asked to indicate their level of agreement with the statements on a 7-scale of agreement proposed by Likert (1932). This section elaborates on the statements and the environmental awareness of the respondents. Table 12 presents the survey statements related to the environment and climate change, along with the corresponding response frequencies. It is evident that respondents consistently maintained a similar attitude across the various statements, indicating a uniform perspective on environmental and climate change issues. Additionally, it is worth noting that the majority of respondents expressed a positive attitude towards the environment. Which is further analyzed in this section.

Table 12 Level of agreement of respondents with the environmental awareness statements.

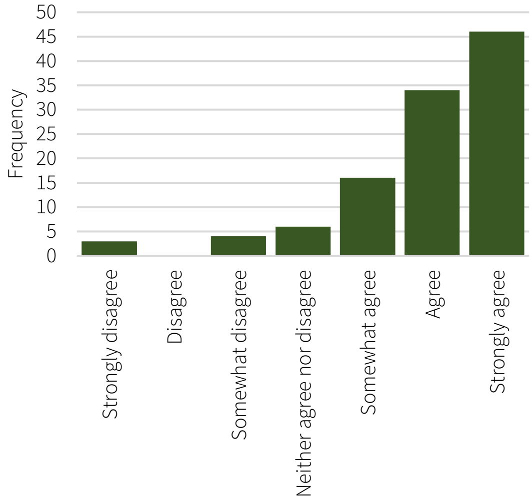
1. I believe that climate change is exaggerated.



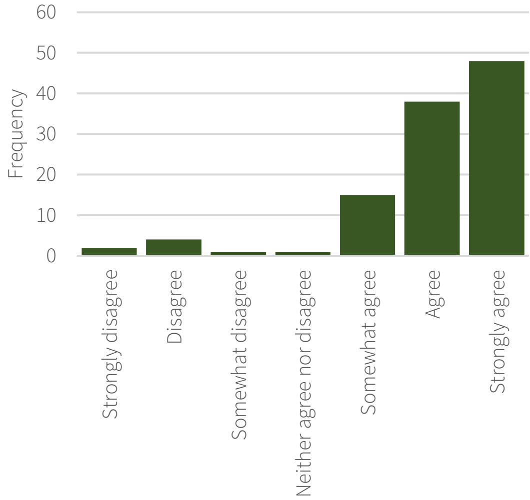
2. I believe that human activities are the main cause of climate change.



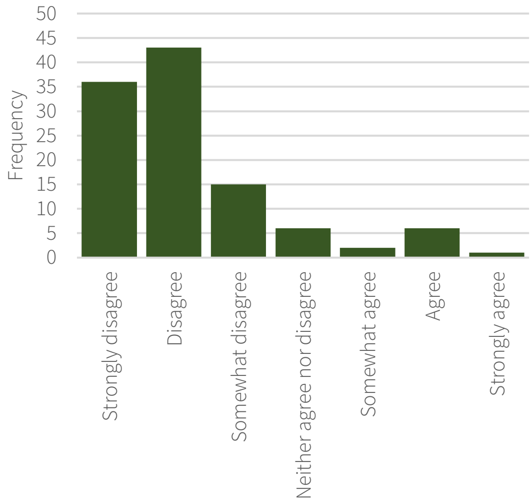
3. I believe that climate change will have serious negative consequences.



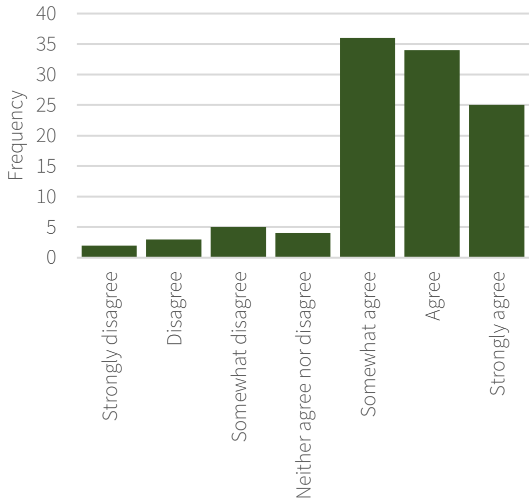
4. I believe that each of us can make a contribution to environmental protection.



5. I am NOT willing to make sacrifices in order to protect the environment.



6. I am willing to pay extra for sustainable products/measures.



Among the statements, four reflected a positive attitude towards the environment (statements 2, 3, 4 & 6), while the remaining two reflected a negative attitude (statements 1 & 5). To ensure the consistency of the data, it is necessary to reverse the coding of the two statements with a negative attitude. This adjustment allowed all statements to cohere to the same scoring scale, where a score of 1 represented a very negative attitude, and a score of 7 indicated a very positive attitude towards the environment. The scores for the six statements are summed to derive an overall measure of environmental awareness. A categorization scale is then used to classify respondents based on their total environmental awareness scores. A method to divide the scoring into categories is using the 25th and 75th percentile, also referred to as the quartiles (StatCan, 2021). With a maximum score of 42 (6 x 7) and a minimum score of 6 (6 x 1), resulting in a score range of 36 (42 – 6), the 25th percentile falls at 15, while the 75th percentile is at 33. Respondents' environmental awareness levels are categorized using these percentiles, as illustrated in Figure 25.

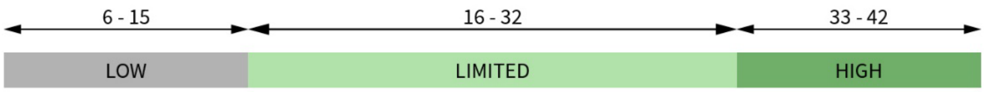


Figure 25 Levels of environmental awareness and the related scores.

The research sample expressed a significantly positive attitude towards environmental awareness, with 77,1% of respondents categorized as having a "high environmental awareness" (visible Figure 26 and Table 13). In contrast, only 1,8% of the respondents expressed a low level of environmental awareness, leaving the remaining 21,1% categorized as having “limited environmental awareness”. This significant overrepresentation of individuals with a high environmental awareness within the sample can have an influence on the research outcomes. As discussed in Chapter 3. Sustainable Behaviour, it is reasonable to assume that individuals with a positive attitude towards the environment are more willing to pay for sustainable material usage in multi-family housing.

In self-report scales as used in this study, it is difficult to fully exclude response biases. Respondents might have been subject to social desirability bias, wherein they provide responses they believe to be socially acceptable or expected (Kreitchmann et al., 2019). In a survey focused on environmentally friendly choices, respondents may feel societal pressure to express a larger commitment to environmentally friendly alternatives. This can possibly lead to an overestimation of their attitude towards the environment.

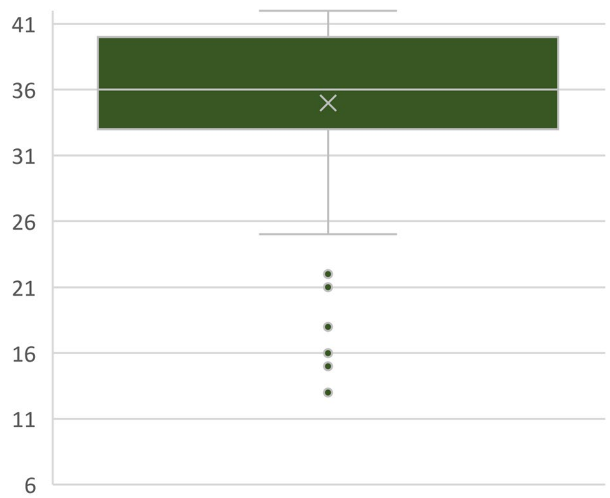


Figure 26 Box & whiskers diagram of the score on environmental awareness of the research sample.

Table 13 Frequencies and values from the score on environmental awareness of the research sample.

Frequencies	
Low environmental awareness (6 – 15)	2
Limited environmental awareness (16 – 32)	23
High environmental awareness (33 – 42)	84
Values	
Maximum	42
Minimum	13
Mean	35
Median of whole	36
Median of 1st quartile	33
Median of 3rd quartile	40

7.4 Recode Respondent Data

From Section 7.2 Socio-Demographic Data, it became evident that several socio-demographic characteristics showed a disproportionate distribution, resulting in variable levels with low frequencies. To limit the low-frequency variable levels, these are recoded into 3-level variables using Python code (see Appendix H). The characteristics that underwent recoding include age, highest achieved education level, household composition, and net household income. Age is classified into three groups: 18 to 34, 35 to 54, and 55 years and older. The highest achieved education level is redefined as lower education (primary school, vmbo, havo, vwo, mbo, and others), bachelor education (HBO and WO Bachelor programs), and master education (HBO and WO Master's and Doctorate/PhD programs). Household composition is transformed into a 3-level variable with the following categories: single/couple households without child(ren) (living at home), single or couple households with child(ren) living at home, and co-living with others. Furthermore, net household income is recoded into the levels less than €2.000,-, €2.000,- till €4.000,-, and more than €4.000,-. By recoding the data into a smaller number of levels, variable levels with low frequencies are eliminated, ensuring that each category contains a sufficient number of cases for meaningful statistical analysis. Figures 27, 28, 29, and 30 visualize the distribution of the recoded socio-demographic characteristics and their variable levels.

The recoding of socio-demographic characteristics also limits the total number of estimated parameters in the analysis. The effects of gender, age, highest achieved education level, net household income, and household composition are estimated as interaction variables with the main effects in the model. The socio-demographic characteristics are dummy coded, resulting in two columns per interaction variables. The levels assigned to the variable levels of socio-demographic characteristics are provided in Table 14.

Table 14 3-level variable coding of the socio-demographic characteristics.

Value	*Gender*	*Age*	*Education Level*	*Household Composition*	*Household Income*
[1, 0]	Male	18 – 34	Lower education	Single/couple with child(ren)	< €2.000,-
[0, 0]		35 – 54	HBO-, WO-Bachelor	Co-living with others	€2.000,- till €4.000,-
[0, 1]	Female	55+	HBO-, WO-Master	Single/couple without child(ren)	> €4.000,-

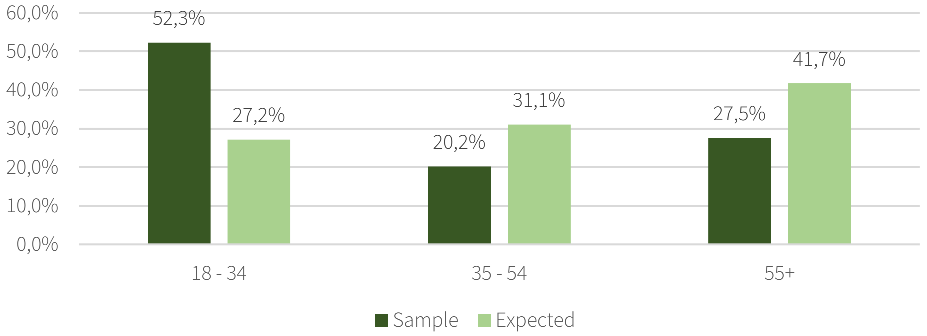


Figure 27 Distribution of the recoded characteristic age (Years).

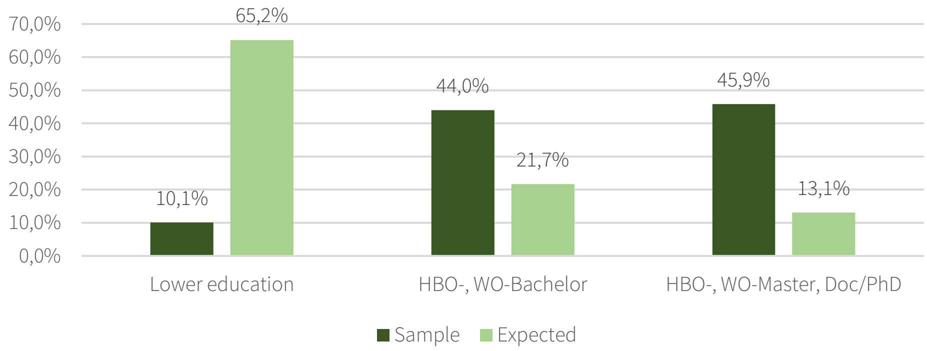


Figure 28 Distribution of the recoded characteristic highest achieved education level.

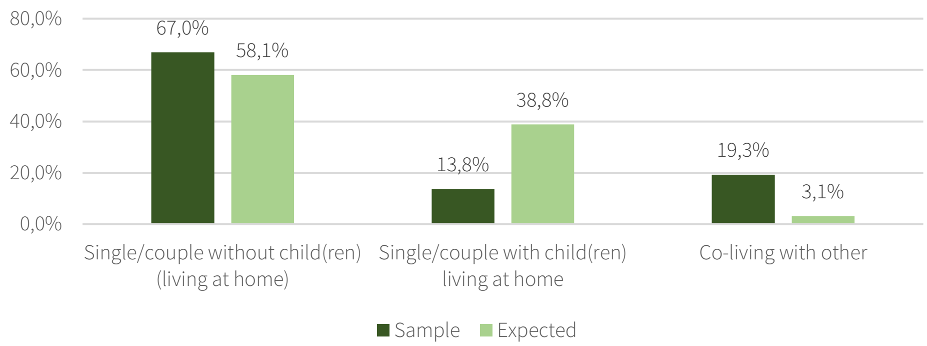


Figure 29 Distribution of the recoded characteristic household composition.

Figure 30 Distribution of the recoded characteristic net household income.

7.5 Conclusion

This chapter presented a descriptive analysis of the research sample gathered via an online survey, which included 109 respondents. It revealed significant differences from the Dutch population (population data from the WoON2021 database or CBS) in terms of gender, age, education level, and household composition. Only household income matched the Dutch population's distribution. Four socio-demographic characteristics (i.e. age, highest achieved education level, household composition, and net household income) are recoded into 3-level variables to reduce variable levels with low frequencies and limit the number of interaction variables. Within the research sample, a significant positive environmental awareness among our respondents is concluded. A large share (77,1%) of the research sample can be categorized as the group with “high environmental awareness”. It is important to consider this further in the study in regard to possible generalization of the results, since the choices one makes regarding sustainable material use are influenced by one’s environmental attitude.

8. Results

In this chapter, the outcomes of the data analysis are presented, with the goal to determine the WTP of respondents for alternative sustainable material options. Two statistical models are estimated using the NLOGIT6 software program (Econometic Software, 2016). The choice preferences of the respondents are determined according to the model estimation. Furthermore, the influence of the socio-demographic characteristics and the environmental awareness is analysed and presented in this chapter. The estimates of the models are used to determine the WTP for the different material alternatives in comparison to the traditional level. The results of the WTP are compared to the material costs in. This will allow for a conclusion on the relation between WTP for sustainable material use in housing an additional material costs.

8.1 Model Estimation

The primary analytical tools employed are the multinominal logit (MNL) model and the mixed logit (ML) model, executed through the NLOGIT6 software program (Econometic Software, 2016). The MNL model allows the estimation of the influence of various attributes on respondent preferences concerning alternative material options. Following the MNL model, the ML model is estimated to additionally explore potential heterogeneity within the sample. Besides the examination of attribute preferences, the impact of socio-demographic characteristics and environmental awareness levels of the respondents is tested. This provides insights into the relation between personal characteristics and material preferences.

The logit models are designed to investigate the factors influencing the choice outcome, represented by the variable "Choice". The data are effect-coded, with the traditional level serving as the reference category (refer to Section 6.5 Data Preparation). NLOGIT does not estimate the utility of the base level, but it can be manually computed. By using Equation 10, the utility of the base level is derived as the remainder of the sum of the utilities at levels 1 and 2, up to the value of 1. Consequently, the utilities for the traditional level of the building component attributes and the utility of the 0% price level are calculated and included. However, computing the utilities results in an inability to make statements about the standard error and significance level.

$$U_0 = -1 \times (U_1 + U_2) \qquad [10]$$

8.1.1 Multinominal Logit Model

The analysis of the data starts with the estimation of the MNL model, the model output of NLOGIT is visible in Appendix I. The estimated model shows a significant negative utility for the constant (-1,550 at the 1% significance level), meaning that the respondents are more likely to select one of the two housing options than selection "None of the two". Looking at the choice preference of the respondents, a positive choice probability is visible for the material alternatives in relation to the traditional material level for five of the six building components. Only the façade cladding shows a positive utility for the traditional level in correspondence to the material alternatives. However, due to nonsignificant values, it is not possible to say if this difference is statistically different from zero. Noticeable is that on average biobased materials are preferred over circular materials. The significantly positive utility at the 1% level of the biobased roof covering in interesting value. The significant level of the biobased roof covering indicates the positive attitude of the respondents towards a green roof. Even though the environmental performance of the biobased roof covering has a negative environmental performance in comparison to the other two options, as explained in Section 5.3 Environmental Performance, the "green appearance" probably results in a higher choice probability.

The MNL model suggest that the +7% price level has a negative utility of -0,071. A negative utility implies that a housing option incorporating this attribute level is associated with a lower probability of being chosen. However, the p-value for the +7% level is 0,42, indicating no significance at the 5% level. This means that the observed effect is not substantial. In contrast, the +14% price level exerts a significant influence on the choice outcome, with a utility of -0,345. Meaning that the price level of +14% in a choice option is associated with a lower choice probability in comparison to the average of the three price levels. The high statistical significance ($P < 0{,}01$) confirms the strong adverse impact on the choice outcome. As the price increases, the probability of selecting that profile decreases significantly. This aligns with the information presented in Section 3.1.2 Financial Incentives, where it is mentioned that an increase in cost diminishes the strength of environmental behaviour (Diekmann & Preisendörfer, 2003).

Interaction variables are created to determine the influence of the socio-demographic characteristic on the choice preference of the respondents. The interaction variable is the product of the socio-demographic characteristic and the attribute level. Via a stepwise method, the interaction variables of the five socio-economic characteristics (gender, age, household composition, education level, household income) and the environmental awareness are added in a MNL model. The nonsignificant interaction variables are excluded in the following model estimation, leaving the significant interaction variables in de model. The final estimated MNL model including the significant interaction variables is attached in Appendix J.

The McFadden R-squared (ρ^2) value, as described in Section 6.6.4 Goodness-of-fit, of the estimated MNL model is 0,200 and the R-squared adjusted is 0,192. As mentioned in the stated section, Domencich & McFadden (1973) argued that an acceptable model fit should exhibit an R-squared value in the range of 0,2 to 0,4. In the case of this MNL model, the goodness-of-fit is adequate. It is at a low point of the acceptable range. The lower goodness-of-fit suggests the presence of heterogeneity, which are tested through the ML model in the following section.

8.1.2 Mixed Logit Model

A ML model to test for heterogeneity in the sample is estimated by a stepwise method. This is done by starting with only the constant as random parameter and adding the other attribute levels as random parameter one by one. The levels that do have a nonsignificant utility for the random parameter estimate are removed as random parameter. Keeping the levels that do show significant utility for the random parameter estimate as random parameter. The ML is based on Halton sequences with 1000 draws (pts=1000). The ML model, only including the attributes, as generated using NLOGIT is attached in Appendix K. The McFadden R-squared value of the model indicates an improved model fit in comparison to the estimated MNL model in the previous section. The R-squared value of the model is 0,306, which falls in the proposed range of 0,2 to 0,4 as an acceptable goodness-of-fit by Domencich & McFadden (1973). The adjusted R-squared of the estimated ML model is 0,298.

The significant socio-demographic characteristics determined using the MNL model are included in the ML model to test their utilty of the interaction variables. A ML model is estimated once again based on Halton sequences with 1000 draws (pts=1000). The interaction varables are included in the ML as nonrandom parameters. The attribtues are included as in determined in the ML model of Appendix K. The results of the ML model including the significant interaction variables are stated in Table 15, the output of the model in NLOGIT is attached in Appendix L. The McFadden R-squared value for the ML model including the significant interaction variables suggests and increased model fit compared to the MNL including the significant interaction variables and the ML model only including the attributes. The model its R-squared is 0,369, meaning an acceptable goodness-of-fit according to Domenchich & McFadden (1973). The adjust R-squared for the estimated ML model including the significant interaction variables is 0,353. The adjusted R-squared, which includes the model's degrees of freedom, decreases due to the additional parameters which are estimtated. Nevertheless, with an adjusted R-squared value of 0,353, it becomes evident that the additional parameters contribute to the model fit, and the model is not overestimated (Miles, 2005).

The standard deviation of random parameter indicates if there is heterogeneity within the sample with regards to individual attribute levels (Hensher et al., 2015). A significant value for the standard deviation of random parameter means that there is heterogeneity over the sample population regarding that attribute levels, the significant values for the standard deviation of random parameter are included in the last column of Table 15. This holds for the constant, the biobased levels of the building structure, inner walls, façade cladding, roof covering, and for the +14% price level. The value of the standard deviation of random parameter indicates the size of the standard deviation related to the average of that attribute. A larger standard deviation means that people either have a strong preference for or a strong aversion against that specific attribute level. Looking at the significant values, it indicates that respondents have different attitudes towards the use of biobased construction materials in housing. The biobased level of the façade cladding has a significant standard deviation of random parameter with a value of 1,085. This means that the respondents either preferred the biobased alternative (i.e. wooden cladding) or did not prefer that alternative in comparison to the average of the attribute. The strong preference in the standard deviation results in an average utility close to the average, meaning a non-significant value for the utility. The significance of the utility combined with a significant value of the standard deviation of random parameter, for example is the case for the biobased building structure, is the result of either strongly positive or strongly negative preference by the sample, in which then occurs heterogeneity. In the case of the biobased alternative for the building structure and the roof covering, this is a positive attitude towards this choice alternative. Meaning that these alternatives are significantly preferred by the research sample. The significant negative utility and the significant standard deviation from random parameter for the +14% price level indicate that the distribution of the research sample significantly shifted to not chosen an alternative which included this price level. For the attribute level which do not have a significant value for the standard deviation of random parameter, one single parameter estimate is sufficient to represent all sampled individuals.

Table 15 Estimation mixed logit model including significant socio-demographic interaction variables.

Parameter		*Util.*	*Distribution Util.*	*Prob. |z| > Z**	*Std. Dev. Ran. Par.*
Constant	None of the two	-3,715***		0,000	2,332***
Foundation	Traditional	-1,044[a]			-
	Circular	0,671***		0,000	-
	Biobased	0,373		0,119	-
Building Structure	Traditional	-0,138[a]			-
	Circular	0,251*		0,062	-
	Biobased	-0,114		0,753	0,809***
Inner Walls	Traditional	0,605[a]			-
	Circular	0,286		0,105	-
	Biobased	-0,891***		0,000	0,505**
Façade Cladding	Traditional	0,577[a]			-
	Circular	-0,025		0,868	-
	Biobased	-0,552*		0,072	1,085***
Window Frames	Traditional	-0,250[a]			-
	Circular	-0,108		0,631	-
	Biobased	0,358***		0,005	-
Roof Covering	Traditional	-0,614[a]			-
	Circular	-0,139		0,316	-
	Biobased	0,753***		0,001	0,691***
Price Level	+ 0%	0,574[a]			-
	+ 7%	-0,022		0,882	-
	+ 14%	-0,552		0,122	1,003***
Interaction effects					
Constant – None of the two					
Age: 55+ years old		1,266*		0,083	
Household comp.: Without child(ren)[b]		1,897**		0,015	
Education level: Low[c]		1,033		0,246	
Environmental Awareness: High		-1,611**		0,019	
Foundation - Circular					
Gender: Male		-0,583***		0,008	
Foundation - Biobased					
Age: 18 - 34 years old		0,423**		0,026	
Household comp.: Without child(ren)[b]		-0,687***		0,003	
Building Structure - Circular					
Age: 55+ years old		-0,466**		0,049	
Building Structure - Biobased					
Age: 55+ years old		0,608*		0,068	
Education level: HBO-, WO-Master		0,637***		0,009	
Income: > €4.000,-		-0,949***		0,001	
Environmental awareness: High		0,869**		0,016	
Inner Walls - Circular					
Income: > €4.000,-		-0,496**		0,026	

Inner Walls - Biobased			
Income: < €2.000,-	0,671***		0,008
Environmental awareness: High	1,008***		0,000
Façade Cladding - Biobased			
Household comp.: Without child(ren)[b]	0,496		0,145
Window Frames - Circular			
Gender: Male	-0,407*		0,068
Education level: HBO-, WO-Master	0,581**		0,013
Roof Covering - Biobased			
Income: > €4.000,-	-0,578**		0,882
Environmental awareness: High	0,477**		0,062
Price Level - +14%			
Age: 18 - 34 years old	-0,749*		0,062
Age: 55+ years old	0,592		0,125

***, **, * → Parameter is significant at the 1%, 5%, 10% level.
[a] Utility has been computed manually.
[b] Household comp. – Without child(ren): Single/couple without child(ren) (living at home)
[c] Education level – Low: Primary school, vmbo, havo, vwo, mbo & others

Table 15 also illustrates the impact of socio-demographic characteristics on the choice preference for alternative material options. The following section will detail the interaction between socio-demographic characteristics and material attributes. In addition to socio-demographic factors, respondents are categorized based on their environmental awareness. Due to the limited number of respondents with low environmental awareness (n=2), the model estimation could not estimate reliable results for this subgroup's influence. As a result, the analysis focuses on the relation between high and limited environmental awareness. The subsequent section outlines the significant interactions between socio-demographic characteristics and environmental awareness, followed by explanations of these relations.

- *Constant*
  Individuals aged 55 years and older are more likely to choose the "None of the two" choice compared to the group of respondents between 35 and 54 years old. The same holds true for respondents without child(ren) (living at home). Additionally, those with a high environmental awareness are more likely to select one of the housing options rather than neither.

- *Foundation*
  Male respondents show a negative choice preference for the circular foundation in comparison to the female respondents. The preference for a biobased foundation is influenced by both age and household composition. Individuals within the age group of 18 to 34 years old are more likely to choose the biobased material option compared to those in the age group of 35 to 54 years old. Conversely, respondents without child(ren) express a lower preference for the biobased foundation option.

- *Building Structure*
  The age group of 55 years and older demonstrates a notable preference for the biobased building structure, along with a significant negative preference for the circular building structure compared to the age group of 35 to 54 years old. Moreover, highly educated individuals (i.e., HBO-, WO-Master & PhD/Doc) are more inclined to choose a biobased building structure compared to those with an HBO-, WO-Bachelor. A positive preference is observed among respondents with a high level of environmental awareness in contrast to those with limited environmental awareness for the biobased building structure. Interestingly, individuals with a net household income of more than €4.000,- per month indicate a significant negative preference for the biobased building structure.

- *Inner Walls*
  The group of respondents with a monthly net household income over €4.000,- indicates a negative preference for the circular inner wall compared to the group of respondents with an income between €2.000,- and €4.000,-. Conversely, the income group with a monthly net income below €2.000,- displays a positive preference for the biobased inner walls. Additionally, respondents categorized with high environmental awareness show a significantly positive attitude toward the biobased inner wall in contrast to those with limited environmental awareness.

- *Façade Cladding*
  When examining the façade cladding, only one socio-demographic characteristic came out as a significant influence in the MNL model, specifically the household composition without child(ren) compared to a co-living household for the biobased façade cladding. However, incorporating this interaction variable into the ML model resulted in a nonsignificant value. This implies that it is not possible to state whether the interaction variable differs from zero.

- *Window Frames*
  Regarding the circular window frames, two interaction variables demonstrate a significant influence on the choice preference for this material option. Male respondents show a lower likelihood of choosing circular window frames compared to female respondents. Additionally, individuals with an HBO-, WO-master's degree in education are more likely to choose circular window frames compared to those with an HBO-, WO-Bachelor's degree.

- *Roof Covering*
  Respondents with a monthly net income exceeding €4.000,- indicate a significant negative preference for the biobased roof covering compared to the respondents with a monthly net income between €2.000,- and €4.000,-. Additionally, individuals categorized as highly environmentally aware are more inclined to choose the biobased roof covering compared to respondents categorized as limited environmentally aware.

- *Price Level*
  The significant interaction variables concerning the price level show interesting patterns. Respondents aged between 18 and 34 years old are significantly less likely to choose a housing option with an additional price level of +14%. Conversely, respondents aged over 55 years old exhibit a positive inclination towards the +14% price level. However, when implementing this interaction variable, which is significant within the MNL model, the ML model does not exhibit a significant interaction anymore. Meaning that it is not possible to state if the attitude towards the +14% price level of respondents over 55 years old is different to zero.

Several relations can be concluded from the influence of the significant interaction variables on the choice preference. A noteworthy observation concerns the connection between age groups and attitudes towards the additional price level. Analyzing the correlation (see Appendix N for the correlation matrix) within socio-demographic characteristics reveals a link between age groups and monthly net household income. Respondents aged between 18 and 34 years old show a correlation with an income less than €2.000,-, while those over 55 years old show a correlation with an income exceeding €4.000,-. This correlation explains the attitudes of age groups towards the +14% price level. Generally, younger respondents with lower incomes express a significant negative attitude towards the +14% price level, while respondents in the higher age group, often associated with higher incomes, do not exhibit a negative attitude towards the +14% price level.

The group of respondents who have a monthly net household income over €4.000,- show a negative choice preference for three sustainable material alternatives, namely the biobased building structure, the circular inner walls, and the biobased roof covering. Indicating an overall decreased preference for the sustainable material alternatives by this group. Looking at possible correlation between this group and environmental awareness, it is visible that respondents with a monthly net income of more than €4.000,- tend to have a slightly more limited than high environmental awareness. Individuals with an HBO-, WO-master or PhD/Doc education degree indicate a significant positive choice preference for the biobased building structure, and circular window frames in comparison to the individuals with a bachelor's degree.

Looking at the significant interaction of high environmental awareness compared to limited environmental awareness reveals a pattern. Notably, there is a significant positive choice preference for the biobased building structure, biobased inner wall, and biobased roof covering among respondents with high environmental awareness. Moreover, those classified as highly environmentally aware showed significantly less inclination to choose neither of the two housing options compared to the group with limited environmental awareness. This suggests that highly environmentally aware respondents likely choose a preferred sustainable housing option, with a significant preference for biobased material alternatives for three out of the six building components.

8.1.3 Goodness-of-fit

Looking at the goodness-of-fit of the estimated models, determined by the McFadden R-squared value, the model fit improves during the model estimation process. The ML model outperformed the MNL model for models only including the attributes. Adding the significant interaction variables results in a better model fit for both the MNL model and the ML model. Finally, the ML model including the significant interaction variables results in a R-squared and adjusted R-squared value which fall in the threshold for a satisfactory model fit, as proposed by McFadden (1973).

Table 16 Goodness-of-fit MNL & ML models.

	MNL model		*ML model*	
	Attributes only	*Incl. sig. inter. var.*	*Attributes only*	*Incl. sig. inter. var.*
Rho^2	0,200	0,294	0,306	0,369
Rho^2 adj.	0,192	0,286	0,298	0,353

8.2 Willingness to Pay

The estimates from the ML model are used to determine the WTP for the alternative material options per building component. The addition of the attribute price level with three options allows the determination of the WTP. To determine the WTP, first, the utility per percentage is determined. The estimated utility of the 7% and 14% levels is not precisely linear. For that reason, the average utility per percentage is calculated and implemented to determine the WTP for the alternative materials options.

$$\mu\ per\ \% = \left(\frac{0{,}574 - -0{,}022}{7\%} + \frac{0{,}574 - -0{,}552}{14\%}\right) / \ 2 = 8{,}276 \qquad [11]$$

The outcome of Equation 11 is used to compute the WTP for the material alternatives, representing an additional price percentage on the base level, which is the traditional level. For example, the calculation of the WTP for the biobased window frames is as follows:

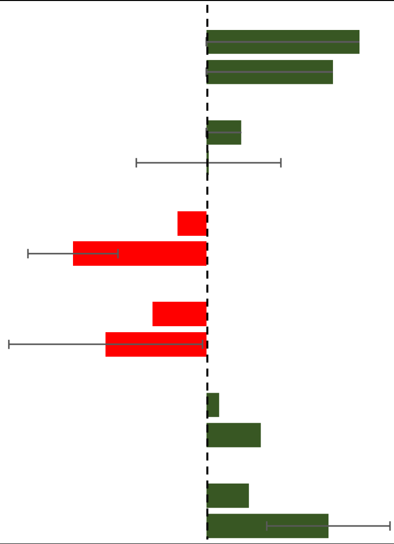
$$WTP = \frac{0{,}358 - -0{,}250}{8{,}276} = 7{,}4\% \qquad [12]$$

Table 17 displays the estimated relative WTP for the alternative material options in relation to the traditional material level. Visible is that the circular and biobased alternative for the foundation, building structure, window frames, and roof covering show a positive WTP in comparison to the traditional level. The inner walls and the façade cladding have a negative WTP for the circular and biobased material alternative in comparison to the traditional level. The biobased building structure, biobased inner walls, biobased façade cladding, and biobased window frames show significant heterogeneity within the research sample. Meaning that individuals within the sample exhibit diverse preferences, results in a range in WTP for that specific attribute level (indicated by the error bars in Table 17).

Noteworthy is the high WTP for both circular and biobased alternatives for the foundation, ranging from 17,1% to 20,7%. The significant utility of the circular foundation indicates a strong choice preference for that option. Looking at the material types, this is a valid outcome. As mentioned in Section 5.2 Material Types, the foundation indicated at the biobased level is not necessarily a biobased product, but a concrete pile. The circular alternative is based on recycled concrete, resulting in a significantly improved environmental performance compared to traditional and biobased counterparts. Moreover, the inclusion of the term "circular" in the presentation of material types during choice tasks likely influenced behaviour, contributing to the negative choice preference for the traditional level and directly increasing the preference for circular and biobased alternatives, resulting in a high WTP.

Table 17 Estimation WTP alternatives material options in relation to the traditional level.

Parameter		*Util.*	*Std. Dev. Ran. Par.*	*WTP*
Foundation	Traditional	-1,044 [a]	-	-
	Circular	0,671***	-	20,7%
	Biobased	0,373	-	17,1%
Building Structure	Traditional	-0,138 [a]	-	-
	Circular	0,251*	-	4,7%
	Biobased	-0,114	0,809***	0,3%
Inner Walls	Traditional	0,605 [a]	-	-
	Circular	0,286	-	-3,9%
	Biobased	-0,891***	0,505**	-18,1%
Façade Cladding	Traditional	0,577 [a]	-	-
	Circular	-0,025	-	-7,3%
	Biobased	-0,552*	1,085***	-13,6%
Window Frames	Traditional	-0,250 [a]	-	-
	Circular	-0,108	-	1,7%
	Biobased	0,358***	-	7,4%
Roof Covering	Traditional	-0,614 [a]	-	-
	Circular	-0,139	-	5,7%
	Biobased	0,753***	0,691***	16,5%



***, **, * → Parameter is significant at the 1%, 5%, 10% level.

[a] Utility has been computed manually.

A significant WTP is observed for the biobased alternative of the roof covering, exhibiting an additional 16,5% in relation to the traditional level. This WTP is nearly three times higher than that of the circular alternative for the roof covering. The biobased roof covering involves a green sedum roof, while the circular alternative comprises recycled bitumen. The significantly higher WTP for the biobased alternative is likely associated with its more sustainable appearance and the overall aesthetics of the green roof. People tend to associate greenery with sustainability (Ferraz, Petroni, & Santos, 2023), leading to a higher WTP for a green roof as a preferred sustainable alternative. Despite the lower environmental performance indicated in Section 5.3 Environmental Performance, the ECI of the green roof is higher than the traditional level due to additional material, the biobased alternative remains preferred with a monetary value.

For inner walls and façade cladding, the alternative material options exhibit a negative WTP compared to the traditional material level. The lack of knowledge and possible negative perception of circular and biobased material alternatives likely influences the negative choice preference for these materials. Notably, the range in WTP for biobased façade cladding is considerable, with a standard deviation resulting in a WTP ranging from -26,8% to -0,5%. This indicates a significant variation in respondent preference for this type of façade cladding. Despite façade cladding's substantial visible and physical impact on a house, it introduces heterogeneity within this perspective. Preferences within this group are divided, where some strongly favour them due to their sustainability, while others probably perceive them as less durable, requiring more maintenance and replacement costs. A similar trend is observed in the biobased building structure, a CLT structure, with a range in WTP from -9,5% to 10,1%. This diversity suggests that individuals either positively or negatively associate with this material. Probably due to the perception with wood as a construction material which is perceived as having less durability, longevity, and low fire resistance (Gold & Rubik, 2009). However, timber as a construction material is positively associated with aesthetics, well-being, and eco-friendliness, as indicated in a study by Lähtinen et al. (2019). This study concludes that there are two main consumer categories concerning the perception of wood as a construction material: those favouring the ecological and technological benefits of wood and those favouring the aesthetic and well-being benefits. This implies a higher willingness to live in a timber house for those valuing aesthetics and well-being.

Examining the overall WTP for alternative material options reveals a trend. On average, the circular alternative material shows a WTP of 3,6% compared to the traditional material level, while the biobased material alternatives indicate a WTP of 1,6%. The biobased material level displays a range in the WTP of -3,0% to 6,2% due to significant heterogeneity.

8.2.1 Influence Socio-Demographic Characteristics on Willingness to Pay

As described in Section 8.1.2 Mixed Logit Model, there are several socio-demographic characteristics that have a significant influence on the choice preference of individuals for the alternative material options. The WTP for the alternative material options as described in the previous section is for the overall research sample. In this section, the influence of the socio-demographic characteristics on the WTP for the alternative material options is described, meaning that for different groups of individuals, based on a certain socio-demographic characteristic or the level of environmental awareness, the WTP is stated. The effects of the interaction variables are as stated in Table 15. Table 18 gives an overview of the average WTP for the circular and biobased material levels in comparison to the traditional level with the influence of the mentioned socio-demographic characteristic. Appendix M includes a full overview of the influence per interaction variable and the influence on the WTP for a specific material option.

Table 18 Average WTP per material type, influenced by the socio-demographic & environmental awareness.

		Gender	*Age*		*Income*		*Degree*	*Hou. Comp.*	*Envir. aw.*
	Overall	*Male*	*18 – 34*	*55+*	*< €2.000*	*> €4.000*	*Master*	*No child(ren)*	*High*
Circular	3,6%	1,6%	3,5%	2,7%	3,6%	2,6%	4,8%	3,6%	3,6%
Biobased	1,6%	1,6%	1,8%	2,8%	2,9%	-1,5%	2,9%	0,2%	6,3%

- *Gender*
  The influence of gender is identified by two significant interaction variables, namely a negative choice preference of male respondents for the circular foundation and the circular window frames. Consequently, this translates to a lower average WTP for circular material alternatives among male respondents compared to the overall average of the research sample.

- *Age*
  The age group between 18 and 34 years old indicated a significant negative utility for the +14% price level. This significant interaction variable results in a more moderate WTP for the alternative material options compared to the average of the research sample. Due to different utility for the price attribute, the WTP for alternative material options converges toward the base level (i.e. the traditional material). Also resulting in a minor adjustment in the average WTP for the circular and biobased alternatives and bringer them closer to each other. The 55 years and older age exhibited a significant preference for the biobased alternative in the building structure, accompanied by a negative preference for the circular alternative in the same components. This shift in preference affects the WTP for different material alternatives in the building structure. While the WTP for the circular building structure, for the overall research sample is 4,7%, it decreases to -0,9% for the 55+ age group. For the biobased building structure, this shifts from 0,3% to 7,6%, indicating a strong preference for the biobased alternative over the circular and traditional levels among respondents aged 55 and older.

- *Household income*
  The significant negative choice preference for the biobased building structure, circular inner walls, and the biobased roof covering of the respondents with a monthly net income over €4.000,-, results in an overall lower WTP for both the circular as the biobased material alternatives in comparison to the traditional level. The WTP for the biobased material even decreases to -1,5%, indicating a negative attitude towards the biobased materials by high income respondents. The respondents with a monthly net income of less than €2.000,- show a different in the WTP. There is a significant positive interaction between the biobased inner walls and this income group, bringing the negative WTP for the biobased inner wall to -10,0%. Resulting in a change in the overall WTP for to biobased alternatives to 2,9%.

- *Education degree*
  Respondents with an HBO-, WO-master or PhD/Doc education degree exhibit a significantly higher choice preference for the biobased building structure and circular window frames. Consequently, this leads to an overall higher WTP for both circular and biobased material alternatives compared to the traditional level. Specifically, the average WTP among individuals with a master's degree increases to 4,8% for circular materials and 2,9% for biobased materials, surpassing the average of the research sample.

- *Household composition*
  The household composition has a marginal impact on the biobased foundation, indicating a negative choice preference for this material alternative. This results in a WTP for the biobased foundation of 8,8%, contributing to an average WTP for biobased material alternatives of 0,2%.

- *Environmental awareness*
  Three significant interaction variables are identified for the environmental awareness. Individuals with a high environmental awareness exhibit a higher choice preference for the biobased building structure, biobased inner walls, and biobased roof covering compared to those with a limited environmental awareness. Consequently, this leads to a higher WTP for these material alternatives. Looking at the overall WTP for the circular and biobased material alternatives reveals a shift. Overall, the circular material level result in a higher WTP in comparison to the biobased level (3,6% versus 1,6%). Subsequent, when implementing the influence of the high environmental awareness shift to an average WTP for the biobased level of 6,3%, surpassing the average circular level WTP.

8.2.2 Material Costs in relation to Willingness to Pay
The relation between the material costs of the alternative material types and the WTP is an important relation to consider. In this section, the relation between the WTP for the alternative material options and the costs is discussed. In Section 5.4 Material Costs the material costs for the materials of the profiles per building component are determined. Within the SCE, these costs are translated into two additional price levels for residential consumers, namely +7% and +14%. The same weight of 70% is used on the material costs to determine the relation between the material costs and the WTP. Table 19 includes the additional/reduction price level of the circular and biobased materials in comparison to the traditional material with the 70% weight (i.e. column ↑↓%). The WTP for the material alternatives in comparison to the traditional level, as discussed in Section 8.2 Willingness to Pay, are stated in the table. With finally, the Δ% columns, stating the difference between the additional/reductional material costs and the WTP for that specific material alternative.

It can be concluded that there is a discrepancy between the additional material costs of circular and biobased materials and the WTP for these materials. Overall, the increase in the costs of circular and biobased materials, is not covered by the WTP for these materials. The loss ranges between -2,3%, with outliers due extreme additional material costs of -98,8% for the circular façade cladding.

The material costs of the circular and biobased materials for the window frames are lower than the traditional material, resulting in a positive relation between the material costs and the WTP. There is also a positive relation between the material costs and the WTP for the foundation, as the results of high WTP values for the circular and biobased material alternatives of the foundation. The additional material costs of the circular building structure are with -2,3% almost covered by the WTP. On average the additional material costs of the biobased building structure are not covered by the WTP. However, within the research sample there is large heterogeneity concerning the preference for this material alternatives. When looking at the WTP for the biobased building structure of the respondents group with a high environmental awareness, the 10,8% WTP covers the additional 10,5% material costs.

Table 19 Relation material costs and WTP for the material alternatives per building component.

Building Component	*Profile 2: Circular*			*Profile 3: Biobased*		
	↑↓%	*WTP*	Δ%	↑↓%	*WTP*	Δ%
Foundation	7,0%	20,7%	13,7%	7,8%	17,1%	9,3%
Building Structure	7,0%	4,7%	-2,3%	10,5%	0,3%	-10,2%
Inner Walls	8,5%	-3,9%	-12,3%	44,2%	-18,1%	-62,3%
Façade Cladding	91,5%	-7,3%	-98,8%	13,6%	-13,6%	-27,2%
Window Frames	-7,4%	1,7%	9,1%	-6,5%	7,4%	13,9%
Roof covering	17,9%	5,7%	-12,2%	70,9%	16,5%	-54,3%

8.3 Conclusion

This chapter provides an analysis of the data gathered to determine the willingness to pay (WTP) of respondents for alternative sustainable material options. The multinomial logit (MNL) model serves as the primary analytical tool to determine the choice preference for the different attribute levels. The MNL model suggest an overall positive attitude towards sustainable material alternatives, with a preference for biobased materials. Furthermore, the MNL model suggest a negative choice preference with an increased price level. Via a stepwise estimation of the MNL model, the significant socio-demographic and environmental awareness interaction variables are determined. Using a mixed logit (ML) model, heterogeneity within the preferences of the research sample is tested. This results in a significant standard deviation of random parameter for four of the six biobased material alternatives, namely the biobased building structure, biobased inner walls, biobased façade cladding, and biobased roof covering. This indicates that the respondents tend to have a different attitude towards biobased construction materials. This discrepancy is probably caused by the perception of reduced quality, durability, and increased maintenance. However, on the other side, there is an increased perception in well-being and aesthetics.

There is deviation between the preferred material type among the building components. Where the traditional material is preferred for the inner walls and the façade cladding, the circular material is most preferred for the foundation and the building structure, and the biobased material alternative is most preferred for the window frames and roof covering. The +14% price level shows a significant negative utility and standard deviation, suggesting a substantial shift in the sample's distribution away from choice options including this price level.

The analysis of significant interaction variables reveals relations between socio-demographic characteristics and choice preferences for sustainable construction materials. Younger respondents, who show a correlation with lower incomes express a significant negative attitude toward the +14% price level. The respondents in higher age groups, associated with higher incomes, do not share this negative attitude. Additionally, respondents with monthly net household income exceeding €4.000,- show a significant negative choice preference for specific sustainable material alternatives, such as biobased building structure, circular inner walls, and biobased roof covering. Environmental awareness emerges as a crucial factor, with high environmentally aware respondents exhibiting a positive choice preference for biobased building structure, biobased inner walls, and biobased roof covering. This group also shows a reduced possibility to choose neither housing option, indicating a preference for sustainable alternatives.

The WTP for the sustainable material alternatives is determined as additional price level compared to the traditional level of a building component. Looking at the WTP for the circular and biobased alternatives for the foundation, a remarkably high WTP (ranging from 17,1% to 20,7%) is exhibited, driven by the significant utility of the circular foundation and its improved environmental performance. The WTP for the biobased roof covering is significantly higher (16,5%) than the circular alternative. This besides the higher environmental impact of the green roof due to additional material, indicating a preference likely influenced by the perceived sustainability and aesthetics of a green roof. For inner walls and façade cladding, negative WTP values compared to the traditional level are observed. This is probably caused by a lack of knowledge about the alternative material options, tending to a preference for traditional materials. The biobased façade cladding exhibits a wide range of WTP (-26.8% to -0.5%), emphasizing significant variation in respondent preferences. A same sort of range is visible at the WTP for the biobased building structure, this ranges from -9,5% to 10,1%. The heterogeneity within the sample, resulting in these ranges in WTP, indicate a variation in the perception people have towards wood as a construction material. On one hand, people positively associate wood as a construction material with aesthetics, well-being, and eco-friendliness. On the other side, it is associated with less durability, longevity, and low fire resistance.

The overall WTP per material profile results in a preference for circular materials, showing an average WTP of 3,6% compared to the traditional level, surpassing the biobased materials with a WTP of 1,6%. The WTP for the materials is influenced by socio-demographic characteristics and environmental awareness. Individuals with a high environmental awareness exhibit a higher WTP for biobased materials, bringing to overall WTP for the biobased materials to 6,3%. Gender plays a minor role, lowering the overall WTP for the male respondents to 1,6%. The different age groups show different preferences for the material alternatives. The 18 till 34 years old group show a significant negative utility for the +14% price level, moderating the WTP for alternative materials. The respondents of 55 years and older indicate a strong preference for the biobased building structure (WTP 7,6%)

and a negative preference for the circular building structure (WTP -0,9%). Monthly net income also affects preferences, with respondents earning over €4.000,- expressing a negative choice preference for certain alternative materials, leading to an overall lower WTP for both circular and biobased alternatives compared to the traditional level. Education level influences preferences positively, with master educated individuals exhibiting higher WTP for both the circular (4,8%) and the biobased (2,9%) material alternatives. While household composition has a marginal impact, as indicated by a negative choice preference for the biobased foundation, it results in a modest WTP for biobased material alternatives overall.

The analysis of the relation between material costs and WTP for sustainable material alternatives reveals a notable discrepancy. Generally, the increased costs of circular and biobased materials are not entirely covered by the corresponding WTP. The WTP for circular building structure almost covers the additional costs, with a shortage of 2,3%. However, there are also extreme outliers due to substantial additional material costs, such as the circular façade cladding (i.e. click brick), resulting in a loss of 98,8%. The average WTP for the biobased building structure does not entirely cover the extra costs. However, with the large variation in the preference for this material type, it is covered by some respondents group. The WTP for the biobased building structure by high environmentally aware respondents covers the additional material costs (10,8% against 10,5%). This emphasizes the influence of environmental considerations on preferences and willingness to invest in sustainable alternatives.

The results underscore the complexity of individual preferences and perceptions with sustainable materials. It implies that people are willing to invest in sustainable material alternatives, but this willingness is dependent upon their direct experience or strong perceptions with the perceived sustainability of the materials. People tend to have an increased WTP for sustainable materials if they associate a material with sustainability. Material alternatives which “look sustainable”, such as the green roof, show significant WTP. However, the WTP for sustainable materials as concluded in this study, do not outweigh the additional material costs associated with those circular and biobased material alternatives.

9. Conclusion & Discussion

This study looked into the willingness to pay (WTP) of Dutch residents for sustainable material alternatives in multi-family housing. There is WTP for sustainable material alternatives in comparison to several commonly used construction materials, but this differs per building components and material type. The following research question is answered with this study:

> *What is the willingness to pay for a sustainable material use in the Dutch multi-family owner-occupied housing sector, and to what extent is the willingness to pay influenced by material type used and socio-demographic characteristics of the residential consumer?*

The transition in the construction sector from the use of CO_2 intensive materials to more sustainable construction looks most promising with the use of circular and biobased construction materials. Circular materials, emphasizing demounting and reusing, show environmental performance (based on the environmental cost indicator (ECI)) ranging from -33,0% to -87,2% compared to traditional materials. Biobased materials, derived from biomass sources, exhibit environmental performance (based on the ECI) between -30,5% and -89,6%. In comparison to traditional materials. The circular and biobased material alternatives result generally in an additional material cost ranging from +10% to +20%. Accounting for 70% of construction costs, the overall impact on sales level translates to +7% to +14%. Implementing this information in a stated choice experiment (SCE) makes it possible to determine the WTP for the sustainable material alternatives. A number of six building components are selected to include in the SCE, these building components are the foundation, building structure, inner walls, façade cladding, window frames, and roof covering. Per building component a traditional, a circular, and a biobased material option are selected.

The SCE, conducted via an online survey, received 109 responses of individuals valid for analysis. Utilizing the multinomial logit (MNL) model as the primary analytical tool, the study reveals an overall positive attitude toward sustainable material alternatives, particularly favouring biobased materials. The MNL model indicates a negative choice preference with an increased price level, emphasizing the influence of cost on choice outcomes. The analysis includes a stepwise estimation of the MNL model to identify significant socio-demographic and environmental awareness interaction variables. The mixed logit (ML) model tests heterogeneity within preferences, revealing a significant standard deviation for certain biobased material alternatives. This reduces the strong preference for biobased material alternatives as estimated by the MNL. The ML indicates that there is large variation of the attitude towards biobased, especially wood, as a construction material within the research sample. This is probably caused by the perception of lower quality, durability, and more maintenance, but on the other side increased well-being and aesthetics.

Distinct preferences are observed for different building components. With traditional materials preferred for inner walls and façade cladding, circular materials for the foundation and building structure, and biobased materials for window frames and roof covering. Significant negative utilities for the +14% price level suggest a substantial shift in the sample's distribution away from options with this price level. Analysis of interaction variables highlights the relations between socio-demographic characteristics and the choice preference. Younger respondents with lower incomes express a negative attitude toward the +14% price level, contrasting with higher age groups and incomes. Environmental awareness emerges as a crucial factor, with environmentally aware respondents exhibiting positive preferences for certain sustainable material alternatives.

The selection of sustainable materials for the foundation has probably resulted in a significant WTP for these materials in comparison to the traditional level, respectively 20,7% for the circular and 17,1% for the biobased alternative. The estimated utility indicates a significant preference for the alternatives in comparison to the traditional level. The WTP for biobased roof covering is significantly higher (16,5%) than the circular alternative (5,7%). Since the environmental impact of the biobased roof covering is higher, due to additional material, the preference is likely influenced by the perceived sustainability and aesthetics of a green roof.

For inner walls and façade cladding, negative WTP values compared to the traditional level are observed. This negative trend is probably caused to a lack of knowledge or bad perceptions about these materials, leading to a preference for traditional materials. Notably, the biobased façade cladding exhibits a wide range of WTP values (-26,8% to -0,5%), highlighting significant variation in respondent preferences. Similar variability is evident in the WTP for the biobased building structure (i.e. CLT structure), ranging from -9,5% to 10,1%. This variation is probably caused by the perceptions of wood as a construction material. On one hand, there is an impression of wood having less durability, longevity, and low fire resistance. On the other hand, timber is positively linked to aesthetics, well-being, and eco-friendliness. This implies that individuals valuing aesthetics and well-being are more likely to express a higher willingness to live in a timber house.

Socio-demographic characteristics and environmental awareness play a crucial role in influencing WTP. Individuals with higher environmental awareness exhibited a higher WTP for biobased materials, bringing the overall WTP for biobased materials to 6,3%. Gender had a minor impact, slightly lowering the overall WTP for male respondents. Different age groups exhibited distinct preferences, with the respondents of 18 to 34 years old showing a significant negative utility for the +14% price level, moderating the WTP for alternative materials. In contrast, respondents aged 55 years and older expressed a strong preference for the biobased building structure and a negative preference for the circular building structure. Monthly net income also affected preferences, with respondents earning over €4.000,- expressing a negative choice preference for certain alternative materials, resulting in an overall lower WTP for both circular and biobased alternatives compared to the traditional level. Education level positively influenced preferences, with master-educated individuals exhibiting higher WTP for both circular (4,8%) and biobased (2,9%) material alternatives. Household composition had a marginal impact, as indicated by a negative choice preference for the biobased foundation, resulting in a modest WTP for biobased material alternatives overall.

The overall WTP trends revealed an unexpected pattern, with circular materials showing an average WTP of 3,6%, surpassing the biobased materials with a WTP of 1,6%. Also caused by the large heterogeneity in the attitude towards biobased material options. Literature suggests that people tend to associate circular materials (either recycled or reused) with lower quality (Pretner, Darnall, Testa, & Iraldo, 2021). However, the same literature also indicates that the WTP for circular materials increases when labelled as environmentally friendly, explaining the WTP for circular material alternatives in this study. Furthermore, the results are probably influenced by so-called "greenwashing". Describing a deceptive practice wherein a product or service is presented as more environmentally friendly than it truly is (United Nations, 2023). This effect is visible at the high WTP for the green roof, where the perception with sustainability outweighs the real environmental performance of the material. Next to this, the terminology – for example including the term "bio" and "circular" – can have influence on the perception of people with a certain material, influence their choice preference.

It should be noted that the WTP in this scenario is stated WTP, meaning that is based on observations in a hypothetical scenario (Zalesjska-Jonsson, 2014). Stated WTP can be exaggerated in comparison to actual WTP due to the fact that respondents due not actually have to invest real money at that stage (Wood, Kenyon, Desvousges, & Morander, 1995). Outlying values such as -18,1% or 20,7% are values which are the results of the research set up and the analytical method, in a real situation the WTP will probably be less significant and the values will be more limited. Literature suggests that there is a positive WTP by individuals for sustainability improvements of houses (e.g. Zalesjska-Jonsson, 2014; Mandell & Wilhelmsson, 201; Park, Hagishima, Tanimoto, & Chun, 2013). The WTP is mainly based on the beliefs that people are willing to pay for something if it provides personal benefits rather than the wider benefits for the society and the environment (Chau, Tse, & Chung, 2010). So, in literature this includes reduced operational costs due to improved energy performance (Zalesjska-Jonsson, 2014). However, it is also concluded that there is a positive WTP for the reduction of CO_2 emitted during the life cycle of a building (Park et al., 2013). When comparing the results from literature to the WTP concluded in this study, it is in the general trend that there is stated WTP by individuals for sustainability measures in a house. However, the scale of the WTP concluded in this study outlies the WTP concluded in literartuere, and the WTP which will probably be expressed by individuals when one actually has to invest own capital.

The analysis of the relation between material costs and WTP for alternative materials underscores a notable discrepancy. Increased costs of circular and biobased materials are not covered by corresponding WTP. The difference between costs and WTP ranges from a small coverage shortage of 2,3% for the circular building structure to extreme coverage shortage for significantly more expensive materials as the circular façade cladding (shortage 98,8%). The influence of the socio-demographic characteristics leads to possible costs coverage. Individuals who are highly environmentally aware have a WTP for the biobased building structure of 10,8%, covering the additional 10,5% costs.

This underscores the complexity of individual preferences and perception with sustainable materials. Revealing that, while people express a willingness to invest in sustainable alternatives, this inclination is dependent upon direct experiences or perceptions with the perceived sustainability of the materials. The study emphasizes that individuals tend to exhibit increased WTP for materials they associate with sustainability. Notably, materials with a "sustainable appearance", such as the green roof, show significant WTP. However, the study concludes that, overall, the WTP for sustainable materials does not outweigh the additional material costs associated with circular and biobased material alternatives.

9.1 Limitations

The research outlined in this report has various limitations, underscoring the importance of caution when interpreting results and findings without validation. Firstly, the determination of material profiles used as attributes and attribute levels in the SCE poses a limitation. Given that a building includes numerous components and a large number of materials, a subjective selection process took place for the components and materials which would be included in the research. The choice of building components is based on their share they take upon the value for the environmental performance (indicated by the "Milieuprestatie Gebouwen" in the Dutch construction sector) and the potential for variation in materialization. For the selection of materials, three profiles are established: traditional, circular, and biobased. Within each profile, one material is selected per building component. However, it is of importance to note that there are many more different material options, each with its unique environmental performance and material costs. Consequently, individuals may indicate different WTP values to different material options for the building components. Bringing difficulties in the generalization of the results of this study.

Moreover, the presentation of materials in the SCE introduces potential bias. Participants needed knowledge of material types, environmental performance, and costs, which not every individual possesses. The explanation and visualization which therefore are included in the online survey could influence participants' responses due to the subjective nature of comprehension and perception. Additionally, there is a potential influence of "greenwashing" in the choice experiment. Given the presentation of alternative materials within the SCE and the research focus on sustainable materials, respondents may have been inclined to respond in a more environmentally conscious manner. This suggests that respondents' aspirations towards making environmentally responsible choices may have inflated the determined WTP.

Furthermore, deriving the WTP using a hypothetical scenario in a choice experiment may not necessarily align with the real values individuals are willing to invest when purchasing a house. When completing the survey, respondents consider a hypothetical situation and are not required to make real monetary investments at that stage. Respondents may express a greater WTP in the hypothetical scenario, and their actual considerations for the real purchase of a house might differ. Confirming the analysis results to absolute values of WTP could be achieved through additional survey with larger research samples and comparing stated values and revealed values of WTP.

A limitation lies in the representativeness of the research sample. A significant majority (77,1%) of respondents self-identified as "high environmentally aware". As stated in the literature review on sustainable behaviour, environmentally aware individuals are more willing to pay for sustainable products and services. Consequently, the overrepresentation of environmentally aware respondents may have inflated the determined WTP for sustainable material alternatives. Consequently, extending these findings to the wider population should be handled with caution.

9.2 Recommendations

The study on the WTP for sustainable material alternatives in housing concludes that individuals are indeed willing to invest in sustainable materials. Notably, this willingness increases when materials exhibit a sustainable appearance or when individuals associate them with sustainability. Designers and project developers should take note of the findings when conceptualizing sustainable houses. However, it should be controlled due to the potential effect of "greenwashing," where materials and products are promoted as more sustainable than they truly are. This practice is undesirable as it fails to reduce emissions, whilst it is thought by individuals that they behave more sustainably. Awareness should be created under consumers about the performance, characteristics, and quality of sustainable material alternatives, encouraging them to make sustainable choices.

It is crucial to raise awareness about the need to enhance the use of sustainable materials in construction. Instead of primarily concentrating on reducing energy-related emissions, there is a need to find a balance that also addresses material-related emissions. By raising awareness and underscoring the need of finding a balance between these two factors, the construction of houses can happen in a more sustainable manner. Furthermore, recommendations for policymakers include an emphasis on improving awareness of sustainability benchmarks and sustainable materials in general. This can be achieved through targeted efforts in marketing sustainability in housing, coupled with initiatives to increase public knowledge about the incentives associated with purchasing a sustainable home. This aligns with the fact that individuals are more willing to pay for a material or product labelled with a certificate which they are familiar with or when they have knowledge about the advantages of the product.

As discussed in Section 9.1 Limitations, the research sample of this study has a significant majority of high environmentally aware respondents. In future research, a more diverse sample is crucial for the full generalizability of the results of WTP for sustainable material alternatives. Environmental awareness is known to correlate with a greater WTP for sustainable options, and the dominance of environmentally aware respondents could have influenced the results. By incorporating a more diverse research sample in future research, including individuals with varying levels of environmental awareness, more reliable results can be concluded. That contributes to the external validity of the study, enabling to apply the findings to a wider range of individuals, reflecting the whole society.

References

ABN AMRO. (2023). *Duurzaamheidskorting*. Retrieved June 5, 2023, from ABN AMRO: https://www.abnamro.nl/nl/prive/hypotheken/duurzaam-wonen/duurzaamheidskorting.html

AbouHamad, M., & Abu-Hamd, M. (2019). Framework for construction system selection based on life cycle cost and sustainability assessment. *Journal of Cleaner Production, 241*. doi:10.1016/j.jclepro.2019.118397.

Abrahamse, W., & Matthies, E. (2019). Informational Strategies to Promoto Pro - Environmental Behaviour: Changing Knowledge, Awareness, and Attidues. In L. Steg, & J. Groot, *Environmental Psychology: An Introduction* (pp. 263-272). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20

Actieagenda Wonen. (2021). *Samen werken aan goed wonen.* Actieagenda Wonen.

Addelman, S. (1962). Orthogonal Main-Effect Plans for Asymmetrical Factorial Experiments. *Technometrics, 4*(1), 21-46. doi:10.2307/1266170

Allwood, J. M. (2014). Chapter 30 - Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies. In E. Worrel, & M. A. Reuter, *Handbook of Recycling* (pp. 445-477). Chambridge: Elsevier. doi:10.1016/C2011-0-07046-1

Arnoldussen, J., Endhoven, T., & Lange, M. d. (2023). *Analyse aanscherping MPG-norm.* Amsterdam: Stichting Economisch Instituut voor de Bouw.

Arnoldussen, J., Errami, S., Semenov, R., Roemers, G., Blok, M., Kamps, M., & Faes, K. (2020). *Matiaalstromen, milieu-impact en energieverbruik in de woning- en utiliteitsbouw: Uitgangssituatie en doorkijk naar 2030.* Amsterdam: Stichting Economisch Instituut voor de Bouw & Metabolic.

ASN. (2023, May 27). *Advieswijzer Hypotheken.* Retrieved from ASN Hypotheken.

Bekker-Grob, E. d., Donkers, B., Jonker, M., & Stolk, E. (2015). Sample Size Requirements for Discrete-Choice Experiments in Healthcare: a Practical Guide. *Practical Application, 8*, 373-384. doi:10.1007/s40271-015-0118-z

Birgisdottir, H., & Rasmussen, F. (2016). *Introduction to LCA of Buildings.* Aalborg University. Aalborg: Trafik-og Byggestyrelsen.

Bisschop, P., & Waal, L. d. (2023). *Stand van de Bouw.* Amsterdam: ABN AMRO.

Blocker, T., & Eckberg, D. (1997). Gender and Environmentalism: Results from the 1993 General Social Survey. *Social Science Quarterly, 78*(4), 841-858.

Blom, I., Itard, L., & Meijer, A. (2011). Environmental impact of building-related and user-related energy consumption in dwellings. *Building and Environment, 46*(8), 1657-1669. doi:10.1016/j.buildenv.2011.02.002

Bolderdijk, J., Lehman, P., & Geller, E. (2019). Encouraging Pro - Environmental Behaviour with Rewards and Penalties. In L. Steg, & J. d. Groot, *Environmental Psychology: An Introduction* (pp. 273-282). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20

Brand, S. (1994). *How buildings learn: what happens after they're built.* New York: Viking.

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., & Thiel, A. (2016). Cross laminated timber (CLT): overview and development. *European Journal of Wood and Wood Product, 74*, 331-351. doi:doi.org/10.1007/s00107-015-0999-5

Bronsvoort, E., Veldboer, T., Slaa, A. t., & Kaptein, T. (2020). *Bouwen aan een houten toekomst.* Amsterdam: Circle Economy.

Brounen, D., & Kok, N. (2011). On the economics of energy labels in the housing market. *Journal of Environmental Economics and Management, 62*(2), 166-179. doi:doi.org/10.1016/j.jeem.2010.11.006

C2C Products Innovation Institute. (2021). *Cradle to Cradle Certified Version 4.0 Product Standard.* Amsterdam: Crade to Cradle Products Innovation Institute. Retrieved October 2, 2023, from https://api.c2ccertified.org/assets/cradle-to-cradle-certified-product-standard-version-4.0---cradle-to-cradle-products-innovation-institute.pdf

C2C Products Innovation Institute. (2023). *Circular Economy*. Retrieved September 18, 2023, from c2ccertified: https://c2ccertified.org/topics/circular-economy

Cabeza, L., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews, 29*, 394-416. doi:10.1016/j.rser.2013.08.037

Cambridge University Press & assessment. (2023). *Dictionary*. Retrieved June 22, 2023, from Chambridge Dictionary: https://dictionary.cambridge.org/dictionary/english/roof

Capital Value. (2023). *3. Koop- en huurwoningmarkt*. Retrieved March 1, 2023, from De woning(beleggings)markt in beeld 2023: https://research.capitalvalue.nl/pages/koop-en-huurwoningmarkt

CBI. (2017, November 1). *Exporting cross laminated timber (CLT) to Western Europe*. Retrieved July 6, 2023, from CBI: Ministry of Foreign Affairs: https://www.cbi.eu/market-information/timber-products/cross-laminated-timber/europe

CBS. (2022a, October 27). *Voorraad woningen; gemiddeld oppervlak; woningtype, bouwjaarklasse, regio*. Retrieved March 1, 2023, from StatLine: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82550NED/table?fromstatweb

CBS. (2022b). *Kerncijfers per postcode - Naar numerieke postcode (PC4), 2022.* Retrieved October 23, 2023, from Centraal Bureau voor de Statistiek: https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/gegevens-per-postcode

CBS. (2023a, February 22). *Prijsstijging koopwoningen nam af in januari*. Retrieved March 1, 2023, from Centraal Bureau voor de Statistiek: https://www.cbs.nl/nl-nl/nieuws/2023/08/prijsstijging-koopwoningen-nam-af-in-januari

CBS. (2023b, January 19). *Voorraad woningen; eigendom, type verhuurder, bewoning, regio*. Retrieved March 1, 2023, from StatLine: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82900NED/table?fromstatweb

CBS. (2023c, February 17). *Minder vergunde nieuwbouwwoningen in 2022*. Retrieved March 1, 2023, from Centraal Bureau voor de Statistiek: https://www.cbs.nl/nl-nl/nieuws/2023/07/minder-vergunde-nieuwbouwwoningen-in-2022

CBS. (2023d, August 25). *Bevolking; geslacht, leeftijd en burgerlijke staat, 1 januari*. Retrieved October 2, 2023, from StatLine: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7461BEV/table?fromstatweb

Chau, C., Tse, M., & Chung, K. (2010). A choice experiment to estimate the effect of green experience on preferences and willingness-to-pay for green attributes. *Building and Environment, 45*(11), 2553-2561. doi:10.1016/j.buildenv.2010.05.017

CKC Structural Engineers. (2018). *Cross Laminated Timber Feasibility Study.* Seattle: Cart Kopezynski & Company. Retrieved from https://buildingresiliencecoalition.org/comparing-the-costs-of-cross-laminated-timber-clt-and-cast-in-place-reinforced-concrete-structures/

Cornell University. (2005). *Glossary of Construction Terms*. Retrieved June 22, 2023, from Cornell University Facilities and Campus Services Facilities Operations: https://operations.fs.cornell.edu/info/ir_glossary.cfm

Crabtree, L., & Hes, D. (2009). Sustainability Uptake in Housing in Metropolitan Australia: An Instituational Problem, Not a Technological One. *Housing Studies, 24*(2), pp. 203-224. doi:10.1080/02673030802704337

Dalton, T., Horne, R., & Maller, C. (2008). The practice of going green: policy drivers and homeowners' experiences of improving housing environmental performance in Victoria. *Shrinking Cities, Sprawling Suburbs, Changing Countrysides.* Dublin: European Housing Researchers' Network Conference.

Davidson, D. J., & Freudenburg, W. R. (1996). Gender and Environmental Risk Consers: A Review and Analysis of Available Research. *Environment and Behavior, 28*(3), 302-339. doi:10.1177/0013916596283003

Dean, M. (2022). *A Pratical Guide to Multi-Criteria Analysis.* London: Bartlett School of Planning, University College London.

DGBC. (2023a). *Meten: Sturen op werkelijk gebruik*. Retrieved March 8, 2023, from Dutch Green Building Council: https://www.dgbc.nl/meten-sturen-op-werkelijk-gebruik-235

DGBC. (2023b). *Paris Proof*. Retrieved March 29, 2023, from Dutch Green Building Council: https://www.dgbc.nl/themas/paris-proof

DGBC. (2023c). *Over BREEAM-NL*. Retrieved March 28, 2023, from BREEAM-NL: https://www.breeam.nl/wat-is-breeam-nl-1

Diekmann, A., & Preisendörfer, P. (2003). Green and Greenback: The Behavioral Effects of Environmental Attitudes in Low-Cost and High-Cost Situations. *Rationality and Society, 15*(4), 441-472. doi:10.1177/1043463103154002

Dobson, D., Sourani, A., Sertyesilisik, B., & Tunstall, A. (2013). Sustainable Construction: Analysis of Its Costs and Benefitws. *American Journal of Civil Engineering and Architecture, 1*(2), 32-38. doi:10.12691/ajcea-1-2-2

Domencich, T., & McFadden, D. (1973). Statistical Estimation of Choice Probability Functions. *Urban Travel Demand*, 101-125.

Econometic Software. (2016). *NLOGIT: Superior Statistical Analysis Software*. Retrieved November 30, 2023, from Econometirc Software, inc.: https://www.limdep.com/products/nlogit/

EIB. (2011). *Kostenmodel omgevingsrecht.* Amsterdam: Economisch Instituut voor de Bouw.
EIB. (2023). *Bouw op een keerpunt.* Amsterdam: Economisch Instituut voor de Bouw. Retrieved from https://www.eib.nl/wp-content/uploads/2023/01/227-Bouw_op_een_keerpunt.pdf
EN 15804. (2019). *EN 15804 - EPD: Environmental Product Declaration.*
EPA. (2023, April 18). *Understanding Global Warming Potentials*. Retrieved June 5, 2023, from United States Environmental Protection Agency: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials
ETH Zürich. (2018). *Constructing architecture: materials, processess, structures: a handbook* (Fourth, revised ed.). (A. Deplazes, Ed.) Basel, Departement Architektur.: Birkhäuser.
Eves, C., & Kippes, S. (2010, July). Public awareness of "green" and "energy efficient" residential property An empirical survey based on data from New Zealand. *Property Management, 38*(3), pp. 193-208. doi:10.1108/02637471011051327
Ferraz, L., Petroni, L. M., & Santos, E. d. (2023). How urban green areas influence different dimensions of sustainable behaviour. *Revista De Administração Da UFSM, 16*(1). doi:10.5902/1983465969508
Gálvez-Martos, J.-L., Styles, D., Schoenberger, H., & Zaschmar-Lahl, B. (2018). Construction and demolition waste best management practice in Europe. *Resources, Conservation & Recycling, 136*, 166-178. doi:10.1016/j.resconrec.2018.04.016
Gatersleben, B., & Werff, E. v. (2018). Symbolic Aspects of Environmental Behaviour: An Introduction. In L. Steg, & J. d. Groot, *Environmental Psychology* (pp. 198-206). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20
Geldermans, R. (2016). Design for change and circularity - accomodating circular material & product flows in construction. *SBE16 Tallinn and Helsinki Conference; Build Green and Renovate Deep. 96*, pp. 301-311. Tallinn and Helsinki: Energy Procedia.
Ghaffer, S. H., Burman, M., & Braimah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of Cleaner Production, 244*. doi:10.1016/j.jclepro.2019.118710
Gold, S., & Rubik, F. (2009). Consumer attitudes towards timber as a construction material and towards timber frame houses – selected findings of a representative survey among the German population. *Journal of Cleaner Production, 17*(2), 303-309. doi:10.1016/j.jclepro.2008.07.001
GPR Software. (2023a). *GPR Gebouw*. Retrieved June 22, 2023, from GPR Software: https://gprsoftware.nl/gpr-gebouw/
GPR Software. (2023b, June 7). *GPR Materiaal*. Retrieved June 7, 2023, from GPR Software: https://materiaal.gprportaal.nl/5397ed2a-89d0-4642-8a34-eea13011bac9/component
GPR Software. (2023c). *Over GPR Materiaal*. Retrieved June 7, 2023, from GPR: https://gprsoftware.nl/gpr-materiaal/over-gpr-materiaal/
Groenblauw. (n.d.). *Alle maatregelen - Groendaken*. Retrieved July 12, 2023, from Blauwgroen Vlaanderen: https://blauwgroenvlaanderen.be/professionals/maatregelen/groendaken/
Groot, J. d., & Thøgersen, J. (2019). Values and Pro - Environmental Behaviour. In L. Steg, & J. d. Groot, *Environmental Psychology: An Introduction* (pp. 167-178). Chichester: Johm Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20
Hamilton, L. C. (1985). Concern about Toxic Wastes: Three Demographic Predictors. *Sociological Perspectives, 28*(4), 463-486. doi:10.2307/1389229
Hensher, D. A., & Greene, W. H. (2003). The Mixed Logit model: The state of practice. *Transportation, 30*, 133-176.
Hensher, D. A., Rose, J. M., & Greene, W. H. (2015). *Applied Choice Analysis.* Cambridge: Cambridge University Press.
Hillege, L. (2022, December 13). *Environmental Cost Indicator (ECI) - Overview*. Retrieved April 14, 2023, from Ecochain: https://ecochain.com/knowledge/environmental-cost-indicator-eci/
Hurth, V. (2010, May). Creating Sustainable Identities: The Significance of the Financially Affluent Self. *Sustainable Development, 18*. doi:10.1002/sd.453
IGG Bouweconomie. (2023). *Bijkomende Kosten (NEN2699) Woningbouw*. Retrieved September 6, 2023, from Bouwkostenkompas: https://www.bouwkostenkompas.nl/nl/extra-kosten/A
ING. (n.d.). *Hypotheek voor een duurzaam huis*. Retrieved June 5, 2023, from ING: https://www.ing.nl/particulier/hypotheek/hypotheekvormen/duurzaam-huis-kopen
International Living Future Institue. (2019). *Living Building Challenge 4.0.* Seattle: International Living Future Institue.

Iwaro, J., & Mwasha, A. (2010). Implications of building energy standard for sustainable energy efficient design in buildings. *International Journal of Energy and Environment, 1*(5), 745-756.

Judge, M., Warren-Meyers, G., & Paladino, A. (2019). Using the theory of planned behaviour to predict intentions to purchase sustainable housing. *Journal of Cleaner Production, 215*, 259-267. doi:10.1016/j.jclepro.2019.01.029

Keizer, K., & Schultz, P. (2019). Social Norms and Pro - Environmental Behaviour. In L. Steg, & J. d. Groot, *Environmental Psychology: An Introduction* (pp. 179-189). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20

Kibert, C. J. (1994). Sustainable Construction. *Proceedings of the First International Conference of CIB TG.* Tampa: Center for Construction and Environment, M.E. Rinker Sr. School of Building Construction, College of Architecure, University of Florida.

Klöckner, C., & Verplanken, B. (2019). Yesterday's Habits Preventing Change for Tomorrow? About the Influence of Automaticity on Environmental Behaviour. In L. Steg, & J. d. Groot, *Environmental Psychology: An Introduction* (pp. 238-250). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20

Kollmuss, A., & Agyeman, J. (2010, July 1). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research, 8*(3), 239-260. doi:10.1080/13504620220145401

Kreitchmann, R. S., Abad, F. J., Ponsoda, V., Nieto, M. D., & Morillo, D. (2019). Controlling for Response Biases in Self-Report Scales: Forced-Choice vs. Psychometric Modeling of Likert Items. *Frontiers in Psychology, 10*. doi:10.3389/fpsyg.2019.02309

Labbé, M., Laporte, G., Tanczos, K., & Toint, P. (1998). *Operations Research and Decision aid Methodologies in Traffic and Transportation Management* (Vol. 166). Heidelberg: Springer Berlin. doi:10.1007/978-3-662-03514-6

Ladenburg, J., Olsen, S., & Nielsen, R. (2007). Reducing hypothetical bias in choice experiments. *EAERE 2007 Annual Conference* (p. 30). Thessaloniki: University of Copenhagen.

Lähtinen, K., Harju, C., & Toppinen, A. (2019). Consumers'perceptions on the properties of wood affecting their willingness tolive in and prejudices against houses made of timber. *Wood Material Science and Engineering, 14*(5), 325-331. doi:10.1080/17480272.2019.1615548

Lente Akkoord. (2012, May 7). *Omrekening EPC naar energielabel bekend*. Retrieved February 24, 2023, from Lente Akkoord 2.0: https://www.lente-akkoord.nl/nieuws/omrekening-epc-naar-energielabel-bekend

Li, Q., Long, R., & Chen, H. (2018). Differences and influencing factors for Chinese urban resident willingness to pay for green housings: Evidence from five first-tier cities in China. *Applied Energy, 229*, 299-313. doi:10.1016/j.apenergy.2018.07.118

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology, 22*(140), 5-55.

Lindenberg, S., & Steg, L. (2007). Normative, Gain and Hedonic Goal Frames Guiding Environmental Behavior. *Journal of Social Issues, 63*(1), 117-137. doi:10.1111/j.1540-4560.2007.00499.x

Liu, C., Zhang, F., & Zhang, H. (2020). Comprative Analysis of Off-Site Precast Concrete and Cast-In-Place Concrete in Low-Carbon Built Environment. *Fresenius Environmental Bulletin, 29*(03), 1804-1812.

Long, J. S., & Freese, J. (2001). *Regression Models for Categorical Dependent Variables Using Stata.* College Station, Texas: Stata Press.

Lorenz, D., & Lützkendorf, T. (2008). Sustainability in property valuation: Theory and practice. *Journal of Property Investment & Finance, 26*(6), 482-521. doi:10.1108/14635780810908361

Louviere, J., & Timmermans, H. (1990). Hierarchical Infomtation Integration Applied to Residential Choice Behavior. *Geographical Analysis, 22*(2), 127-144. doi:10.1111/j.1538-4632.1990.tb00200.x

Mandell, S., & Wilhelmsson, M. (2010). Willingness to Pay for Sustainable Housing. *Journal of Housing Research, 20*(6). doi:10.1080/10835547.2011.12092034

Mandell, S., & Wilhelmsson, M. (2011). Willingness to Pay for Sustainable Housing. *Journal of Housing Research, 20*(1), 35-51. doi:10.1080/10835547.2011.12092034

Marmolejo-Duarte, C., & Chen, A. (2019). The Uneven Price Impact of Energy Efficiency Ratings on Housing Segmets. Implications for Public Policy and Private Markets. *Sustainability, 11*(2), 372. doi:10.3390/su11020372

MaterialDistrict. (2014, September 6). *GROWING BIOBASED BUILDING MATERIALS*. Retrieved June 28, 2023, from MaterialDistrict: https://materialdistrict.com/article/growing-biobased-building-materials/

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In P. Zarembka, *Frontiers in Econometrics* (pp. 104-142). New York: Acedemic Press.

McFadden, D., & Train, K. (2000). Mixed MNL models for discrete response. *Journal of Applied Econometrics, 15*(5), 447-470. doi:10.1002/1099-1255(200009/10)15:5<447::AID-JAE570>3.0.CO;2-1

Meinzen-Dick, R., Kovarik, C., & Quisumbing, A. R. (2014). Gender and Sustainability. *Annual Review of Environment and Researches, 39*(1), 29-55. doi:10.1146/annurev-environ-101813-013240

Midden, C., & Ham, J. (2019). Persuasive Technology to Promote Pro - Environmental Behaviour. In L. Steg, & J. d. Groot, *Environmental Psychology: An Introduction* (pp. 283-294). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20

Miles, J. (2005). R-Squared, Adjusted R-Squared. *Encyclopedia of Statistics in Behavioral Science*. doi:10.1002/0470013192

Milfont, T. L., Poortinga, W., & Sibley, C. G. (2020). Does having children increase environmental concern? Testing parenthood effects with longitudinal data from the New Zealand Attitudes and Values Study. *PLoS ONE, 15*(3). doi:10.1371/journal.pone.0230361

Milieu Centraal. (2019, February). *Cradle to Cradle Certified*. Retrieved March 30, 2023, from Keurmerkenwijzer: https://keurmerkenwijzer.nl/keurmerken/cradle-to-cradle-certified/

Milieu Centraal. (n.d.). *Energieneutrale woning*. Retrieved January 9, 2024, from Milieu Centraal: https://www.milieucentraal.nl/energie-besparen/aardgasvrij-wonen/energieneutrale-woning/

Ministerie Binnenlandse Zaken en Koninkrijkrelaties. (2020). *Nationale Omgevingsvisie.* Den Haag: Ministerie van Binnenlandse Zaken en Koninkrijkrelaties. Retrieved January 23, 2023, from https://denationaleomgevingsvisie.nl/publicaties/novi-stukken+publicaties/handlerdownloadfiles.ashx?idnv=1760380

Ministerie van Binnenlandse Zaken en Koninkrijkrelaties. (2021). *Aanbieding Rapport Staat van de Woningmarkt 2021.* Den Haag: Rijksoverheid.

Ministerie van Economische Zaken en Klimaat. (2020). *Klimaatplan 2021-2023.* Den Haag: Ministerie van Economische Zaken en Klimaat. Retrieved from https://open.overheid.nl/documenten/ronl-c66c8a00-ac14-4797-a8ea-973a98c5bee0/pdf

Miyatake, Y. (1996). Technology Development and Sustainable Construction. *Journal of Management in Engineering, 12*(4), 23-27.

Molin, E. J. (2011). Conjoint Analysis. In S. Jansen, H. Coolen, & R. Goetgeluk, *The Measurement and Analysis of Housing Preference and Choice* (pp. 127-156). Delft: Springer Science+Business Media B.V. doi:10.1007/978-90-481-8894-9_6

Monier, V., Mudgal, S., Hestin, M., Trarieux, M., & Mimid, S. (2011). *Service Constract on Management of Construction and Demolition Waste - SR1.* Paris: Bio Intelligence Service.

Nasereddin, M., & Price, A. (2021). Addressing the capital cost barrier to sustainable construction. *Developments in the Built Environment, 7*. doi:doi.org/10.1016/j.dibe.2021.100049

New Horizon. (2023). *MINDER CO_2. MEER BOUWEN.* Retrieved June 19, 2023, from New Horizon: https://newhorizon.nl/material-balance/urban-mining-concrete/

Noiseux, K., & Hostetler, M. (2010). Do Homebuyers Want Green Features in Their Communities? *Environment and Behavior, 42*(5), 551-580. doi:10.1177/0013916508326470

Oorschot, J. v., Sprechter, B., Rijken, B., Witteveen, P., Blok , M., Schouten, N., & Voet, E. v. (2023). Toward a low-carbon and circular building sector: Building strategies and urbanization pathways for the Netherlands. *Journal of Industrial Ecology, 27*(2), 535-547. doi:10.1111/jiec.13375

Orme, B. (2019). Sample Size Issues for Conjoint Analysis. In *Getting started with conjoint analysis: strategies for product design and pricing research* (pp. 57-65). Madison: Research Publishers LLC.

Özden, M. (2008). Environmental Awareness and Attitudes of Student Teachers: An Empirical Research. *International Research in Geographical and Environmental Education, 17*(1), 40-55. doi:10.2167/irgee227.0

Pajchrowski, G., Noskowiak, A., Lewandowska, A., & Strykowski, W. (2014). Wood as a building material in light of environmental assessment of full life cycle of four building. *Construction and Building Materials, 52*(15), 428-436. doi:10.1016/j.conbuildmat.2013.11.066

Pitt & Sherry. (2014). *National Energy Efficient Building Project.* State of South Australia: Department of State Development - Government of South Australia.

Pivo, G., & McNamara, P. (2005). Responsible Property Investing. *International Real Estate Review, 8*(1), 128-143.

Planbureau voor de Leefomgeving. (2021, November 1). *Circulair beton*. Retrieved July 6, 2023, from PBL: https://themasites.pbl.nl/o/circulariteit-in-de-bouw/rutte-groep/

Prete, I. M., Piper, L., Rizzo, C., Pino, G., Capestro, M., Mileti, A., . . . Guido, G. (2017). Determinants of Southern Italian households' intention to adopt energy efficiency measures in residential buildings. *Journal of Cleaner Production, 153*, 83-91. doi:10.1016/j.jclepro.2017.03.157

Pretner, G., Darnall, N., Testa, F., & Iraldo, F. (2021). Are consumers willing to pay for circular products? The role of recycled and second-hand attributes, messaging, and third party certification. *Resources, Conservation and Recycling, 175*. doi:10.1016/j.resconrec.2021.105888

Punmia, B., & Jain, A. (2005). *Building Construction.* New Delhi: Laxmi Publications (P) LTD.

Quist, Z. (2023, May 22). *Life Cycle Assessment (LCA) - Complete Beginner's Guide*. Retrieved June 7, 2023, from Ecochain.

Raad van State. (2022, November 2). *Bouwvrijstelling stikstof van tafel, maar geen algehele bouwstop*. Retrieved March 3, 2023, from Raad van State: https://www.raadvanstate.nl/actueel/nieuws/%40133608/bouwvrijstelling-stikstof-van-tafel/

Rabobank. (2023). *Duurzaamheidskorting op je hypotheek*. Retrieved June 5, 2023, from Rabobank: https://www.rabobank.nl/particulieren/hypotheek/hypotheekrente/duurzaamheidskorting

Ramesh, T., Prakash, R., & Shukla, K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings, 42*, 1592-1600. doi:10.1016/j.enbuild.2010.05.007

Randle, M., Kemperman, A., & Dolnicar, S. (2019). Making cause-related corporate social responsibility (CSR) count in holiday accommodation choice. *Tourism Management, 75*, 66-77. doi:10.1016/j.tourman.2019.05.002

Rijksoverheid. (2020, December 18). *Nieuw energielabel voor gebouwen per 1 januari 2021*. Retrieved February 15, 2023, from Rijksoverheid: https://www.rijksoverheid.nl/actueel/nieuws/2020/12/18/nieuw-energielabel-voor-gebouwen-per-1-januari-2021#:~:text=Sinds%202008%20is%20een%20energielabel,de%20Europese%20richtlijn%20energieprestatie%20gebouwen.

Rijksoverheid. (2022, October 13). *Minister Hugo de Jonge maakt provinciale woningbouwafspraken voor 900.000 nieuwe woningen*. Retrieved March 3, 2023, from Rijksoverheid: https://www.rijksoverheid.nl/actueel/nieuws/2022/10/13/minister-hugo-de-jonge-maakt-provinciale-woningbouwafspraken-voor-900.000-nieuwe-woningen

Rogers, E. M. (2003). *Diffusion of Innovations* (Fifth Edition ed.). New York: Free Press.

Royne, M. B., Levy, M., & Martinez, J. (2011). The Public Health Implications of Consumers' Environmental Concern and Their Willingness to Pay for an Eco-Friendly Product. *Journal of Consumer Affairs, 45*(2), 329-343. doi:10.1111/j.1745-6606.2011.01205.x

RVO. (2010). *LEED.* Den Haag: Agentschap NL - Ministerie van Binnenlandse Zaken en Koninkrijkrelaties. Retrieved from https://www.rvo.nl/sites/default/files/bijlagen/LEED.pdf

RVO. (2017, May 15). *Energielabel woningen*. Retrieved February 23, 2023, from Rijksdienst voor Ondernemend Nederland: https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/energielabel-woningen#energielabel-woningen-verplicht

RVO. (2021, Oktober 11). *MilieuPrestatie Gebouwen - MPG*. Retrieved February 6, 2023, from Rijksdienst voor Ondernemend Nederland: https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/milieuprestatie-gebouwen-mpg

RVO. (2022, September 30). *Energieprestatie - BENG*. Retrieved February 6, 2023, from Rijksdienst voor Ondernemend Nederland: https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/beng

RVO. (2023, January 2). *Wetten en regels gebouwen*. Retrieved February 8, 2023, from Rijksdienst voor Ondernemend Nederland: https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen#nieuwbouw

Sartori, I., & Hestnes, A. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings, 39*, 249-257. doi:10.1016/j.enbuild.2006.07.001

Smit, H.-H., & Dirkse, G. (2022, August 29). *Het effect van stijgende bouwkosten op nieuwbouwprojecten en grondprijzen*. Retrieved June 20, 2023, from Rabobank: https://www.rabobank.nl/kennis/d011296949-het-effect-van-stijgende-bouwkosten-op-nieuwbouwprojecten-en-grondprijzen

Sobota, M., Driessen, I., & Holländer, M. (2022). *Carbonbased Design.* Rijksdienst voor Ondernemend Nederland. Den Haag: Transitieteam Circulaire Bouweconomie.

Solís-Guzman, J., Marrero, M., Montes-Delgado, M. V., & Ramírez-de-Arellano, A. (2009). A Spanish model for quantification and management of construction waste. *Waste Management, 29*(9), 2542-2548. doi:10.1016/j.wasman.2009.05.009

Spitsbaard, M., & Leeuwen, M. v. (2021). *Proejct Paris Proof Materiaalgebonden Emmissies.* Den Haag: Dutch Green Building Council.

StatCan. (2021). *4.5.1 Calculating the range and interquartile range*. Retrieved December 12, 2023, from Statistics Canada: https://www150.statcan.gc.ca/n1/edu/power-pouvoir/ch12/5214890-eng.htm

Steg, L., Bolderdijk, J., Keizer, K., & Perlaviciute, G. (2014). An integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. *Journal of Environmental Psychology, 38*, 104-115. doi:10.1016/j.jenvp.2014.01.002

Stern, P. C., Dietz, T., & Kalof, L. (1993). Value Orientations, Gender, and Environmental Concern. *Environment and Behavior, 25*(5). doi:10.1177/0013916593255002

Stichting Bouwkwaliteit. (2011). *Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken.* Rijswijk: Stichting Bouwkwaliteit.

Stichting Nationale Milieudatabase. (2020a). *Gids Milieuprestatieberekeningen.* Rijswijk: Stichting Nationale Milieudatabase.

Stichting Nationale Milieudatabase. (2020b). *Inkopen met de milieuprestatie gebouwen (MPG).* Rijswijk: Stichting Nationale Milieudatabase.

Stichting Nationale Milieudatabase. (2022). *Bepalingsmethode Milieuprestatie Bouwwerken.* Rijswijk: Stichting Nationale Milieudatabase.

Stuart-Fox, M., Kleinepier, T., Ligthart, D., & Blijie, B. (2022). *Wonen langs de meetlat: Resultaten van het WoonOnderzoek Nederlands 2021.* ABF Research. Den Haag: Ministerie van Binnenlandse Zaken en Koninkrijkrelaties. Retrieved from https://open.overheid.nl/documenten/ronl-6ba59413e76cef7c060942077d1ab7eb072ed52d/pdf

Suki, N. M. (2013). Young consumer ecological behaviour: The effects of environmental knowledge, healthy food, and healthy way of life with the moderation of gender and age. *Management of Environmental Quality An International Journal, 24*(6), 726-737. doi:10.1108/MEQ-02-2013-0010

Synchroon. (2023). *Klimaatplan 2023.* Utrecht: Synchroon.

Tan, T. (2011). Measuring the willingness to pay for houses in a sustainable neighborhood. *International Journal of Environmental, Cultural, Economic and Social Sustainability, 7*(1). doi:10.18848/1832-2077/CGP/v07i01/54854

Taufik, D., & Venhoeven, L. (2019). Emotions and Pro - Environmental Behaviour. In L. Steg, & J. d. Groot, *Environmental Psychology: An Introduction* (pp. 189-197). Chichester: John Wiley & Sons Ltd. doi:10.1002/9781119241072.ch20

Thomas, G. O., Fisher, R., Whitmarsh, L., Milfont, T. L., & Poortinga, W. (2018). The impact of parenthood on environmental attitudes and behaviour: a longitudinal investigation of the legacy hypothesis. *Population and Environment, 39*, 261-276. doi:10.1007/s11111-017-0291-1

Train, K. E. (2009). *Discrete Choice Methods with Simulation* (2nd ed.). Berkeley: University of California, Cambridge University Press. doi:10.1017/CBO9780511805271

Triodos Bank. (2023). *Triodos Hypotheek*. Retrieved June 5, 2023, from Triodos Bank: https://www.triodos.nl/hypotheek

Tuinenga, H., Plas, J., & Huijbers, M. (2022). *Zo ontwerp je Paris Proof.* Arnhem: dgmr.

United Nations. (2015a). *Sustainable Development Goals*. Retrieved February 14, 2023, from United Nations: https://unric.org/en/united-nations-sustainable-development-goals/

United Nations. (2015b). *Paris Agreement.* Paris: United Nations.

United Nations. (2020). *Emissions Gap Report 2020.* Nairobi: United Nations Environment Programme.

United Nations. (2023). *Greenwashing - the deceptive tactics behind environmental claims*. Retrieved December 6, 2023, from United Nations: https://www.un.org/en/climatechange/science/climate-issues/greenwashing

Universidad Europea. (2023). *Building installations: The key elements*. Retrieved June 22, 2023, from Universidad Europea: https://universidadeuropea.com/en/blog/building-installations/#what-installations-buildings

University of Queensland. (n.d.). *Chi-square Distribution Table*. Retrieved October 27, 2023, from University of Queensland: https://people.smp.uq.edu.au/YoniNazarathy/stat_models_B_course_spring_07/distributions/chisqtab.pdf

Veul, R. (2022, 12 26). *Duurzame hypotheek: hypotheek met duurzaamheidskorting*. Retrieved June 5, 2023, from Hypotheek.nl: https://www.hypotheek.nl/kennisbank/hypotheek-afsluiten/duurzame-hypotheek-duurzaamheidskorting/#:~:text=Een%20duurzame%20hypotheek%20(ook%20wel,je%20woning%20energiezuiniger%20te%20maken.

VORM. (2023a). *Bouwdeelbegroting: MBP11, Moederbegroting Bouw Plus Jaargang 1 Versie 1.* Rotterdam: VORM Bouw B.V.

VORM. (2023b). *VORM 2050 Benchmark.* Rotterdam: VORM Holding B.V.

Vos, M., Yildiz, B., Jackson, G., & Berg, J. v. (2021). *Cross Laminated Timber: Handleiding voor architecten en bouwkundigen.* Eindhoven: INBO.

W/E Adviseurs. (2023a). *Verkenning MPG-score ≤ 0,5.* Utrecht: W/E Adviseuers.

W/E Adviseurs. (2023b, April 15). *Zo bouwen we binnen ons CO2-budget*. Retrieved June 6, 2023, from W/E: https://www.w-e.nl/kennisbank/zo-bouwen-we-binnen-ons-co2-budget/

Warren-Myers, G., Carre, A., Vines, M., & Wakefield, R. (2012). Existing Buildings Research Project: Isolating Opportunities for the Improvement of the Environmental Performance of Existing Housing Stock. (V. Government, Ed.) *Sustainaiblity Victoria*.

Warren-Myers, G., Judge, M., & Paladino, A. (2018, July 29). Sustainability ratings in residential development: a worthwhile endeavour? *International Journal of Building Pathology and Adaptation, 36*(4), pp. 353-372. doi:10.1108/IJBPA-02-2018-0024

Wienerberger. (2023). *ClickBrick Pure: een doorbraak in circulaire baksteenarchitectuur*. Retrieved July 11, 2023, from Wienerberger: https://www.wienerberger.nl/product/gevel/systemen/clickbrick.html

Wood, L. L., Kenyon, A. E., Desvousges, W. H., & Morander, L. K. (1995). How much are customers willing to pay for improvements in health and environmental quality? *The Electricity Journal, 8*(4), 70-77. doi:10.1016/1040-6190(95)90038-1

World Commission on Environment and Development. (1987). *Our Common Future.* Oxford: Brundtland Commission, Oxford University Press.

Yadav, M., & Agarwal, M. (2021). Biobased building materials for sustainable future: An overview. *Materialstoday: proceedings, 43*(5), 2895-2902. doi:10.1016/j.matpr.2021.01.165

Zalesjska-Jonsson, A. (2014). Stated WTP and retional WTP: Willingness to pay for green apartments in Sweden. *Sustainable Cities and Society, 13*, 46-56. doi:10.1016/j.scs.2014.04.007

Zhou, L., & Lowe, D. (2003). Economic Challenge of Sustainable Construction. In D. Proverbs (Ed.), *RICS Construction and Building Research Conference, School of Engineering and the Built Environment, University of Wolverhampton* (pp. 113-126). Wolverhampton: RICS Foundation.

Appendix A. Environmental Performance Benchmarks

Benchmark	*(Inter)national*	*Building Type*	*Scale Level*	*Emission Type*	*Life cycle Stage*	*Standard / Voluntary*
Energy Label[a] Initiator: Dutch Government	The energy label is a Dutch certificate introduced in 2008. In 2021 the certification method is adapted to European guidelines.	The energy label implies on all building types, both residential as utility.	The energy label accounts to one building, or one unit in multi-family residential complexes.	The energy label focusses on the energy performance of a building during the operational stage.	The energy label focusses on the use stage.	The energy label is an obliged certificate for all buildings in the Netherlands.
BREEAM[b] Initiator: Building Research Establishment	BREEAM is an international certificate used in over 80 countries. The DGBC adapted the determination method for the Dutch market.	BREEAM focusses on all building types, both residential as utility.	BREEAM is applicable to both singular buildings as to complete areas.	BREEAM includes all three emission types. Besides that it also includes health, ecology, waste, management, and more.	BREEAM focusses on all the life cycle stages of a building. Separate certificates are possible for a specific life cycle stage.	BREEAM is a voluntary certificate that can be given to a building that exceeds normal regulations and meets the BREEAM standard.
LEED[c] Initiator: US Green Building Council	LEED is from origin an American certificate, now used internationally.	LEED focusses on all building types, both residential as utility.	LEED is applicable to both singular buildings as to complete areas.	LEED includes all three emission types. Besides that it also includes health, ecology, waste, management, and more.	LEED focusses on all the life cycle stages of a building. Separate certificates are possible for specific life cycle stages.	LEED is a voluntary certificate that can be given to a building that exceeds normal regulations and meets the LEED standard.
BENG[d] Initiator: Dutch Government	BENG is a Dutch benchmark. The requirements arise from the Energy Agreement from the European Energy Performance of Buildings Directive.	BENG is used both for residential as for utility buildings.	BENG is applicable to one building or building complex.	BENG focusses only on the operational-related emissions. It classifies energy performance.	BENG only focusses on the use stage of the building, during the operational emissions.	BENG is obliged in the Netherlands and is tested during the permit application for new construction.
MPG[e] Initiator: Dutch Government	MPG is a Dutch benchmark introduced in 2018 and adjusted in 2021 to higher standards.	MPG is used both in residential and office construction.	MPG is applicable to one building or building complex.	MPG focusses on material-related emissions in the construction of a buildings.	MPG includes the material-related emissions during all life cycle stages of a buildings.	MPG is obliged in the application of an environmental permit for new construction in the Netherlands.

GPR Gebouw[f] *Initiator: W/E Adviseurs*	*GPR Gebouw is a Dutch method to classify the sustainable performance of buildings.*	*GPR Gebouw is used for residential, office, and educational buildings.*	*GPR Gebouw is applicable to one building or building complex.*	*GPR Gebouw focusses on five themes: energy, environment, health, user-quality, and future-value. In this is includes both operational- as material-related emissions.*	*GPR Gebouw includes all life cycle stages of a building.*	*GPR Gebouw is a voluntary benchmark to assess the sustainable performance of buildings.*
Paris Proof[g] Initiator: DGBC	Paris Proof is an agreement between Dutch companies from the construction sector.	Paris Proof is applicable to all building types, both residential and utility.	Paris Proof is applicable to one building or building complex.	Paris Proof focusses on the material-related emissions of a building.	Paris Proof includes material-related emissions during all life cycle stages of a building.	Paris Proof is a relatively new benchmark in the Dutch construction sector.
Cradle to Cradle Certified[h] Initiator: EPEA & MBDC	Cradle to Cradle is an internationally acknowledged certification.	Cradle to Cradle is applicable to all building types, both residential as utility.	Cradle to Cradle is applicable to one building or building complex.	Cradle to Cradle focusses on the reuse of materials, so primarily material-related emissions.	Cradle to Cradle focusses on the reuse of materials and products, so all stages except the use stage.	Cradle to Cradle is a voluntary certification for circular buildings.

[a](Rijksoverheid, 2020). [b](DGBC, 2023c). [c](RVO, 2010). [d](RVO, 2022). [e](RVO, 2021). [f](GPR Software, 2023a). [g](DGBC, 2023b). [h](Milieu Centraal, 2019).

Appendix B. Influence Design Factors

Besides materials there are also design factors that have influence on the MPG. The NMD describes five design parameters of a residential building that can have a significant influence on the MPG of a building. These five design parameters are: gross floor area (GFA), number of stories, story height, façade area, and share of open parts in the façade. The reasoning behind the significant influence of these design parameters is described below (Stichting Nationale Milieudatabase, 2020a).

- *Gross floor area*
  The influence of the GFA on the value of the MPG has mostly to do with the ratio between floor and envelope surface area. For smaller dwellings, the influence of the gross floor area on the environmental performance score is relatively high. This is due to the relatively unfavourable ratio between floor and envelope surface area in combination with the regular necessary building installations and facilities, which are independent of the size of the home. The MPG score can quickly add up for very small homes. On the contrary, the score for the MPG will decrease as the gross floor area increases.

- *Number of stories*
  The MPG score is relatively high for residential buildings with a low number of stories. This is because materials for communal facilities, such as the foundation, entrance and access, can be distributed over a limited number of stories (and GFA). With an increase in the number of building layers, the score of the environmental performance per building layer decreases. However, the reduction rate is getting lower as the number of stories increases, because a heavier construction is required with an increase in the number of layers.

- *Story height*
  The increase in the score of the environmental performance has to do with the fact that the façade surface increases with a constant gross floor area. For every 10% increase in floor height, the MPG score increases by 2% to 3%. However, even with a floor height of well over three meters, the increase in MPG will be limited.

- *Façade area*
  This is relatable to the aforementioned design factor. If the façade surface increases with the same number of square meters of gross floor area (façade/GFA ratio), the MPG score also increases. Houses with a patio, or bay windows, extensions and decorative façades have relatively more material per square meter of GFA and therefore a more negative score on the environmental performance.

- *Share of open parts in the façade*
  The open parts of the façade have a higher environmental impact than the closed parts. This is partly caused by the high environmental impact per square meter of glazing (especially with triple glazing). An increase of 25% in the share of open façade parts leads to an increase of the MPG of several per cent. Combined with an unfavorable façade/GFA ratio, this can lead to relevantly negative environmental performance.

Besides the mentioned design parameters and their influence on the MPG, the lifespan of a building also has a significant influence on the scoring. The scoring is based on the LCA, so taking phases of the life cycle into account. No strict value for the lifespan of a building is known but use is made of a default value of 75 years for a residential building (Stichting Nationale Milieudatabase, 2020a). When motivated and substantiated, one can deviate from this value and include a shorter or longer lifespan in the determination of the MPG. So lifespan is a relevant factor and the influence of a shorter or longer lifespan can be explained as follows.

- *Shorter lifespan*
  When the life span of a building is shorter than the default 75 years, the environmental performance increases rapidly while materialization remains unchanged, resulting in a higher MPG value. If a relatively

short lifespan is to be expected, it is critical to pay attention to products with a low environmental impact, and products with circular principles such as reuse and recycling.

- *Longer lifespan*
  The environmental performance of a building decreases relative to the default value of 75 years, but not proportionally. Long-cycle elements with a lifespan longer than a building are the only ones relevant to a longer lifespan. In those 75 years, the other elements are already replaced one or more times, so the total environmental impact increases almost proportionally. Building structures and closed facades are the main long-cycle elements.

Appendix C. Material Selection GPR Materiaal

Profile	*Building Component*	*Cat.*	*Product*[a]	*MKI*	*Unit*
Traditional	Foundation Poles	3	Funderingspalen, Schroefpaal; beton,in het werk gestort, C20/25; incl.wapening, diameter 320	13,73	m
	Foundation Beams	3	Fundatiebalken, Beton,in het werk gestort, C3037; incl.wapening + eps	17,19	m
	Structural Floors	2	Vrijdragende Vloeren, Betonhuis; druklaag breedplaatvloer; betonmortel C30/37,CEMIII; incl. wapening	2,61	m^2
	Structural Floors	2	Vrijdragende Vloeren, Breedplaat, excl. druklaag, 60mm; prefab beton; AB-FAB	3,86	m^2
	Structural Walls	3	Massieve wanden, dragend, Beton,in het werk gestort, C3037; incl.wapening	13,72	m^2
	Inner Walls	2	Gipsblokken, hoge dichtheid, 70 mm (NBVG)	4,32	m^2
	Facade Cladding	3	Spouwmuren buitenblad, Leemsteenmetselwerk; incl. cementpleister	5,44	m^2
	Window Frames	3	Buitenkozijnen, Aluminium vast en/of draaiend, gecoat	2,94	m^2
	Roof Covering	3	Afwerklagen, Grind	0,10	m^2
	Roof Covering	2	Plat dakbedekking, Stg. Dak en Milieu, Bitumen gemod. eenlaags 4,3 mm, 5,3 kg per m2, volledig gekleefd brandmethode system 01, incl. 1x overlagen	1,85	m^2
Circular	Foundation	1	Urban Mining Concrete 50[b]	4,00	m
	Structural Floors	1	Urban Mining Concrete 50[b]	1,76	m^2
	Structural Walls	1	Urban Mining Concrete 50[b]	1,76	m^2
	Inner Walls	1	Faay Volpaneel 54mm	1,16	m^2
	Facade Cladding	1	Clickbrick Timm Antiek HV, Wienerberger BV, geproduceerd op locatie Nuance	1,56	m^2
	Window Frames	1	Buitenkozijnen: Europrovyl kunststof kozijn KVision Trend draaideel raam PVC uit 100% recyclaat 800mmx1500mm	1,97	m^2
	Roof Covering	1	Derbigum NT 4 mm	0,64	m^2
Biobased	Foundation Poles	2	Heipaal, beton, prefab, 250x250 mm, Betonhuis	2,33	m
	Foundation Beams	2	Fundatiebalken, Beton, prefab; AB-FAB	9,86	m
	Structural Floors	1	KLH CLT massieve vloer	1,20	m^2
	Structural Walls	1	KLH CLT massieve binnenwand	1,43	m^2
	Inner Walls	2	Systeemwanden niet dragend, Houten niet dragende binnenwand, HSB prefab; duurzaam bosbeheer	0,65	m^2
	Facade Cladding	3	Bekledingen, Vuren delen, thermisch behandeld; duurzame bosbouw	3,78	m^2
	Window Frames	2	Buitenkozijnen, Aziatisch loofhout (Meranti), kozijn vast; geschilderd, duurz. bosb.	1,94	m^2
	Roof Covering	2	Plat dakbedekking, Stg. Dak en Milieu, Bitumen gemod. eenlaags 4,3 mm, 5,3 kg per m2, volledig gekleefd brandmethode system 01, incl. 1x overlagen	1,44	m^2
	Roof Covering	3	Afwerklagen, Begroend dak; drainage+filter+subtraat+sedum (excl dakbedekking)	1,85	m^2

[a] Since the database is in Dutch and to avoid translation errors, the building components are also presented here in Dutch. This concerns the literal names as used in the GPR Material software.
[b] The impact value in the NMD is per m^3, this is recalculated to m or m^2 values using the same dimensions as the traditional level.
Source: (GPR Software, 2023b)

Appendix D. Orthogonal Design

Profile	*Attribute #1*	*Attribute #2*	*Attribute #3*	*Attribute #4*	*Attribute #5*	*Attribute #6*	*Attribute #7*
1	0	0	0	0	0	0	0
2	0	0	0	0	1	1	2
3	0	0	0	0	2	2	1
4	0	1	1	2	0	0	0
5	0	1	1	2	1	1	2
6	0	1	1	2	2	2	1
7	0	2	2	1	0	0	0
8	0	2	2	1	1	1	2
9	0	2	2	1	2	2	1
10	1	0	1	1	0	1	1
11	1	0	1	1	1	2	0
12	1	0	1	1	2	0	2
13	1	1	2	0	0	1	1
14	1	1	2	0	1	2	0
15	1	1	2	0	2	0	2
16	1	2	0	2	0	1	1
17	1	2	0	2	1	2	0
18	1	2	0	2	2	0	2
19	2	0	2	2	0	2	2
20	2	0	2	2	1	0	1
21	2	0	2	2	2	1	0
22	2	1	0	1	0	2	2
23	2	1	0	1	1	0	1
24	2	1	0	1	2	1	0
25	2	2	1	0	0	2	2
26	2	2	1	0	1	0	1
27	2	2	1	0	2	1	0

Appendix E. Survey

The Willingness to Pay for Sustainable Material use in Housing

AVAILABLE IN ENGLISH AND DUTCH. THE SURVEY WORKS BEST ON A LAPTOP.

You are invited to complete a questionnaire about the willingness to pay for sustainable material use in the Dutch, owner-occupied, multi-family housing sector. This survey was made at Eindhoven University of Technology in collaboration with project developer VORM. The aim of this study is to gain a better understanding of the willingness to pay of Dutch homeowners of multi-family houses for sustainable material use.

Dear respondent,

Welcome to this questionnaire for my graduation research at the Eindhoven University of Technology. My research concerns the willingness to pay for sustainable material use in the Dutch, owner-occupied, multi-family housing sector.

Completing this questionnaire is voluntary. In this questionnaire, you are asked to make a choice between different housing options, each with its own material types and price level. The questionnaire will start with a few questions about your personal characteristics, followed by several questions about your current housing situation. The questionnaire will conclude with several statements regarding the environment and climate change, which you should indicate whether you agree or disagree with them. Completing the questionnaire takes approximately 10-15 minutes.

Your answers will be stored and processed anonymously. I would like to thank you in advance for completing the questionnaire. If you have any questions, please contact me via: j.j.w.dirx@student.tue.nl.

With kind regards,

Joep Dirx

Before starting the survey, you will have to accept the privacy conditions. As a reminder, completing the questionnaire is completely voluntary. I ask you to read the information form: click here for the information form. If you have any questions about this information, please contact me at: j.j.w.dirx@student.tue.nl. If you have no questions and agree with the information provided, you can indicate this below.

☐ * To continue please first accept our survey data policy

* By signing this consent form, I acknowledge that I have been adequately informed about the survey data policy by means of a separate information sheet. I read the information sheet and had the opportunity to ask questions. I voluntarily participate in this research. It is clear to me that I can stop participation in the study at any time without giving any reason. I give permission to process the personal data collected from me during the research as included in the attached

Personal Characteristics

*What is your age?

Choose one of the following answers

- 17 years or younger
- 18 - 24 years old
- 25 - 34 years old
- 35 - 44 years old
- 45 - 54 years old
- 55 - 64 years old
- 65 - 74 years old
- 75 years or older

*What is your gender?

Choose one of the following answers

- Male
- Female
- Other / I prefer not to say

*What is your household composition?

Choose one of the following answers

- Single without child(ren) (living at home)
- Single with child(ren) living at home
- Couple without child(ren) (living at home)
- Co-living with other(s)
- Other

*What is your highest level of completed education?

Choose one of the following answers

- Primary school
- mavo, vmbo
- havo
- vwo
- MBO
- HBO-, WO-Bachelor
- HBO-, WO-Master, Doctor (PhD)
- I don't know / I prefer not to say

*What is your household's monthly net income?

❷ The monthly net income is the amount of money that is transferred to your bank account on a monthly basis. This includes your salary, social benefits, and pension income. If your household has more than one income, you must add these together.

❷ Choose one of the following answers

- ◯ €2.000 or less a month
- ◯ €2.001 - €4.000 a month
- ◯ €4.001 - €6.000 a month
- ◯ €6.001 or more a month
- ◯ I don't know / I prefer not to say

*What are the four digits of your zip code?

❷ Please fill in 4 numbers.

❷ Only numbers may be entered in this field.

Housing Characteristics

*In what type of building do you live at the moment?

See the images for examples.

Ground-bounded house 	Porch apartment 
Gallery apartment 	Corridor apartment 
Maisonette 	

- Ground-bounded house (single-family)
- Porch apartment complex
- Gallary apartment complex
- Corridor apartment complex
- Maisonette (2-story apartment)
- Other

*How many bedrooms does your current house have?

Choose one of the following answers

- Studio (no separate bedroom)
- 1 - 2 bedrooms
- 3 - 4 bedrooms
- 5+ bedrooms

*In which year is your current house constructed?

Choose one of the following answers

- 1959 or before
- 1960 - 1979
- 1980 - 1999
- 2000 - 2019
- 2020 or later
- I don't know

*What is the total square meters of living area of your current house?

Choose one of the following answers

- Less than 50 square meters
- 50 - 75 square meters
- 76 - 100 square meters
- 101 - 150 square meters
- More than 150 square meters

*Are you a homeowner or a tenant?

Choose one of the following answers

- Homeowner
- Tenant - Social-Housing
- Tenant - Other

Information for choice situations

Please read this text carefully.

Image the following situation: You want to move to a newly constructed apartment and you get a choice of two houses within the same region where you want to live. Which of the two houses do you choose?

In the next 8 questions, two housing options are shown to you, "House A" and "House B". It is an imaginary situation where two houses differ in characteristics, and we ask you to choose the one that you prefer the most. If neither of the two housing options appeals to you, you can choose the option "None of the two". The housing options differ in material use and price level. Per building component, there are three material options (traditional, circular & biobased), these options are explained below. Additionally, a price level is given. This is a percentage in which the price of the house increases in comparison to a "traditional" house.

Below there are several definitions stated and the material options are shown, these are important to understand.

At the bottom of the page, an example question is stated.

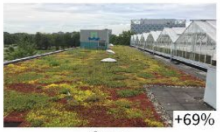
Environmental impact

The construction sector is one of the largest contributors to pollution in the world, resulting in a negative environmental impact. The environmental impact of a house is determined by the impact of pollution and emissions from the materials used in a house. Sustainable materials, including recycled, renewable, circular, and biobased resources, typically demonstrate lower environmental impact. Meaning that these materials are more environmentally friendly.

Price level

The price of a house depends, among other factors, on the materials used in its construction. In this survey, the term "price levels" refers to a possible additional percentage increase in the selling price of the house. This means that you would need to pay that extra percentage for that housing option.

Traditional materials	**Circular materials**	**Biobased materials**
Traditionally, the Dutch construction sector uses stony materials like brick, cement, and concrete. These materials are CO_2-intensive to produce and therefore have a negative effect on the environment. The environmental impact of traditional materials is set at 100% as the base value.	Circular construction materials can either be based on the principle of demounting and reusing materials without degradation of the quality or using construction and demolition waste in new materials. Per material, the reduction of the environmental impact compared to the traditional level is indicated in the figure.	Biobased materials are materials derived partially or entirely from biomass sources. Biobased materials are a natural and renewable material source. Per material, the reduction of the environmental impact compared to the traditional level is indicated in the figure.

Building Component	Level 1. Traditional	Level 2. Circular	Level 3. Biobased
1. Foundation	 100% Concrete Screw Pile	 -87% Prefab Circular Concrete Pile	 -61% Prefab Concrete Pile
2. Building Structure	 100% Casted Concrete Walls & Floors	 -80% Prefab Cir. Concrete Walls & Floors	 -86% CLT (Prefab Timber) Walls & Floors
3. Inner Walls	 100% Gypsum	 -33% Flax Elements	 -34% Timber Frame
4. Façade Cladding	 100% Masonry Brick	 -73% Click Brick (Dry)	 -85% Wood
5. Window Frames	 100% Aluminium	 -71% Recycled PVC	 -30% Wood
6. Roof Covering	 100% Grit Ballast	 -67% Recycled Bitumen	 +69% Green

Two tools are available to assist you during the selection session:

1. Further information about a building component can be obtained by hovering your mouse over the specific component.
2. It is possible to open the image shown above during the questions, by clicking the '<u>Parts & Material Types</u>' link. This is shown under each question.

Your preference in choice situations

*Select the house that you prefer. Or if neither option appeals to you, choose the option 'None of the two'.

Part	House A	House B	None of the two
Foundation	 Prefab Circular Concrete Pile	 Prefab Concrete Pile	
Building Structure	 Prefab Circular Concrete Walls & Floors	 Casted Concrete Walls & Floors	
Inner Walls	 Timber Frame	 Timber Frame	
Façade Cladding	 Masonry Brick	 Wood	
Window Frames	 Wood	 Wood	
Roof Covering	 Gritt	 Recycled Bitumen	
Price Level	€ +14%	€ +0%	

If you want to see the example with all the parts again, click the link below:

Parts & Material Types

Choose one of the following answers

House A

House B

None of the two

Environmental Awareness Statements

*Indicate how much you agree or disagree with the following statements about climate change and environmental awareness.

Please choose the appropriate response for each item:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I believe that climate change is exaggerated.	○	○	○	○	○	○	○
I believe that the human activities are the main cause of climate change.	○	○	○	○	○	○	○
I believe that climate change will have serious negative consequences for the earth.	○	○	○	○	○	○	○
I believe that each of us can make a contribution to environmental protection.	○	○	○	○	○	○	○
I am NOT willing to give up activities/products in order to protect the environment.	○	○	○	○	○	○	○
I am willing to pay extra for sustainable products/measures.	○	○	○	○	○	○	○

Final Comments

Do you have any final comments regarding the survey and/or the research?

Appendix F. Definitions Building Components

- *Foundation*
  The foundation of a building is the supporting structure below the ground floor or the surface of a building. To support the building structure, long foundation piles are brought into the ground till they hit stronger soil. There are several types of concrete foundation piles, either prefabricated or cast-in-place. The prefabricated concrete foundation piles are drilled into the ground by hitting the piles with a large mass. Another option is a large screw pile that is drilled into the ground and when removing the screw from the ground, concrete is poured out into the ground. It is also an option to make use of circular concrete when placing a screw pile.

- *Building structure*
  The building structure provides the structural strength of a building and distributes the forces exerted on the building to the foundation. In the vertical plane, the building structure consists of columns and walls. In the horizontal plane, the building structure consists of beams and floors. In the Netherlands, building constructions are mainly developed in stony materials such as concrete and masonry. Wood construction is increasingly emerging in the Netherlands as a constructive material. CLT (cross-laminated timber) is often used for this, which are several layers of wood glued together crosswise to ensure that it can withstand more forces.

- *Inner walls*
  The inner walls of a house ensure the division of spaces, this can be both dwelling separating walls and walls separating rooms in a dwelling. The inner walls have no constructive contribution. Inner walls can consist of masonry (sand-lime brick or gypsum blocks) or can be set up with system walls. Systems walls are constructed out of elements/blocks which are prefabricated. An example of systems walls is the use of flax wall elements. Inner walls can also be constructed by timber frame construction, where wooden beams are placed between which insulation is placed and which are covered with plasterboard.

- *Façade cladding*
  Together with the glazing, the facade cladding forms the outermost layer of a building that protects the building against wind and weather and also partly determines the appearance of the building. The facade cladding has no structural value. Façade cladding can consist of masonry (e.g. bricks), wood (e.g. planks), plate material (e.g. zinc or grit plates) or other materials such as natural stone and composite.

- *Window frames*
  The window frames are the framework in which the glazing is placed. The frame provides the connection between the walls and the glass. A frame can be fixed and can have rotating/tilting parts. A window frame can be made of wood, plastics or metals such as aluminium and steel.

- *Roof covering*
  The roof covering is the protective layer of the roof, the top layer of a building. Roofing ensures watertightness and as a protective layer against wind and weather. The roof covering should always contain ballast (often in the form of gravel, tiles or greenery) to protect the roof from wind. In addition, the roof covering also has an aesthetic value.

Appendix G. Effect Coding Attribute Levels

	Attribute		*Attribute Levels*	*A*	*B*
1	Foundation	0	Traditional: Cast-In-Place Concrete Screw Pile	-1	-1
		1	Circular: Cast-In-Place Circular Concrete Screw Pile	1	0
		2	Biobased: Prefab Concrete Pile	0	1
2	Building Structure	0	Traditional: Cast-In-Place Concrete Walls & Floors	-1	-1
		1	Circular: Prefab Circular Concrete Walls & Floors	1	0
		2	Biobased: Cross-Laminated-Timber Walls & Floors	0	1
3	Inner Walls	0	Traditional: Gypsum	-1	-1
		1	Circular: Flax wall elements	1	0
		2	Biobased: Timber Frame	0	1
4	Façade Cladding	0	Traditional: Mortar & Brick (Masonry)	-1	-1
		1	Circular: Click Brick (Dry Masonry)	1	0
		2	Biobased: Wood	0	1
5	Window Frames	0	Traditional: Aluminium	-1	-1
		1	Circular: Recycled PVC	1	0
		2	Biobased: Wood	0	1
6	Roof Covering	0	Traditional: Gritt	-1	-1
		1	Circular: Recycled Bitumen	1	0
		2	Biobased: Green	0	1
7	Price Level	0	No additional costs	-1	-1
		1	+7% additional costs	1	0
		2	+14% additional costs	0	1

Appendix H. Python Code for Data Transformation

Listing H1. Python code for data preparation & transformation

```
"""
Created on Wed Oct 18 09:21:34 2023

@author: 20174501
"""

import pandas as pd
import numpy as np

#reading data
path_to_file = r"C:\XXX.csv"
df = pd.read_csv(path_to_file, sep=',')

#removal of columns
df = df.drop(["submitdate", "lastpage", "startlanguage", "seed", "startdate",
              "datestamp", "Q200", "Q500"], axis=1)
df.head()

#removal of respondent
df = df[df['id'] != 87]

df.to_csv(r"C:\XXX.csv", index=False)

#seperate choice data & personal data
columns_to_select = ['id', 'Q001', 'Q002', 'Q003', 'Q004', 'Q005', 'Q006', 'Q100',
                     'Q101', 'Q102', 'Q103', 'Q401[SQ001]', 'Q401[SQ002]', 'Q401[SQ003]',
                     'Q401[SQ004]', 'Q401[SQ005]', 'Q401[SQ006]']
df1 = df[columns_to_select]
df1.to_csv(r"C:\XXX.csv", index=False)

columns_to_select = ['id', 'Q301', 'Q302', 'Q303', 'Q304', 'Q305', 'Q306', 'Q307',
                     'Q308', 'Q309', 'Q310', 'Q311', 'Q312', 'Q313', 'Q314', 'Q315',
                     'Q316', 'Q317', 'Q318', 'Q319', 'Q320', 'Q321',
                     'Q322', 'Q323', 'Q324', 'Q325', 'Q326', 'Q327']
df2 = df[columns_to_select]
df2.to_csv(r"C:\XXX.csv", index=False)

#rename columns 'Q301' to 'Q327' to 'E1' to 'E27'
for i in range(301, 328):
    old_column_name = f'Q{i}'
    new_column_name = f'E{i-300}'
    df2 = df2.rename(columns={old_column_name: new_column_name})

df2.to_csv(r"C:\XXX.csv", index=False)

#replacing choice task options with profile number
df2.column_mapping = {
    'E1': {1.0: 15, 2.0: 21, 3.0: 28},
    'E2': {1.0: 3, 2.0: 19, 3.0: 28},
    'E3': {1.0: 14, 2.0: 27, 3.0: 28},
    'E4': {1.0: 22, 2.0: 7, 3.0: 28},
    'E5': {1.0: 25, 2.0: 14, 3.0: 28},
    'E6': {1.0: 9, 2.0: 11, 3.0: 28},
    'E7': {1.0: 20, 2.0: 18, 3.0: 28},
    'E9': {1.0: 1, 2.0: 16, 3.0: 28},
    'E10': {1.0: 18, 2.0: 12, 3.0: 28},
    'E11': {1.0: 8, 2.0: 1, 3.0: 28},
    'E12': {1.0: 4, 2.0: 9, 3.0: 28},
    'E13': {1.0: 2, 2.0: 24, 3.0: 28},
    'E14': {1.0: 24, 2.0: 5, 3.0: 28},
    'E15': {1.0: 19, 2.0: 13, 3.0: 28},
    'E16': {1.0: 6, 2.0: 8, 3.0: 28},
    'E17': {1.0: 16, 2.0: 3, 3.0: 28},
    'E18': {1.0: 5, 2.0: 26, 3.0: 28},
    'E19': {1.0: 11, 2.0: 4, 3.0: 28},
    'E20': {1.0: 17, 2.0: 23, 3.0: 28},
    'E21': {1.0: 23, 2.0: 6, 3.0: 28},
    'E22': {1.0: 13, 2.0: 10, 3.0: 28},
    'E23': {1.0: 7, 2.0: 22, 3.0: 28},
    'E24': {1.0: 26, 2.0: 15, 3.0: 28},
    'E25': {1.0: 27, 2.0: 25, 3.0: 28},
    'E26': {1.0: 10, 2.0: 20, 3.0: 28},
    'E27': {1.0: 12, 2.0: 17, 3.0: 28}
```

```
}

for col in df2.column_mapping:
    df2[col] = df2[col].replace(df2.column_mapping[col])

df2.to_csv(r"C:\XXX.csv", index=False)

#wide to long format
path_to_file = r"C:\XXX.csv"
data = pd.read_csv(path_to_file, sep=',', dtype=str)

data2 = data.set_index(['id']).stack()

data2.to_csv(r"C:\XXX.csv")

#adding names to columns
data2 = pd.read_csv(r"C:\XXX.csv", header=0)

column_mapping = {
    'id':'id',
    '':'task',
    '0':'alternative'
    }

data2.rename(columns=column_mapping, inplace=True)

data2 = data2.rename(columns={'Unnamed: 1': 'task'})

data2.to_csv(r"C:\XXX.csv", index=False)

#adding csv_file with all the possible choices
path_to_file = r"C:\XXX.csv"
data3 = pd.read_csv(path_to_file, sep=',')

data4 = pd.merge(data2, data3, left_on='task', right_on='task')

data4['choice'] = np.where(data4['alternative_x']==data4['profile'], '1', '0')

data4.to_csv(r"C:\XXX.csv", index=False)

#selecting columns

data5 = data4[['id', 'task', 'profile', 'choice', 'alternative_y']]
data5.to_csv(r"C:\XXX.csv", index=False)

#transforming the data
path_to_file = r"C:\XXX.csv"

data6 = pd.read_csv(path_to_file, sep=',')

replace_dict = {
    'E1': '1',
    'E2': '2',
    'E3': '3',
    'E4': '4',
    'E5': '5',
    'E6': '6',
    'E7': '7',
    'E8': '8',
    'E9': '9',
    'E10': '10',
    'E11': '11',
    'E12': '12',
    'E13': '13',
    'E14': '14',
    'E15': '15',
    'E16': '16',
    'E17': '17',
    'E18': '18',
    'E19': '19',
    'E20': '20',
    'E21': '21',
    'E22': '22',
    'E23': '23',
    'E24': '24',
    'E25': '25',
    'E26': '26',
    'E27': '27'
}
```

```python
data6['task'] = data6['task'].replace(replace_dict)

sorted_id = data6.sort_values(['id', 'task'])

sorted_id = sorted_id[['id', 'task', 'choice', 'profile', 'alternative_y']]

sorted_id.to_csv(r"C:\XXX.csv", index=False)

#adding constant & case number
path_to_file = r"C:\XXX.csv"
data7 = pd.read_csv(path_to_file, sep=',')

data7['constant'] = 0
data7.loc[data7['profile'] == 28, 'constant'] = 1
data7['case'] = range(1, len(data7) + 1)

data7.to_csv(r'C:\XXX.csv', index=False)

#combining sorted data for MNL with effect-coding
path_to_file = r"C:\XXX.csv"
dataeffect = pd.read_csv(path_to_file, sep= ';')

path_to_file= r'C:\XXX.csv'

datasorted = pd.read_csv(path_to_file, sep= ',')

data8 = pd.merge(datasorted, dataeffect, left_on='profile', right_on='Profile')
data8 = data8.sort_values(['case'])

data8.to_csv(r'C:\XXX.csv', index=False)

#making data neater
path_to_file = r'C:\XXX.csv'
data9 = pd.read_csv(path_to_file, sep=',')

data9.rename(columns={'Alternative1_effect_1': 'foun_X1', 'Alternative1_effect_2': 'foun_X2',
                      'Alternative2_effect_1': 'bs_X1', 'Alternative2_effect_2': 'bs_X2',
                      'Alternative3_effect_1': 'iw_X1', 'Alternative3_effect_2': 'iw_X2',
                      'Alternative4_effect_1': 'fc_X1', 'Alternative4_effect_2': 'fc_X2',
                      'Alternative5_effect_1': 'wf_X1', 'Alternative5_effect_2': 'wf_X2',
                      'Alternative6_effect_1': 'rc_X1', 'Alternative6_effect_2': 'rc_X2',
                      'Alternative7_effect_1': 'pc_X1', 'Alternative7_effect_2': 'pc_X2'},
                     inplace=True)
data9 = data9[['id', 'task', 'profile', 'choice', 'constant', 'case', 'alternative_y',
               'foun_X1', 'foun_X2', 'bs_X1', 'bs_X2', 'iw_X1', 'iw_X2', 'fc_X1', 'fc_X2',
               'wf_X1', 'wf_X2', 'rc_X1','rc_X2', 'pc_X1', 'pc_X2']]

data9.to_csv(r'C:\XXX.csv', index=False)

#combine choice data and personal data
path_to_file = r'C:\XXX.csv'
data10 = pd.read_csv(path_to_file, sep=',')

path_to_file = r"C:\XXX.csv"
data11 = pd.read_csv(path_to_file, sep=',')

data12 = pd.merge(data10, data11, left_on='id', right_on='id')

data12.to_csv(r"C:\XXX.csv", index=False)
```

Listing H2. Python code for recoding personal characteristics data

```
"""
Created on Tue Nov  7 12:07:05 2023

@author: 20174501
"""

import pandas as pd

# Read the original data file
df = pd.read_csv(r"C:\XXX.csv")

#removal of respondent
df = df[df['id'] != 87]

# Remove columns
df = df.drop(['Q006', 'Q100', 'Q101', 'Q102', 'Q103'], axis=1 )

# Recount environmental awareness
df['Q401[SQ001]'] = 8 - df['Q401[SQ001]']
df['Q401[SQ005]'] = 8 - df['Q401[SQ005]']

df['EnAwTot'] = df['Q401[SQ001]'] + df['Q401[SQ002]'] + df['Q401[SQ003]'] +
            df['Q401[SQ004]'] + df['Q401[SQ005]'] + df['Q401[SQ006]']
df = df.drop(['Q401[SQ001]', 'Q401[SQ002]', 'Q401[SQ003]', 'Q401[SQ004]',
              'Q401[SQ005]', 'Q401[SQ006]'], axis=1)

# Rename the columns
df = df.rename(columns={'Q001': 'age', 'Q002': 'gender', 'Q003': 'houcom',
                        'Q004': 'degree', 'Q005': 'income'})

# Recode age
df['age'] = df['age'].replace({2: 1, 3: 1, 4: 2, 5: 2, 6: 3, 7: 3, 8: 3})

# Recode houcom
df['houcom'] = df['houcom'].replace({1: 1, 2: 2, 3: 1, 4: 2, 5: 3})

# Recode degree
df['degree'] = df['degree'].replace({1: 1, 2: 1, 3: 1, 4: 1, 5: 1, 6: 2, 7: 3, 8: 1})

# Recode income
df['income'] = df['income'].replace({1: 1, 2: 2, 3: 3, 4: 3, 5: 1})

# Recode EnAwTot
bins = [0, 15, 32, 42]
labels = ['low', 'medium', 'high']
df['EnAwTot'] = pd.cut(df['EnAwTot'], bins=bins, labels=labels)

#unwanted_columns = ['gender_3', 'houcom_6', 'degree_8']
#df = df.drop(unwanted_columns, axis=1)

# Save the modified DataFrame to a new CSV file
df.to_csv(r"C:\XXX.csv", index=False)
```

Appendix I. Output MNL Model

```
|-> NLOGIT
    ; Lhs=CHOICE
    ; choices=0,1,2
    ;
Rhs=CONSTANT,FOUN_X1,FOUN_X2,BS_X1,BS_X2,IW_X1,IW_X2,FC_X1,FC_X2,WF_X1,WF_X2,RC_X1,
RC_X2,PC_X1,PC_X2
    ; pds=8$
Iterative procedure has converged
Normal exit:   6 iterations. Status=0, F=    .7667656D+03

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable                 Choice
Log likelihood function      -766.76563
Estimation based on N =     872, K =  15
Inf.Cr.AIC  =   1563.5 AIC/N =    1.793
---------------------------------------
            Log likelihood R-sqrd R2Adj
Constants only   -820.6878  .0657 .0576
Note: R-sqrd = 1 - logL/Logl(constants)
Warning:  Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
---------------------------------------
Response data are given as ind. choices
Number of obs.=   872, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
CONSTANT|   -1.55037***     .11692   -13.26  .0000   -1.77952  -1.32122
 FOUN_X1|     .14973*       .07798     1.92  .0548    -.00310    .30256
 FOUN_X2|     .06573        .07115      .92  .3556    -.07373    .20519
   BS_X1|     .02536        .07566      .34  .7375    -.12293    .17364
   BS_X2|     .27064***     .06970     3.88  .0001     .13402    .40725
   IW_X1|     .01909        .08312      .23  .8183    -.14381    .18200
   IW_X2|     .08115        .07211     1.13  .2604    -.06018    .22248
   FC_X1|    -.14307        .09075    -1.58  .1149    -.32095    .03480
   FC_X2|    -.12017        .07758    -1.55  .1213    -.27222    .03187
   WF_X1|    -.05553        .07383     -.75  .4519    -.20024    .08917
   WF_X2|     .16084**      .07455     2.16  .0310     .01472    .30695
   RC_X1|    -.10957        .08844    -1.24  .2154    -.28292    .06377
   RC_X2|     .42959***     .08281     5.19  .0000     .26730    .59189
   PC_X1|    -.07112        .08766     -.81  .4171    -.24293    .10068
   PC_X2|    -.34516***     .06880    -5.02  .0000    -.47999   -.21032
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jan 03, 2024 at 11:55:47 AM
-----------------------------------------------------------------------------
```

Appendix J. Output MNL Model – Significant Interaction Variables

```
|-> NLOGIT
    ; Lhs=CHOICE
    ; choices=0,1,2
    ;
Rhs=CONSTANT,FOUN_X1,FOUN_X2,BS_X1,BS_X2,IW_X1,IW_X2,FC_X1,FC_X2,WF_X1,WF_X2,RC_X1,
RC_X2,PC_X1,PC_X2,G1F1,G1W1,A1F2,A1P2,A2C,A2B1,A2B2,A2P2,H1C,H1F2,H1FC2,D1C,D2B2,D2
W1,I1I2,I2B2,I2I1,I2R2,E2C,E2B2,E2I2,E2R2
    ; pds=8$
Iterative procedure has converged
Normal exit:   7 iterations. Status=0, F=    .6766084D+03

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable               Choice
Log likelihood function      -676.60844
Estimation based on N =    872, K =  37
Inf.Cr.AIC  =   1427.2 AIC/N =    1.637
---------------------------------------
            Log likelihood R-sqrd R2Adj
Constants only   -820.6878  .1756 .1577
Note: R-sqrd = 1 - logL/Logl(constants)
Warning:  Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
---------------------------------------
Response data are given as ind. choices
Number of obs.=   872, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
CONSTANT|   -2.32178***     .37434    -6.20  .0000    -3.05547  -1.58810
 FOUN_X1|     .45228***     .13050     3.47  .0005      .19651    .70805
 FOUN_X2|     .16072        .15043     1.07  .2854     -.13412    .45555
   BS_X1|     .15264        .09692     1.57  .1153     -.03731    .34260
   BS_X2|     .01023        .15484      .07  .9473     -.29324    .31370
   IW_X1|     .21226*       .11896     1.78  .0744     -.02090    .44541
   IW_X2|    -.49426***     .15994    -3.09  .0020     -.80773   -.18079
   FC_X1|    -.11497        .09832    -1.17  .2423     -.30768    .07774
   FC_X2|    -.35706***     .13465    -2.65  .0080     -.62096   -.09316
   WF_X1|    -.03592        .14725     -.24  .8073     -.32451    .25268
   WF_X2|     .18406**      .08016     2.30  .0217      .02694    .34117
   RC_X1|    -.09528        .09439    -1.01  .3128     -.28028    .08973
   RC_X2|     .41676***     .15918     2.62  .0088      .10477    .72875
   PC_X1|    -.04591        .09390     -.49  .6249     -.22994    .13812
   PC_X2|    -.32936**      .13376    -2.46  .0138     -.59152   -.06720
    G1F1|    -.45518***     .14614    -3.11  .0018     -.74161   -.16874
    G1W1|    -.32624**      .15636    -2.09  .0369     -.63271   -.01977
    A1F2|     .30866**      .12621     2.45  .0145      .06129    .55603
    A1P2|    -.36697**      .15564    -2.36  .0184     -.67202   -.06192
     A2C|     .76687***     .26095     2.94  .0033      .25541   1.27832
    A2B1|    -.34482**      .16237    -2.12  .0337     -.66306   -.02657
    A2B2|     .44868***     .16398     2.74  .0062      .12728    .77009
    A2P2|     .42822**      .16757     2.56  .0106      .09979    .75664
     H1C|    1.41030***     .38309     3.68  .0002      .65945   2.16114
    H1F2|    -.34238**      .14264    -2.40  .0164     -.62195   -.06281
   H1FC2|     .32298**      .15025     2.15  .0316      .02850    .61746
     D1C|     .64963*       .33159     1.96  .0501     -.00027   1.29954
    D2B2|     .33987**      .13417     2.53  .0113      .07689    .60284
    D2W1|     .38822***     .14763     2.63  .0085      .09886    .67758
    I1I2|     .33274**      .16191     2.06  .0399      .01541    .65007
    I2B2|    -.56784***     .14332    -3.96  .0001     -.84875   -.28693
    I2I1|    -.41571***     .15684    -2.65  .0080     -.72311   -.10832
    I2R2|    -.36382***     .13693    -2.66  .0079     -.63220   -.09544
     E2C|    -.97050***     .27320    -3.55  .0004    -1.50597   -.43503
```

```
    E2B2|     .39186***      .15051     2.60  .0092      .09686    .68686
    E2I2|     .66594***      .16826     3.96  .0001      .33616    .99573
    E2R2|     .36023**       .15546     2.32  .0205      .05553    .66493
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jan 10, 2024 at 02:36:30 PM
-----------------------------------------------------------------------------
```

Appendix K. Output ML Model

```
|-> Nlogit
    ; Lhs = CHOICE
    ; choices=0,1, 2
    ; RHS = CONSTANT, FOUN_X1, FOUN_X2, BS_X1, BS_X2, IW_X1, IW_X2, FC_X1, FC_X2,
WF_X1, WF_X2, RC_X1, RC_X2, PC_X1, PC_X2
    ; RPL
    ; Fcn = CONSTANT (n), BS_X2 (n), IW_X2 (n), FC_X2 (n), RC_X2 (n), PC_X2 (n)
    ; halton
    ; pts=1000
    ; pds=8
    ; robust$
Iterative procedure has converged
Normal exit:   6 iterations. Status=0, F=    .7667656D+03

-----------------------------------------------------------------------------
Start values obtained using MNL model
Dependent variable                Choice
Log likelihood function       -766.76563
Estimation based on N =    872, K =  15
Inf.Cr.AIC  =    1563.5 AIC/N =    1.793
----------------------------------------
            Log likelihood R-sqrd R2Adj
Constants only   -820.6878  .0657 .0543
Note: R-sqrd = 1 - logL/Logl(constants)
Warning:  Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
----------------------------------------
Using robust VC matrix, V = <H>*GtG<<G>
Response data are given as ind. choices
Number of obs.=   872, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
CONSTANT|   -1.55037***     .11968    -12.95  .0000    -1.78494  -1.31580
   BS_X2|     .27064***     .06958      3.89  .0001      .13427    .40701
   IW_X2|     .08115        .07291      1.11  .2657     -.06176    .22405
   FC_X2|    -.12017        .07753     -1.55  .1211     -.27213    .03178
   RC_X2|     .42959***     .08208      5.23  .0000      .26872    .59046
   PC_X2|    -.34516***     .06913     -4.99  .0000     -.48065   -.20966
 FOUN_X1|     .14973**      .07629      1.96  .0497      .00020    .29926
 FOUN_X2|     .06573        .07099       .93  .3545     -.07340    .20487
   BS_X1|     .02536        .07279       .35  .7276     -.11730    .16802
   IW_X1|     .01909        .08415       .23  .8205     -.14585    .18403
   FC_X1|    -.14307        .09108     -1.57  .1162     -.32159    .03545
   WF_X1|    -.05553        .07394      -.75  .4526     -.20046    .08939
   WF_X2|     .16084**      .07566      2.13  .0335      .01254    .30913
   RC_X1|    -.10957        .08840     -1.24  .2152     -.28284    .06369
   PC_X1|    -.07112        .08754      -.81  .4165     -.24269    .10044
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jan 03, 2024 at 00:00:03 PM
-----------------------------------------------------------------------------

Iterative procedure has converged
Normal exit:  29 iterations. Status=0, F=    .6646199D+03

-----------------------------------------------------------------------------
Random Parameters Multinom. Logit Model
Dependent variable                CHOICE
Log likelihood function       -664.61989
Restricted log likelihood     -957.98992
Chi squared [ 21](P= .000)     586.74004
Significance level               .00000
```

```
McFadden Pseudo R-squared       .3062350
Estimation based on N =     872, K =  21
Inf.Cr.AIC  =    1371.2 AIC/N =    1.573
---------------------------------------
            Log likelihood R-sqrd R2Adj
No coefficients  -957.9899  .3062 .2978
Constants only   -820.6878  .1902 .1803
At start values  -766.7656  .1332 .1227
Note: R-sqrd = 1 - logL/Logl(constants)
Warning:  Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
---------------------------------------
Response data are given as ind. choices
Replications for simulated probs. =2000
Used Halton sequences in simulations.
RPL model with panel has      109 groups
Fixed number of obsrvs./group=        8
Robust Covariance Matrix,  VC = <H>G<H>.
Number of obs.=   872, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
        |Random parameters in utility functions..............................
CONSTANT|   -3.26060***      .47446    -6.87  .0000     -4.19053  -2.33067
   BS_X2|      .54517***     .15076     3.62  .0003       .24968    .84066
   IW_X2|      .02962        .14322      .21  .8361     -.25109    .31034
   FC_X2|    -.16743         .16819    -1.00  .3195     -.49707    .16222
   RC_X2|      .71926***     .16065     4.48  .0000       .40440   1.03413
   PC_X2|    -.71878***      .18723    -3.84  .0001    -1.08573   -.35182
        |Nonrandom parameters in utility functions...........................
 FOUN_X1|      .32973***     .11423     2.89  .0039       .10584    .55363
 FOUN_X2|      .05305        .10750      .49  .6216     -.15764    .26375
   BS_X1|      .04901        .12145      .40  .6865     -.18903    .28706
   IW_X1|      .02701        .13037      .21  .8359     -.22850    .28252
   FC_X1|    -.08723         .14758     -.59  .5545     -.37647    .20202
   WF_X1|    -.08402         .12506     -.67  .5017     -.32913    .16108
   WF_X2|      .33671***     .12660     2.66  .0078       .08857    .58484
   RC_X1|    -.13998         .13360    -1.05  .2948     -.40182    .12187
   PC_X1|    -.01348         .14478     -.09  .9258     -.29725    .27029
        |Distns. of RPs. Std.Devs or limits of triangular...................
NsCONSTA|    2.78227***      .43886     6.34  .0000      1.92213   3.64242
 NsBS_X2|      .88025***     .19087     4.61  .0000       .50614   1.25435
 NsIW_X2|      .74431***     .16225     4.59  .0000       .42631   1.06231
 NsFC_X2|    1.14097***      .22415     5.09  .0000       .70165   1.58029
 NsRC_X2|      .75849***     .24774     3.06  .0022       .27293   1.24405
 NsPC_X2|    1.07134***      .18415     5.82  .0000       .71041   1.43227
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jan 03, 2024 at 00:24:19 PM
-----------------------------------------------------------------------------
```

Appendix L. Output ML Model – Significant Interaction Variables

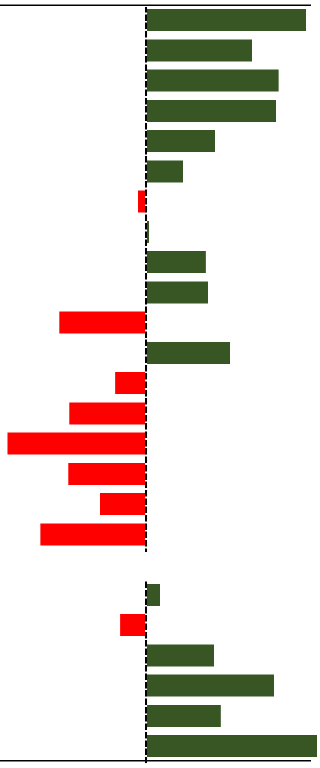
```
|-> Nlogit
    ; Lhs = CHOICE
    ; choices=0,1, 2
    ; RHS = CONSTANT, FOUN_X1, FOUN_X2, BS_X1, BS_X2, IW_X1, IW_X2, FC_X1, FC_X2,
WF_X1, WF_X2, RC_X1, RC_X2, PC_X1,
PC_X2,G1F1,G1W1,A1F2,A1P2,A2C,A2B1,A2B2,A2P2,H1C,H1F2,H1FC2,D1C,D2B2,D2W1,I1I2,I2B2
,I2I1,I2R2,E2C,E2B2,E2I2,E2R2
    ; RPL
    ; Fcn = CONSTANT (n), BS_X2 (n), IW_X2 (n), FC_X2 (n), RC_X2 (n), PC_X2 (n)
    ; halton
    ; pts=1000
    ; pds=8
    ; robust$
Iterative procedure has converged
Normal exit:   7 iterations. Status=0, F=    .6766084D+03

-----------------------------------------------------------------------------
Start values obtained using MNL model
Dependent variable                Choice
Log likelihood function       -676.60844
Estimation based on N =     872, K =  37
Inf.Cr.AIC  =   1427.2 AIC/N =     1.637
---------------------------------------
            Log likelihood R-sqrd R2Adj
Constants only   -820.6878  .1756 .1547
Note: R-sqrd = 1 - logL/Logl(constants)
Warning:  Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
---------------------------------------
Using robust VC matrix, V = <H>*GtG<<G>
Response data are given as ind. choices
Number of obs.=   872, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
CONSTANT|   -2.32178***     .35991    -6.45  .0000    -3.02720  -1.61637
   BS_X2|     .01023        .15532      .07  .9475     -.29420    .31465
   IW_X2|    -.49426***     .16130    -3.06  .0022     -.81041   -.17811
   FC_X2|    -.35706***     .13290    -2.69  .0072     -.61754   -.09659
   RC_X2|     .41676***     .15278     2.73  .0064      .11733    .71620
   PC_X2|    -.32936**      .13801    -2.39  .0170     -.59986   -.05886
 FOUN_X1|     .45228***     .13131     3.44  .0006      .19491    .70964
 FOUN_X2|     .16072        .15022     1.07  .2847     -.13370    .45514
   BS_X1|     .15264        .09495     1.61  .1079     -.03346    .33874
   IW_X1|     .21226*       .11701     1.81  .0697     -.01709    .44160
   FC_X1|    -.11497        .09759    -1.18  .2388     -.30624    .07630
   WF_X1|    -.03592        .14051     -.26  .7982     -.31131    .23947
   WF_X2|     .18406**      .08243     2.23  .0255      .02250    .34561
   RC_X1|    -.09528        .09595     -.99  .3207     -.28334    .09279
   PC_X1|    -.04591        .09270     -.50  .6204     -.22760    .13578
    G1F1|    -.45518***     .14668    -3.10  .0019     -.74267   -.16768
    G1W1|    -.32624**      .15308    -2.13  .0331     -.62627   -.02622
    A1F2|     .30866**      .12397     2.49  .0128      .06569    .55164
    A1P2|    -.36697**      .15629    -2.35  .0189     -.67329   -.06065
     A2C|     .76687***     .24782     3.09  .0020      .28115   1.25258
    A2B1|    -.34482**      .16430    -2.10  .0358     -.66685   -.02279
    A2B2|     .44868***     .17390     2.58  .0099      .10786    .78951
    A2P2|     .42822**      .17608     2.43  .0150      .08310    .77333
     H1C|    1.41030***     .37439     3.77  .0002      .67651   2.14408
    H1F2|    -.34238**      .13896    -2.46  .0137     -.61473   -.07003
   H1FC2|     .32298**      .14869     2.17  .0298      .03156    .61440
     D1C|     .64963**      .29780     2.18  .0292      .06596   1.23331
    D2B2|     .33987**      .13461     2.52  .0116      .07603    .60371
```

```
    D2W1|     .38822***      .14881     2.61  .0091      .09656    .67988
    I1I2|     .33274**       .15991     2.08  .0374      .01933    .64615
    I2B2|    -.56784***      .14265    -3.98  .0001     -.84743   -.28825
    I2I1|    -.41571***      .15300    -2.72  .0066     -.71558   -.11585
    I2R2|    -.36382***      .13359    -2.72  .0065     -.62565   -.10199
     E2C|    -.97050***      .25350    -3.83  .0001    -1.46735   -.47364
    E2B2|     .39186***      .14970     2.62  .0089      .09844    .68527
    E2I2|     .66594***      .16761     3.97  .0001      .33743    .99446
    E2R2|     .36023**       .14781     2.44  .0148      .07052    .64994
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jan 10, 2024 at 02:38:44 PM
-----------------------------------------------------------------------------

Iterative procedure has converged
Normal exit:  51 iterations. Status=0, F=    .6044308D+03

-----------------------------------------------------------------------------
Random Parameters Multinom. Logit Model
Dependent variable               CHOICE
Log likelihood function      -604.43081
Restricted log likelihood    -957.98992
Chi squared [ 43](P= .000)    707.11821
Significance level               .00000
McFadden Pseudo R-squared      .3690635
Estimation based on N =     872, K =  43
Inf.Cr.AIC  =    1294.9 AIC/N =    1.485
---------------------------------------
            Log likelihood R-sqrd R2Adj
No coefficients  -957.9899  .3691 .3531
Constants only   -820.6878  .2635 .2449
At start values  -676.6084  .1067 .0841
Note: R-sqrd = 1 - logL/Logl(constants)
Warning:  Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
---------------------------------------
Response data are given as ind. choices
Replications for simulated probs. =1000
Used Halton sequences in simulations.
RPL model with panel has     109 groups
Fixed number of obsrvs./group=        8
Robust Covariance Matrix,  VC = <H>G<H>.
Number of obs.=    872, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
  CHOICE|  Coefficient     Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
        |Random parameters in utility functions..............................
CONSTANT|   -3.71511***      .81736    -4.55  .0000    -5.31711  -2.11311
   BS_X2|    -.11360         .36096     -.31  .7530     -.82107    .59387
   IW_X2|    -.89124***      .22502    -3.96  .0001    -1.33226   -.45022
   FC_X2|    -.55205*        .30697    -1.80  .0721    -1.15369    .04960
   RC_X2|     .75303***      .23050     3.27  .0011      .30127   1.20479
   PC_X2|    -.55224         .35709    -1.55  .1220    -1.25212    .14763
        |Nonrandom parameters in utility functions...........................
 FOUN_X1|     .67120***      .17854     3.76  .0002      .32126   1.02114
 FOUN_X2|     .37251         .23873     1.56  .1187     -.09540    .84042
   BS_X1|     .25140*        .13442     1.87  .0615     -.01207    .51486
   IW_X1|     .28608         .17655     1.62  .1052     -.05995    .63212
   FC_X1|    -.02508         .15102     -.17  .8681     -.32107    .27091
   WF_X1|    -.10829         .22535     -.48  .6309     -.54997    .33339
   WF_X2|     .35849***      .12868     2.79  .0053      .10627    .61070
   RC_X1|    -.13891         .13859    -1.00  .3162     -.41054    .13273
   PC_X1|    -.02164         .14531     -.15  .8816     -.30644    .26316
    G1F1|    -.58311***      .21923    -2.66  .0078    -1.01280   -.15343
    G1W1|    -.40663*        .22268    -1.83  .0678     -.84307    .02981
    A1F2|     .42290**       .19022     2.22  .0262      .05008    .79572
```

```
    A1P2|    -.74901*        .40119     -1.87  .0619     -1.53531     .03730
     A2C|    1.26561*        .72925      1.74  .0827      -.16370    2.69491
    A2B1|    -.46638**       .23724     -1.97  .0493      -.93137    -.00139
    A2B2|     .60832*        .33288      1.83  .0676      -.04411    1.26074
    A2P2|     .59221         .38592      1.53  .1249      -.16418    1.34860
     H1C|    1.89677**       .78186      2.43  .0153       .36435    3.42918
    H1F2|    -.68652***      .22856     -3.00  .0027     -1.13449    -.23854
   H1FC2|     .49587         .34002      1.46  .1447      -.17056    1.16230
     D1C|    1.03279         .89086      1.16  .2463      -.71327    2.77884
    D2B2|     .63693***      .24242      2.63  .0086       .16179    1.11207
    D2W1|     .58144**       .23401      2.48  .0130       .12280    1.04008
    I1I2|     .67057***      .25318      2.65  .0081       .17435    1.16678
    I2B2|    -.94948***      .27371     -3.47  .0005     -1.48594    -.41302
    I2I1|    -.49598**       .22304     -2.22  .0262      -.93313    -.05884
    I2R2|    -.57842**       .23999     -2.41  .0159     -1.04880    -.10804
     E2C|   -1.61095**       .68798     -2.34  .0192     -2.95936    -.26254
    E2B2|     .86938**       .36228      2.40  .0164       .15932    1.57944
    E2I2|    1.00771***      .26324      3.83  .0001       .49177    1.52365
    E2R2|     .47666**       .23251      2.05  .0404       .02096     .93236
        |Distns. of RPs. Std.Devs or limits of triangular....................
NsCONSTA|    2.33154***      .33069      7.05  .0000      1.68340    2.97967
 NsBS_X2|     .80933***      .17992      4.50  .0000       .45669    1.16196
 NsIW_X2|     .50491**       .21925      2.30  .0213       .07519     .93463
 NsFC_X2|    1.08526***      .22287      4.87  .0000       .64843    1.52208
 NsRC_X2|     .69064***      .24983      2.76  .0057       .20099    1.18029
 NsPC_X2|    1.00275***      .19695      5.09  .0000       .61673    1.38877
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jan 10, 2024 at 03:16:47 PM
-----------------------------------------------------------------------------
```

Appendix M. Influence Socio-Demographic Characteristics on WTP

Parameter	*Util.*	*WTP*	*Δ%*	*WTP*	*Distribution WTP*
Foundation - Circular		20,7%			
Gender: Male	-0,583***		-7,0%	13,7%	
Foundation - Biobased		17,1%			
Age: 18 - 34 years old	0,423**		-0,3%	16,8%	
Household comp.: Without child(ren)[a]	-0,687***		-8,3%	8,8%	
Building Structure - Circular		4,7%			
Age: 55+ years old	-0,466**		-5,6%	-0,9%	
Building Structure - Biobased		0,3%			
Age: 55+ years old	0,608*		7,4%	7,6%	
Education level: HBO-, WO-Master	0,637***		7,7%	8,0%	
Income: > €4.000,-	-0,949***		-11,5%	-11,2%	
Environmental awareness: High	0,869**		10,5%	10,8%	
Inner Walls - Circular		-3,9%			
Income: > €4.000,-	-0,496**		-6,0%	-9,8%	
Inner Walls - Biobased		-18,1%			
Income: < €2.000,-	0,671***		8,1%	-10,0%	
Environmental awareness: High	1,008***		12,2%	-5,9%	
Façade Cladding - Biobased		-13,6%			
Household comp.: Without child(ren)[a]	0,496				
Window Frames - Circular		1,7%			
Gender: Male	-0,407*		-4,9%	-3,2%	
Education level: HBO-, WO-Master	0,581**		7,0%	8,7%	
Roof Covering - Biobased		16,5%			
Income: > €4.000,-	-0,578**		-7,0%	9,5%	
Environmental awareness: High	0,477**		5,8%	22,3%	



***, **, * → Parameter is significant at the 1%, 5%, 10% level.

[a] Household comp. – Without child(ren): Single/couple without child(ren) (living at home)

[b] Education level – Low: Primary school, vmbo, havo, vwo, mbo & others

Appendix N. Correlation Matrix Socio-Demographic Characteristics

	Gender: Male	*Gender: Female*	*Age: 18 - 34 years old*	*Age: 55+ years old*	*Household Comp.: Without child(ren)*	*Household Comp.: With child(ren)*	*Education: Low*	*Education: Master*	*Income: <€2.000,-*	*Income: >€4.000,-*	*Environmental awareness: Low*	*Environmental awareness: High*
Gender: Male		-1,00	0,01	0,05	0,03	0,06	-0,08	0,04	-0,07	-0,05	-0,05	-0,16
Gender: Female	-1,00		-0,01	-0,05	-0,03	-0,06	0,08	-0,04	0,07	0,05	0,05	0,16
Age: 18 - 34 years old	0,01	-0,01		-0,65	-0,16	-0,31	-0,23	-0,01	0,35	-0,41	-0,14	0,05
Age: 55+ years old	0,05	-0,05	-0,65		0,35	-0,13	0,07	0,05	-0,24	0,32	-0,08	0,14
H. Comp.[a]: No child(ren)	0,03	-0,03	-0,16	0,35		-0,57	0,04	0,22	-0,27	0,24	0,10	0,13
H. Comp.[a]: With child(ren)	0,06	-0,06	-0,31	-0,13	-0,57		0,04	-0,05	-0,09	0,15	-0,05	-0,23
Education: Low	-0,08	0,08	-0,23	0,07	0,04	0,04		-0,31	-0,11	-0,14	-0,05	-0,03
Education: Master	0,04	-0,04	-0,01	0,05	0,22	-0,05	-0,31		-0,28	0,26	0,15	0,06
Income: <€2.000,-	-0,07	0,07	0,35	-0,24	-0,27	-0,09	-0,11	-0,28		-0,52	-0,07	-0,01
Income: >€4.000,-	-0,05	0,05	-0,41	0,32	0,24	0,15	-0,14	0,26	-0,52		0,14	0,00
En. Aw.[b]: Low	-0,05	0,05	-0,14	-0,08	0,10	-0,05	-0,05	0,15	-0,07	0,14		-0,25
En. Aw.[b]: High	-0,16	0,16	0,05	0,14	0,13	-0,23	-0,03	0,06	-0,01	0,00	-0,25	

[a] Household Composition
[b] Environmental awareness

EINDHOVEN
UNIVERSITY OF
TECHNOLOGY