SLUTRAPPORT

BRIC: Building Right

Innovativa arbetssätt för en cirkulär byggindustri

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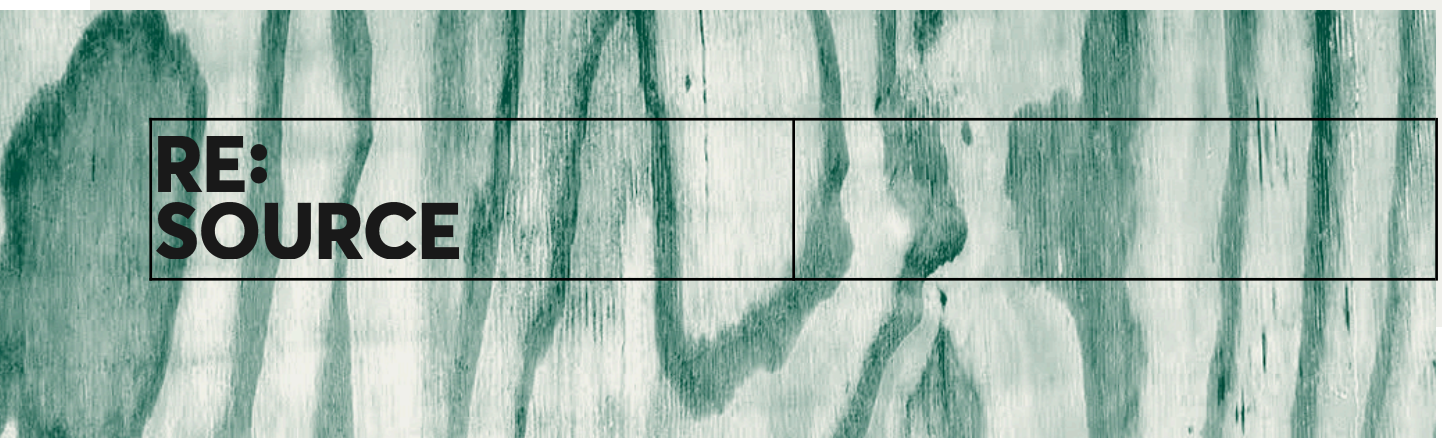

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Förord

Detta projekt genomfördes från september 2023 till januari 2024. Finansiering erhölls från RE:Source. Deltagande parter har även bidragit med egen tid och resurser i projektet.

I projektet har följande deltagare medverkat från olika parter (i namnordning). Utöver nedanstående har studenter från ett antal olika utbildningar vid de deltagande universiteten medverkat. Dessa är listade i projektrapporterna under Bilagor, kap 11.

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Innehåll

1. Sammanfattning

Byggprocessen är komplex och hanterar många olika intressenter. Dessa intressenter har ofta olika målbilder och avsikter med sitt arbete, vilket blir ett hinder för att införa mer hållbara materialflöden och byggprocesser för att klara omställningen till en mer resurseffektiv och cirkulär byggsektor. Nya lösningar och innovativa arbetssätt har svårt att få genomslag i byggbranschen, vilket också bidrar till att göra byggandet mer kostsamt, ohållbart och resurseffektivt.

I forskningsprojektet BRIC har vi adresserat detta, genom att utvärdera nya metoder för att nå ett mer hållbart byggande.

Ett antal workshops har genomförts med deltagarna i projektet för att kartlägga de hinder och möjligheter som finns för att åstadkomma ett mer hållbart och cirkulärt byggande. Resultatet från dessa workshops har formulerats till ett antal utmaningar. Dessa utmaningar har därefter omformulerats till ett antal utgångspunkter för utforskande, i form av projektbeskrivningar som distribuerats till olika studentgrupper på de olika lärosätena. De olika studentgrupperna har problematiserat utmaningarna och prövat olika möjliga metoder och lösningar samt identifierat olika typer av hinder som finns för att implementera nya idéer och lösningar för ett hållbart byggande. Ett antal olika metoder inom design och innovation har prövats och utvärderats. Studenterna har sedan redovisat sina resultat för projektdeltagarna i workshops.

Resultaten har använts för att förtydliga och förstå olika utmaningar, förutsättningar och behov samt identifiera möjligheter och utmaningar för att ställa om byggsektorn så den blir mer ekologiskt och ekonomiskt hållbar genom hela värdekedjan, från policy, design, produktion och byggskede, till användning, demontering och återbruk.

Projektet har genomförts i direkt samverkan genom workshops och samverkan i en participativ och inkluderande process. Resultatet är en plan för hur identifierade möjligheter kan implementeras i ett framtida projekt med deltagande parter.

En sammanfattande sk “pitch” togs fram i syfte att sammanfatta studien, dess resultat samt kommande utmaningar och idéer om möjliga vägar framåt för att utmana till ett mer hållbart byggande. Pichen distribuerades till olika projektpartners, nuvarande samt tilltänkta. Uppföljande möten och diskussioner med dessa genomfördes.

En ansökan för ett fortsättningsprojekt har formulerats och skickats in i syfte att utveckla, pröva och implementera nya innovativa, resurseffektiva och hållbara material, materialflöden, samt att pröva och införa nya metoder och byggprocesser för att åstadkomma ett mer hållbart byggande, tillsammans med de olika projektdeltagarna i participativ process. Målet är att skapa någon form av demonstrator för att pröva och diskutera möjliga nya innovativa och hållbara material, samt att testa olika processer och möjligheter att kommunicera idéer, slutsatser och resultat.

2. Summary

The construction process is complex and deals with many different stakeholders. It builds up obstacles in the form of different target images and intentions for the various stakeholders, which becomes an obstacle to introducing more sustainable material flows and construction processes in order to cope with the transition to a more resource-efficient and circular construction sector. New solutions and innovative working methods have difficulty gaining traction in the construction industry. This contributes to making construction more costly, unsustainable and resource-efficient.

A number of workshops have been carried out with the participants in the project to map the obstacles and opportunities that exist to achieve a more sustainable and circular construction. The results of these workshops have been formulated into a number of challenges. These challenges have subsequently been reformulated into a number of project challenges in the form of project descriptions that have been distributed to different student groups at the various universities. The different student groups have problematized the challenges and tested different possible methods and solutions as well as identified different types of obstacles that exist to implement new ideas and solutions for sustainable construction. A number of methods in design and innovation have been tested. The students have presented their results to the project participants in workshops.

The results have been used to clarify and understand various challenges, conditions and needs as well as identify opportunities and challenges to change the construction sector so that it becomes more ecologically and economically sustainable through the entire value chain, from policy, design, production and construction stage, to use, dismantling and recycling.

The project has been carried out in direct collaboration through workshops and collaboration in a participatory and inclusive process. The result is a plan for how identified opportunities can be implemented in a future project with participating parties.

A summary, a pitch was drawn up with the aim of summarizing the study, its results as well as upcoming challenges and ideas about possible ways forward to challenge more sustainable construction. The pitch was distributed to various project partners, current and intended. Follow-up meetings and discussions with these were carried out.

A new application has been formulated and submitted with the aim of developing, testing and implementing new innovative, resource-efficient and sustainable materials, material flows, as well as testing and introducing new methods and construction processes to achieve a more sustainable construction. The goal is to create some form of demonstrator to test and discuss possible new innovative and sustainable materials, as well as to test different processes and opportunities to communicate ideas, conclusions and results.

3. Inledning och bakgrund

Byggsektorn står inför två stora utmaningar: resurseffektivitet och hållbarhet. Denna genomförbarhetsstudie, som har gjorts tillsammans med centrala aktörer i byggbranschen och akademin, har undersökt och identifierat innovativa sätt att adressera dessa två utmaningar.

Resurseffektivitet i byggsektorn

Byggindustrin lider av stora effektivitetsbrister. Enligt (McKinsey 2015) överskrider 98% av sk megaprojekt både tidplan och budget, genomsnittlig kostnadsökning är 80%, och projekten avslutas i genomsnitt 20 månader efter ursprunglig tidplan. Även om skalan i detta projekt är långt mycket mindre, är mekanismerna och symtomen likartade. En anledning är att produktionseffektiviteten i byggbranschen har stått still och i perioder minskat sedan början på 1990-talet, medan produktiviteten i industrisektorn, där kontinuerlig förbättring har varit norm, nästan har fördubblats (IHS Global Insight 2012 i McKinsey 2015). Faktorer som bidrar till denna situation inkluderar dålig organisation, otillräcklig kommunikation, dålig resultatstyrning, kontraktsrelaterade missförstånd, bristande sekvensplanering, dålig korttidsplanering, otillräcklig riskhantering, bristande kompetensanvändning. Dessa faktorer är systemiska, allvarliga och vanliga (McKinsey 2015).

Bilden bekräftas av andra källor. Enligt CMB (2019) karaktäriseras byggsektorn av en hög grad av fragmentering och en låg förmåga till förändring. De lyfter fram möjligheter inklusive nya affärsmodeller, ökad effektivitet, förbättrad användning av befintlig och framtida teknik, förbättrade processer och materialflöden, inkludering av nya aktörer och starkare kund- och användarengagemang. NRCC (2001) identifierade drivkrafter för förändring, inklusive kundkrav på förbättrad

kvalitet och värde, digitalisering, miljö- och hållbarhetskrav och nya affärsmodeller.

Dessutom försvåras byggprocessen av rådande byggpraxis, som hanterar varje byggarbetsplats som ett unikt fall, vilket gör varje byggnad till en "prototyp" anpassad till varje kunds speciella krav, där vanligtvis ett stort antal små entreprenörer som gör sin egen del av byggarbetet (Widen 2004). Fossilfritt Sverige (2018) stärker bilden av en fragmenterad byggsektor med många olika aktörer i långa och komplicerade värdekedjor, vilket gör det svårt för en enskild aktör att ha en övergripande strategi för forskning och utveckling. Det blir alltså svårt att både introducera och skala upp innovationer.

För att klara den omställning som krävs behöver sektorn och enskilda aktörer se över sina processer och arbetssätt för hur förändringarna ska drivas fram och implementeras. Sektorn kännetecknas av en projektstruktur vilket försvårar erfarenhetsutbyte och långsiktighet. Även om utmaningarna är många, finns det också potentiella industriella strukturer som är lovande för att införa innovativa förändringar, såsom traditionen att bygga prototyper och pilotprojekt, och erfarenhet av interorganisatoriskt samarbete (CMB 2019). Det föreslagna projektet beaktar de komplexa och inbördes relaterade frågorna som kännetecknar utmaningarna för innovation och resurseffektivitet inom byggsektorn.

Hållbarhet i byggsektorn

Byggsektorn står inför stora hållbarhetsutmaningarna både vad gäller energieffektivitet och miljöaspekter. Cirka 50 procent av jordens naturresurser och cirka 40 procent av den förädlade energin används i byggnader och byggande, och byggsektorn producerar globalt cirka 35 procent av alla växthusgasutsläpp och 30 procent av allt avfall (Finlands Miljöministerium, n.d.).

Enligt Boverket (2022) står bygg- och fastighetssektorn för 35 procent av allt avfall inom EU och orsakar mer än 20 procent av Sveriges koldioxidutsläpp. Byggsektorn behöver ställa om till mer giftfria och resurseffektiva kretslopp och därmed bidra till att minska klimatgasutsläppen och uttaget av naturresurser (ibid).

För att uppnå netto-nollutsläpp i byggindustrin är det avgörande att implementera energi- och resurseffektiva byggmetoder i stor skala. Trots att hållbara byggmetoder är tillgängliga stod den svenska byggsektorn 2020 för 34 % av den

svenska energianvändningen, varav 73 % användes för uppvärmning (Boverket, 2023). Enligt Energimyndigheten (2022) är bostads- och tjänstesektorn den största energikonsumenten i Sverige med 140 TWh år 2020, vilket är mer än industrisektorn med 136 TWh.

Fossilfritt Sverige betonar behovet att premiera cirkulära materialflöden med netto-noll avfallsproduktion liksom standardiserat och modulärt byggande som möjliggör fler funktioner över tid. ”Detta förutsätter design för återanvändning så att materialen kan bidra till funktionalitet i flera tekniska livscykler innan de återgår till naturens kretslopp utan miljöbelastning, till exempel med biobaserade och icke-jungfruliga material och hybridlösningar, eller med produkter från en transformerad basindustri” (Fossilfritt Sverige 2018).

Det finns ett stort behov av att kartlägga och förstå de förutsättningar som gäller för byggbranschen när det gäller omställningen. Detta projekt har syftat till att skapa denna förståelse.

För att nå målet krävs ett fokus på innovation genom byggprocessens alla delar: projektering, design, produktion, byggande, användning och återbruk. Sektorn kännetecknas av en projektstruktur vilket försvårar erfarenhetsutbyte och långsiktighet (Fossilfritt Sverige 2018). Byggsektorns aktörer behöver därför se över sina processer och arbetssätt för hur förändringarna ska drivas fram och implementeras. Omställningsbehoven gäller samtliga aspekter, inklusive attityder, utbildning, arbetssätt, samverkansformer, material, energi, produktion, datahantering och datalagring, affärsmodell, tillståndsprocesser, regelverk och policy.

Enligt Naturvårdsverket är åtgärder inom uppvärmning och materialproduktion särskilt viktiga för att sektorn ska nå netto-noll utsläpp på sikt. Med utgångspunkt från Naturvårdsverket (2023) finns tänkbara åtgärder inom material, transport, energi och uppvärmning, avfall och byggbehov. Finansdepartementet (2022) nämner åtgärder som att designa komponenter och system hållbarhetsmässigt rätt från början samt att ”analysera hur rivning av befintliga byggnadsverk kan undvikas och hur de kan återbrukas i sin helhet samt att analysera vad detta innebär för valet av olika byggmaterial, exempelvis plast”.

McKinsey (2015) identifierar möjligheter för innovation och effektivisering av arbetssätt i tre projektfaser; *koncept och design*, *kontrakt och inköp*, samt *genomförande*. Till dessa kommer i en cirkulär byggindustri projektfasen *demontering och återbruk* av material och resurser.

Störst skillnad kan göras redan i design- och konceptfasen. Viktiga principer som kan tillämpas för att uppnå detta är Design-to-Value (dvs bygga minimal teknisk lösning, MTS, som uppfyller kraven för att reducera investeringskostnader), tillämpa livscykelperspektiv, använda scenarioplanering, utveckla för faktiska förhållanden, tillämpa modulär design och standardisering, arbeta i tvärdisciplinära team, samt optimera designprocessen. Från industriella produktutvecklingsprocesser vet vi att 80% av kostnaderna bestäms i designfasen. Det är troligt att detta även gäller byggindustrin.

Även i utförandefasen finns stora effektiviseringsmöjligheter såsom användning av standardiserade element och ny teknik som 3D-printing, feedbackprocesser och lean-principer. Teknologiutveckling är ett verktyg för att åstadkomma vissa av dessa delar, men den största potentialen finns i förändrade arbetssätt från design till implementering (McKinsey 2015).

På europeisk nivå pågår ett antal initiativ kopplade till detta projekt där akademiska parter samarbetar, såsom avancerade hållbara material (AMI2030), New European Bauhaus som kopplar samman European Green Deal med upplevda värden i byggnader, Smart Cities och Horizon 2030. En stor utmaning för dessa initiativ är implementering av nya smarta metoder, transparenta databaser och förändrade beteenden i befintliga system.

Brist på innovation i byggsektorn

BRIC-projektet har adresserat behovet av en hållbar och cirkulär byggsektor genom samverkande, designdrivna innovationsmetoder. Jämfört med andra industrisektorer har byggsektorn inte förändrats nämnvärt pga delad byggprocess, stort antal aktörer och den rådande projektorienterade synen (Widen 2004).

Många lovande och innovativa lösningar finns på material- och systemnivå, men har svårt att slå igenom. Uppskalning av hållbara initiativ behöver stödjas genom samarbete med samtliga aktörer för att åstadkomma en förändrad syn på innovationer i byggsektorn, introducera användarcentrerade arbetssätt, stimulera nya samarbetsformer, bygga nätverk akademi-industri, identifiera hinder i regelverk och policy, stärka cirkulära principer och livscykeltänk i flödet produktion-byggande-användning-demontering-återbruk.

Det övergripande målet med projektet har därför varit att stödja branschen att ställa om till resurseffektiv och hållbar byggsektor genom att introducera

designbaserade innovationsmetoder som stärker förmågan till branschförändring i syfte att skapa förutsättningar för förändring av byggbranschen. Detta systemiska problem löses dock inte med ett begränsat projekt som detta. I förlängningen behöver lösningar och arbetssätt tas fram genom nya projekt genom aktörssamverkan. Nya innovationsmetoder gällande arbetssätt, metodik, digitala tjänster och systemlösningar behöver introduceras för att åstadkomma ett byggande som är ekologiskt, ekonomiskt och socialt hållbart, samt är klimatneutralt, resurseffektivt, energieffektivt och cirkulärt.

Projektets mål har varit att:

- Kartlägga de förutsättningar och hinder som finns för att förstå utmaningar och möjligheter att radikalt förändra byggbranschens möjligheter att ställa om till hållbart och användarcentrerat byggande.
- Identifiera de aktörer som behöver inkluderas, från kunder och användare till reglerande och tillståndsgivande myndigheter.
- Inom ramen för projektet uppnå förståelse för behovet av förnyelse av kunskaper, metoder, tekniska lösningar och affärsmodeller som bidrar till beteendeförändring och designtänkande i byggbranschen. I detta ingår att identifiera potentiellt användbara arbetssätt och metoder som kan öka innovationsgraden i byggbranschen.

Genom dessa mål har även förutsättningarna för ett fortsatt projekt, med mål att demonstrera hur branschen genom innovations- och designmetoder kan ställa om till mer hållbara och resurseffektiva arbets- och byggsätt, utformats och föreslagits.

Grundläggande hypoteser i arbetet har varit:

1. Det finns potential att effektivisera byggsektorns processer för att åstadkomma mer resurseffektivt byggande genom metoder och arbetssätt från design och innovationsområdet
2. Det finns behov av processer, mekanismer och regelverk som stödjer innovation och underlättar introduktionen av mer hållbara lösningar i byggsektorn
3. Det finns behov av mer samverkan för att sprida kunskap och demonstrera innovativa, resurseffektiva och cirkulära lösningar i byggsektorn för att realisera omställningen mot hållbart byggande

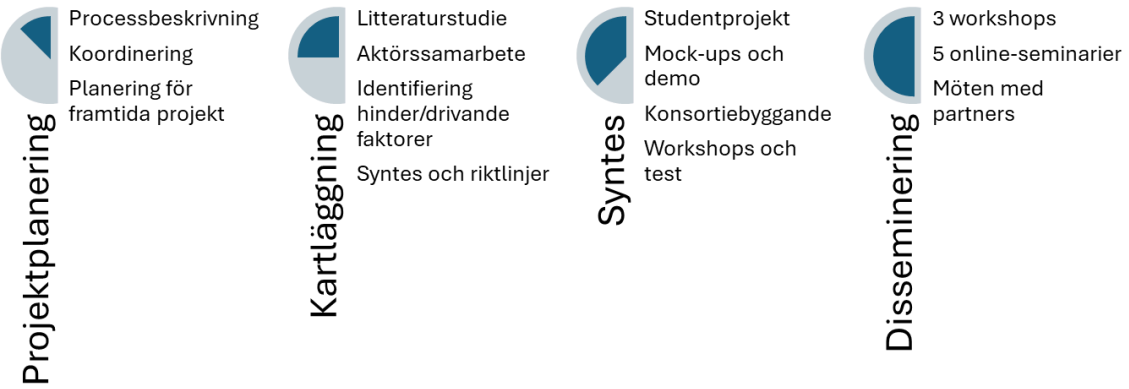
Genom samverkan med deltagande aktörer och parter har projektet utvecklat kunskap om arbetssätt, metoder och lösningar som bidrar till omställningen mot en cirkulär och hållbar byggsektor. Resultaten och slutsatserna från projektet presenteras i denna rapport.

4. Genomförande

I detta kapitel beskrivs den övergripande projektstrukturen och de aktiviteter som genomförts i varje del av projektet. Övergripande kan sägas att BRIC har genomförts med hjälp av projektplanering baserad på etablerad designteori och -metodik, litteraturstudier, workshops, fallstudier och designcentrerad problemanalys.

4.1 Projektstruktur

Projektets aktiviteter genomfördes utgående från de arbetspaket som identifierats i planeringsfasen. Projektet genomfördes i ett antal faser bestående av projektplanering, kartläggning, syntes och disseminering. Figur 1 beskriver projektets logikstruktur.



Figur 1. Logikstruktur för projektets genomförande.

Projektplanering

I planeringsfasen utvecklades en utförlig struktur för projektet och de olika aktiviteterna. Parternas olika roller och ansvar definierades. En arbetsprocess baserad på metoder och arbetssätt från design och innovationsområdet togs fram, bestående av följande huvudmetoder (beskrivs i kapitel 4.2 Metoder):

- Double Diamond Design Process
- Project Journey Mapping
- DEFT: Drivers, Enablers, Friction, Turners
- DVF: Desirability, Viability, Feasibility

Dessa metoder för att etablera en förståelse av behov, upplevda problem, var i byggprocessen dessa finns, vilka faktorer som driver respektiver hindrar förändring, samt hur resultaten ska kunna utvärderas med avseende på genomförbarhet och hållbarhet.

I denna fas planerades även möten och aktiviteter, koordinering av deltagande projektparters bidrag, uppföljning av projektplanen samt hur dessa aktiviteter bidrar till projektets måluppfyllelse. Vidare identifierades förutsättningar för efterföljande projekt med målet att bygga en demonstrator som visar hur identifierade mål kan uppnås, samt en plan för sammanställning av resultat och slutsatser samt rapportering.

Kartläggning

I upptäcktsfasen (Explore), som följer Double Diamond-processen (se 4.2), gjordes en kartläggning och en övergripande förståelse etablerades för de deltagande branschaktörernas upplevelse av byggsektorns status avseende hållbart byggande och processer som stödjer detta mål. Utifrån en inledande litteraturstudie problematiserades nuvarande situation i samverkan med deltagande aktörer och nyckelfaktorer som är centrala vid en omställning till hållbarhet och cirkularitet inom byggsektorn identifierades.

Projektparterna sammanställde problematik och utmaningar de har upplevt i sin verksamhet, identifierade drivkrafter och incitament ur sina respektive perspektiv, och identifierade mål och syften de önskade uppnå. Målsättningen var att utifrån ett holistiskt systemperspektiv och användardrivet synsätt identifiera och utvärdera påverkande faktorer i hela utvecklings- och beslutsprocessen inom byggsektorn hos de deltagande parterna.

Syntes

I syntessteget genomfördes tre workshops där de industriella parterna identifierade utmaningar som sedan problematiserades. I workshop ett fokuserade gruppen på att identifiera och klassificera utmaningar, i workshop två och tre låg fokus på att utveckla kluster av utmaningar och förstå etablerade processtrukturer.

Workshoparna genomfördes genom en kombination av SWOT-analys för att förstå byggsektorns grundläggande förutsättningar och kraftfälts-/DEFT-analys med målsättningen att identifiera drivande respektive hindrande krafter för att nå ett hållbart och cirkulärt byggande genom att förstå processer, relationer, samverkan och beslutsfattande inom byggprojekt. Från kartläggningen identifierades

förutsättningar och utmaningar, aktörsspecifika såväl som branschgenerella, för att reducera/eliminera hinder för att implementera mer hållbarhet inom byggbranschen.

I syntesarbetet skapades riktlinjer för hur hållbarhet och cirkularitet på ett bättre sätt kan integreras i byggprocessen och hur förändringsarbete inom branschen bör utformas. Ett antal fallstudier genomfördes i form av studentprojekt som undersökte möjliga lösningar utifrån de utmaningar som hade identifierats i det föregående arbetet. Dessa fallstudier finns i bilagor i kapitel 11.

Disseminering

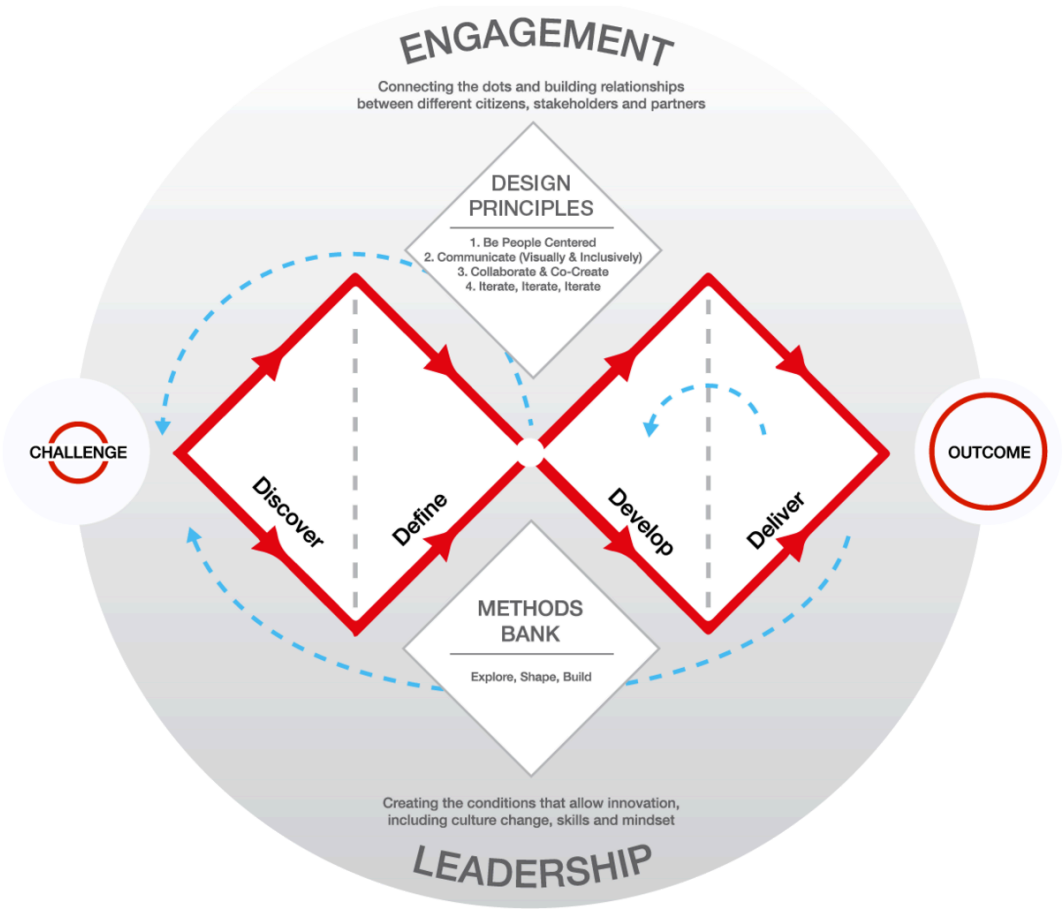
I ett antal presentationer redovisades resultaten av fallstudierna för projektgruppen. Arbetet med att sprida resultat och insikter gjordes kontinuerligt i projektet genom de workshops som gjordes inom ramen för projektet, genom arbetet med fallstudierna där studentgrupper samverkade med projektparterna, samt genom samverkan med nätverk inom och mellan lärosätena.

Genom projektet skedde en kunskapsöverföring kring behov, utmaningar och möjligheter kring cirkularitet- och hållbarhetsaspekter inom byggbranschen till design- och ingenjörsstudenter vid olika utbildningsprogram på LU, JU och LiU. I projekten implementerades metoder från design- och produktutvecklingsområdet i utmaningar från byggsektorn och lösningar togs fram som adresserade utmaningar relaterade till processtyrning, komponent- och systemdesign, samt cirkulära processer.

4.2 Metoder

Double Diamond Design Process

Double Diamond Design Process (Design Council, 2024) introducerades av British Design Council 2004. Det är ett ramverk för innovation som bygger på process, designprinciper, metoder och kulturell förändring. I detta projekt har vi arbetat med Double Diamond som process och metod (se Figur 2).



Figur 2. Double Diamond Design Process (Design Council, 2024). Licensierad under CC BY 4.0 license.

Double Diamond-modellen användes för att strukturera arbetet och visualisera resultaten. Den består av två huvudfaser, var och en representerad av en diamantform: Förståelse (Discover och Define) och Utforska (Develop och Deliver). Varje fas består av en divergent och en konvergent del. Genom denna dynamik kan breddad förståelse och utforskande effektivt kombineras med analys och beslutsfattande utan att dessa aktiviteter kommer i konflikt med varandra.

I den första diamanten fokuserar man på att förstå problemet och användarnas behov (Design Council, 2024). Detta innebär utforskande arbete, insamling av information och att beskriva utmaningarna. Efter att ha förstått och definierat problemet går man in i den andra diamanten. Här handlar det om att utforska möjliga lösningar och hur dessa kan implementeras. Double Diamond-modellen

både breddar och fördjupar förståelsen av problemet innan man går vidare till lösningar. Genom att följa denna process kan man skapa mer användarcentrerade och effektiva designlösningar (jmfr. Cross, 2008).

Processen består av följande huvudsteg:

- **Upptäcka (Explore)**. Den första diamanten hjälper aktörerna att förstå, snarare än att bara anta, vad problemet är. Detta baseras på samverkan och dialog för att förstå vilka faktorer som finns och hur de påverkar vilka aktörer.
- **Definiera (Define)**. Insikterna från upptäcktsfasen används för att definiera utmaningen på ett nytt sätt, som ett tydligt definierat problem.
- **Utveckla (Develop)**. Den andra diamanten uppmuntrar aktörer att ge olika svar på det tydligt definierade problemet, söka inspiration från andra håll och utforma lösningar i samverkan.
- **Leverera (Deliver)**. Leverans innebär att man testar olika lösningar i liten skala, förkastar dem som inte kommer att fungera och förbättrar dem som kommer att fungera.

Kopplat till implementeringen av ett designorienterat synsätt är ett antal grundläggande principer som måste finnas på plats för att ge önskat resultat. Följande huvudprinciper har använts för att skapa fokus på behov och lösningar genom samverkan med deltagande parter:

- **Sätt människan först**. Börja med en förståelse för de människor som använder en tjänst, deras behov, styrkor och ambitioner.
- **Kommunicera visuellt och inkluderande**. Hjälp människor att få en gemensam förståelse för problemet och idéerna.
- **Samarbeta och samskapa**. Arbeta tillsammans, utforska och problematisera gemensamt, inspireras av vad andra gör.
- **Iterera, iterera, iterera**. Arbeta cykliskt för att gradvis öka förståelsen av problemet, upptäcka fel tidigt, undvika risker och bygga upp förtroende för de idéer som skapas.

I detta projekt har vi följt den första diamanten (Discover och Define), dvs fokus har varit att förstå och definiera problemet. Planen är att fortsätta arbetet med att skapa, implementera och testa lösningar i ett framtida projekt som bygger på resultaten i detta projekt.

Project Journey Mapping

I projektet utvecklades en metod för att kartlägga byggprocessen ur respektive aktörs perspektiv. Metoden baserades på User Journey Mapping (se t ex NN Group, 2018). I metoden ses byggprocessen som en resa med ett antal steg. I varje steg dokumenteras aktiviteter, svårigheter (pains) och möjligheter (gains). Även positiv och negativ respons ur respektive aktörs synvinkel (emotionell reaktion) noteras för att mappas vilka delar av processen som upplevs som mest energikrävande, frustrerande eller givande.

User-journeytekniken är en mycket effektiv metod för att snabbt skapa en förståelse av komplexa och systemorienterade sammanhang som annars kan vara svåra att överblicka. Genom att det är en visuellt baserad metod blir användningen intuitiv och relationer mellan olika steg och aktiviteter kan lätt identifieras. I projektet genomfördes en projektresa för varje deltagande part och utmaningar och aktiviteter identifierades i varje steg som innehöll möjligheter till bättre resursutnyttjande.

DEFT Model

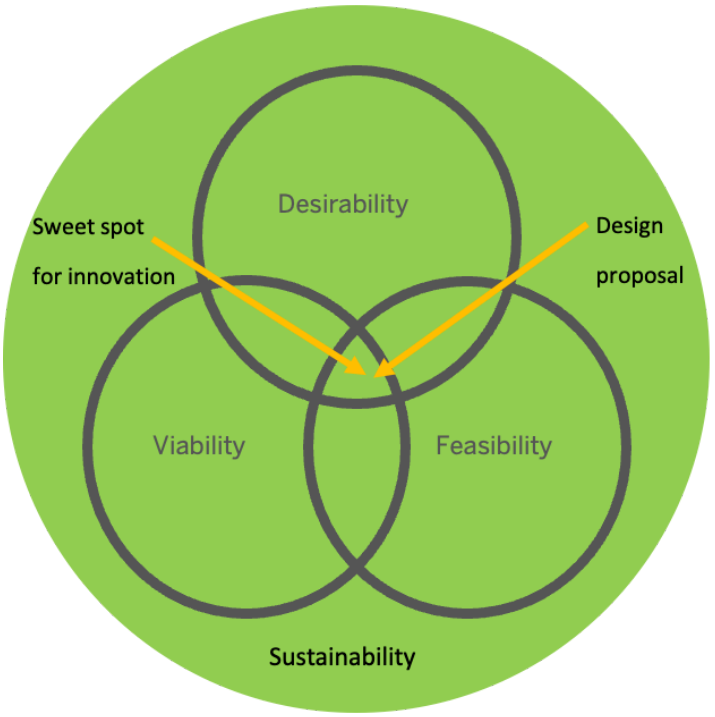
DEFT är trendstudiernas motsvarighet till SWOT-analyser för strategisk planering. Metoden erbjuder ett ramverk för att organisera och analysera faktorer som stödjer eller förhindrar ett initiativ att nå sitt mål. Enligt Gordon (2010) är faktorerna följande:

- Drivkrafter: krafter som skapar och upprätthåller en trend
- Möjliggörare: katalysatorer som stöder drivkrafterna
- Friktion: motstånd som hindrar en trend
- Turners: händelser som aktivt blockerar en trend

I projektet användes DEFT som ett verktyg för att analysera data och etablera faktorer som påverkar upplevda problem i processer, regelverk och kunskap.

Desirability, Viability and Feasibility (DVF)

DVF-modellen beskriver hur de olika delarna, det önskade behovet (desirability), det möjliga att tillverka (feasibility) och hållbara affärsmodeller (viability) kan vägas samman med ett hållbart angreppssätt för att åstadkomma en produkt som vi vill ha, som är möjlig att tillverka, är affärsmässig och hållbar utifrån relevanta hållbarhetsmål.



Figur 3. De tre kriterierna för innovation sammanfattade i DVF-modellen (baserad på IDEO, n.d.). I detta projekt användes modellen för att förstå faktorer som påverkar möjligheten att skapa en hållbar och resurseffektiv byggsektor.

Enligt DVF-modellen skapas framgångsrika innovationer i skärningspunkten mellan det som är önskvärt, genomförbart och affärsmässigt. De lösningar som skapas måste alltså uppfylla samtliga dessa kriterier.

4.3 Workshops

Totalt genomfördes tre olika arbetsworkshops; en med personliga möten, en hybrid och en till fullo online.

Workshop 1: Problemidentifiering

Workshop 1 ägde rum vid Linköpings universitet i början av projektet, och samlade representanter från alla tre lärosäten samt fyra företag som ingick i konsortiet. Deltagarna representerade olika branscher och var involverade i projektets planering, genomförande och användning av bostäder. Målet med mötet var att skapa ett funktionellt samarbete och gemensamt förstå hur dagens byggnadsprocess är strukturerad. Dessutom diskuterades och identifierades de

vanligaste hindren och incitamenten inom byggnadsprocessen. Denna workshop genomfördes med samtliga deltagare på plats.

Inför denna workshop hade deltagarna från industrin fått i uppdrag att förbereda sig genom att sammanställa erfarenheter och önskemål inom tre kategorier:

- Problematik och utmaningar ni har upplevt i er verksamhet
- Drivkrafter och incitament ni ser från ert perspektiv
- Syften och mål ni vill uppnå

Dessa punkter utgjorde utgångspunkten för att identifiera problem med nuvarande byggprocess. Under workshopen presenterade och diskuterade deltagarna sina erfarenheter, varpå materialet kategoriserades och kodades i digitala affinitetsdiagram.

Workshop 2: Planeringsperspektivet

Baserat på resultat från Workshop 1 skapades en karta med tematiska områden som beskrev utmaningar och problemområden. Genom gemensam dialog i workshopen diskuterades, problematiserades och kompletterades dessa temaområden vilket gav en bred förståelse av utmaningar och möjligheter.

Inför denna workshop förbereddes ett underlag för en halvstrukturerad, explorerande intervju i form av en Project Journey Map (projektresa). Fokus var att i en participativ process identifiera var i processen utmaningar och möjligheter finns ur respektive aktörs perspektiv. Denna metod bidrog till att hitta lösningar för att överbrygga de vanligaste hindren och utveckla idéer för incitament för beteendeförändring inom byggbranschen. Företagsrepresentanterna intervjuades separat och efterföljdes av en analyserande diskussion i grupp.

Denna workshop genomfördes i hybridform vid Jönköping University. Medverkande var representanter från alla deltagande högskolor samt två företagsrepresentanter som representerade planeringsaktörer inom byggsektorn.

Workshop 3: Producentperspektivet

En tredje workshop genomfördes digitalt online för att ge möjlighet för samtliga aktörer att bidra till utvecklingen av de identifierade tematiska områdena från Workshop 1 samt i arbetet med att kartlägga utmaningar genom Project Journey Mapping. I workshopen användes samma intervjuunderlag som i Workshop 2. Denna gång deltog representanter för två material- och komponenttillverkande företag med innovativa byggkoncept för byggsektorn som dessutom har erfarenhet av byggentreprenad. I workshopen vidareutvecklades den tematisering som etablerades i Workshop 2.

4.4 Fallstudier

Parallellt med ovan nämnda workshops genomfördes ett antal fallstudier i form av studentprojekt vid de tre deltagande universiteten. Fallstudierna tog upp relevanta frågeställningar som identifierats inom projektet. Studenterna instruerades och handleddes av medverkande forskare i projektet. Resultaten tjänade som grund för vidare forskning och användes bland annat som input till arbetet i Workshop 2 och 3. Nedan beskrivs dessa fallstudier i större detalj (notera att resultaten inte presenteras här utan i kapitel 5).

Fallstudie 1: Utveckling av koncept för infrastrukturoberoende hus

Utförande och handledning: Jönköping University, Lars Eriksson

Mål: Projektet syftade till att med hjälp av ett "boundary object” visa hur ett “Off-Grid-hus” i form av ett Attefallshus för åretruntboende kan tjäna som demonstrator för hur nya hållbara material och ny hållbar teknik skulle kunna implementeras. Många nya tekniska lösningar för vattenförsörjning och avloppshantering liksom uppvärmning och elförsörjning, prövades och utvärderades med hänsyn till cirkularitet och hållbarhet.

Produktutvecklingsmetoder som Double Diamond och Design Thinking användes och utvärderades. Slutresultatet presenterades i form av en postersession för hela JU, samt en redovisning inför grupp.

Utförare: 4 studenter i årskurs 5 som studerar civilingenjörsprogrammet Produktrealisering. Kursen, avancerad projektkurs, samläses av flera masterprogram på Jönköping University.

Tillvägagångssätt: Först identifierades användarbehov för ett hus av karaktären. Därefter togs ett antal förslag på lösningar fram som testades och utvärderades utifrån hållbarhetsmål. Ett antal hinder för att implementera lösningen identifierades. Studenterna hade tillgång till nätverket och kunde tillsammans med forskarna intervjua representanter från arkitekter till byggare. Studenterna samverkade med studenter från Linköpings universitet för att utvärdera idéer och dela kunskap.

Resultat: Ett förslag på Attefallshus för åretruntboende, Off-Grid, med nya tekniska lösningar. En kartläggning av typiska hinder och svårigheter för att implementera nya hållbara tekniska lösningar. En metod, Boundary Object,

prövades för att hantera komplexitet och kommunikationssätt. För mer detaljerad information, se Bilaga 1.

Fallstudie 2: Integrering av standardiserade industriella PU metoder inom byggsektorn

Utförande och handledning: Linköpings universitet, Simon Schütte

Mål: Byggindustrin använder sig av gamla beprövade sätt att ta fram produkter. Dessa genererar ofta unika resultat och har därför mer gemensamt med en prototyp än en massproducerad produkt. Eftersom massproduktion ger effektivitet, låga priser och god kvalitet syftade dessa studentprojekt till att använda standardiserade PU-processverktyg för att demonstrera hur byggnader kan konstrueras enligt alternativa principer.

Utförare: Totalt 12 studenter i 3 grupper av 4 studenter. Studenterna var produktutvecklingsstudenter i årskurs 1 och hade precis lärt sig produktframtagningsmetodiken.

Tillvägagångssätt: Stage-Gate-Modellen användes direkt och utan modifikationer på modulära byggnader såsom studentboende, flyktingförläggningar eller tillfälliga arbetskraftsboenden.
Resultat: Tre rapporter med tre olika konceptuella lösningar för byggnaderna samt en rimlighetsbedömning. För mer detaljerad information, se Bilaga 2.

Fallstudie 3: Utveckling av hjälpmedel för lärande inom akademin och byggindustrin

Utförande och handledning: Linköpings universitet, Simon Schütte & Micael Derelöv

Mål: Projektet syftade till att visa hur produktutvecklingsmetoder som används inom allmän produktutformning kan hjälpa byggbranschen att standardisera och modulera byggblock för att förenkla produktionen, minska kostnaderna och därigenom minimera miljöpåverkan. Genom att tillämpa dessa metoder kan man skapa en strukturerad process för att ta en produkt från den inledande konceptfasen till den slutliga marknadsintroduktionen.

Utförare: Studenter i årskurs 4 inom programmet Design och Produktutveckling

Tillvägagångssätt: Först identifierades stakeholders inom byggbranschen liksom deras krav. Studenterna hade tillgång till nätverket och kunde tillsammans med forskarna intervjua representanter från arkitekter till byggare och forskare.

Resultat: En kartläggning av typiska hinder och svårigheter såsom vägar att hantera dessa och sedan utveckla moderna dissemineringsmetoder och kommunikationssätt (t.ex. ett brädspel). För mer detaljerad information, se Bilaga 3.

Fallstudie 4: Cirkulära processer för återbruk av överblivet byggmaterial

Utförande och handledning: Lunds universitet, Anders Warell

Mål: Byggindustrin genererar stora mängder överblivet material som inte används i byggprojekt utan ofta slängs direkt, eftersom det är den enklaste lösningen. I projektet designades en lösning för att tillvarata dessa materialmängder genom att koppla ihop aktörer som har material med dem som behöver material. I dagsläget finns ingen sådan lösning vilket hindrar effektivt nyttjande av spillmaterial.

Utförare: 5 studenter i årskurs 4 i kursen Innovationsteknik INTN01, 7,5 hp.

Tillvägagångssätt: Studenterna arbetade med en öppen innovationsprocess baserad på Design Thinking-metodik och Double Diamond-modellen och faserna empathise, define, ideate och prototype under en period av 8 veckor.

Resultat: Rapport som presenterar arbetssätt, metoder och resultat i form av en konceptuell lösning som ökar resurseffektiviteten genom att tillvara spillmaterial vid byggplatser. För mer detaljerad information, se Bilaga 4.

5. Resultat

Denna sektion av rapporten presenterar resultat från workshops och genomförda fallstudier. Workshoparna utforskade olika aspekter av byggprocessen och betonade vikten av hållbarhet, proaktiv problemlösning och intressentengagemang.

Inom ramen för projektet utforskades möjligheterna att implementera nya tekniska lösningar för Off-Grid-hus och hinder som detta medförde identifierades. Dessutom undersöktes kritiska hinder för innovation inom byggindustrin, hur attityden till hållbarhet kan förändras, och cirkulära modeller för ökad resurseffektivitet.

5.1 Resultat från workshops

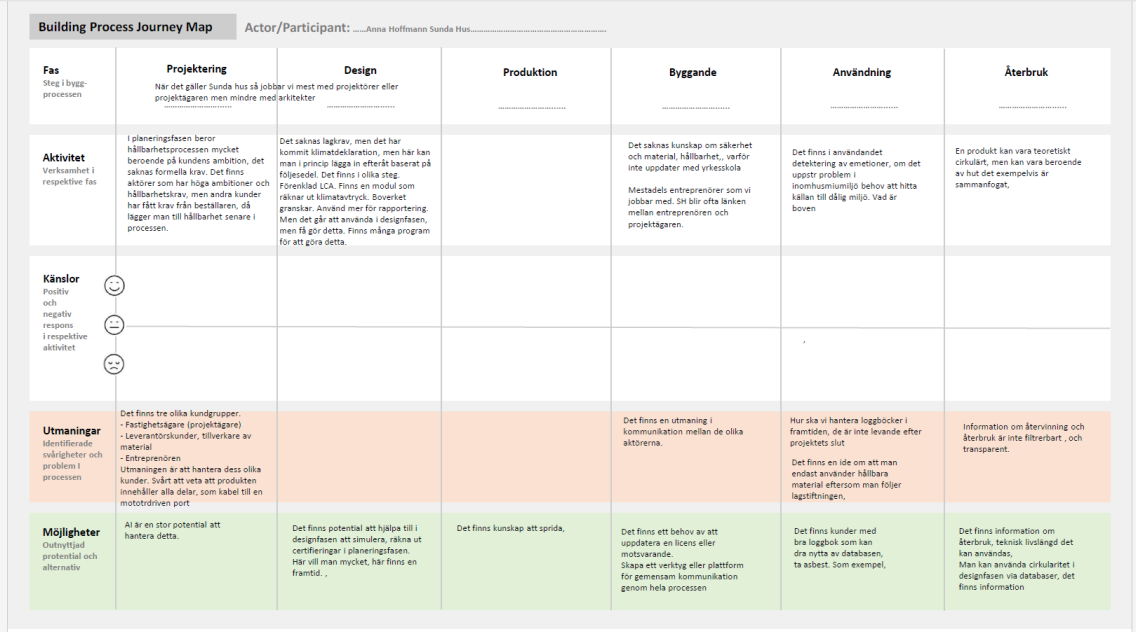
Workshop 1: Problemidentifiering

Byggprocessen uppvisar både utmaningar och möjligheter att integrera hållbarhet i byggprocesser, och denna workshop syftade till att identifiera och generalisera dessa. Speciellt fokus låg på också på att identifiera tänkbara lösningar för att förbättra kommunikation, kunskapsspridning och integrering av hållbarhet i tidiga skeden. En del av arbetet är baserat på Anna Hoffmanns erfarenheter av hållbarhet i byggprojekt på Sunda Hus.

I planeringsfasen är hållbarhetsinsatserna beroende av kundens egen ambition på grund av avsaknad av formella krav. Även om vissa kunder prioriterar hållbarhet, läggs den till senare i processen av andra. Trots avsaknaden av lagliga krav finns det en växande tonvikt på hållbarhet, vilket bevisas av införandet av klimatdeklarationer. Dock förblir efterlevnaden frivillig, med verktyg som förenklade livscykelanalyser (LCA) tillgängliga för de intresserade. Sunda Hus samarbetar främst med projektägare och mindre med arkitekter och betjänar tre huvudsakliga kundgrupper: fastighetsägare, materialleverantörer och entreprenörer. Att hantera olika kundbehov utgör en utmaning, där AI identifieras som en potentiell lösning. Kunskapsluckor inom säkerhet, material och hållbarhet understryker behovet av uppdateringar inom yrkesutbildning.

Kommunikationsproblem kvarstår mellan intressenter, förvärrat av föråldrade projektloggböcker efter konstruktion. Föreslagna lösningar inkluderar att etablera

en enhetlig kommunikationsplattform och integrera hållbarhetsaspekter tidigt i designfasen. Möjligheter finns i att använda AI för simuleringar och certifieringar samt upptäcka inomhusmiljöproblem. Trots utmaningar finns optimism för framtiden. Simulationer och certifieringar har potential i designfasen, och tekniker som känslouppfattning kan förbättra bedömningen av inomhusmiljökvalitet. Dessutom gynnar kunder med omfattande projektloggar från en centraliserad databas, vilket underlättar uppgifter som asbestidentifiering. Idéer för att främja hållbarhet inkluderar att tvinga användningen av hållbara material och utnyttja cirkularitetsprinciper i design genom omfattande databaser. Utmaningar kvarstår dock när det gäller att göra information om återvinningsbarhet och återanvändning lättillgänglig och transparent.



Figur 4. Project Journey Map (projektresa) för Sunda Hus.

Workshop 2: Planeringsperspektivet

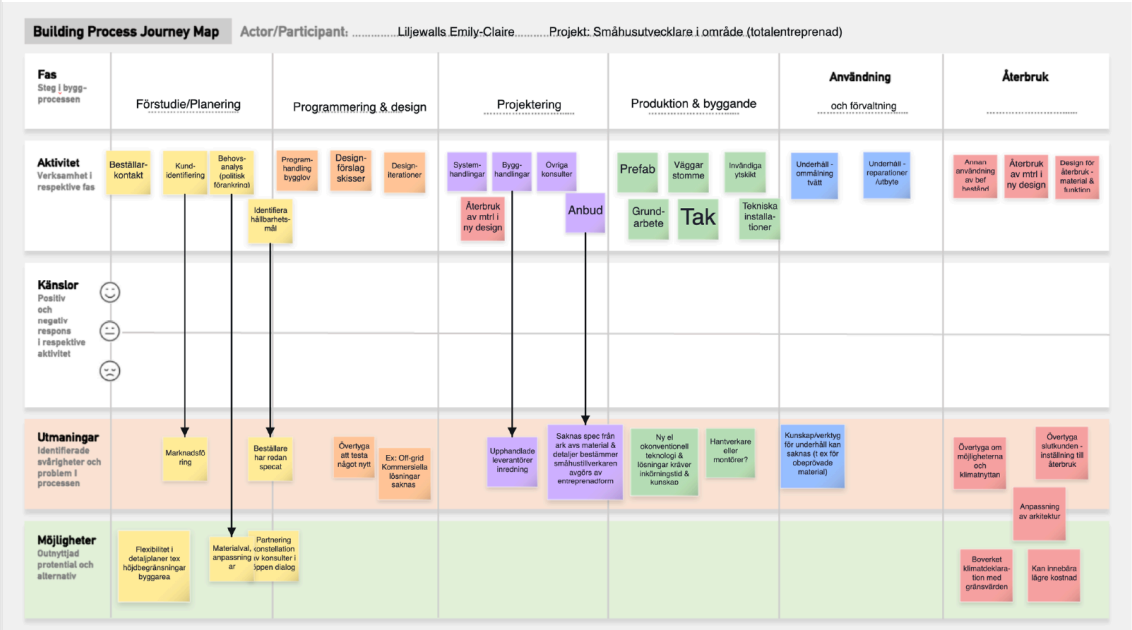
Projektresan (Figur 4 och 5) belyser de invecklade dynamikerna i byggprojekt, balanserande utmaningar med möjligheter för innovation och integrering av hållbarhet. Den betonar vikten av proaktiv problemlösning, engagemang från intressenter och ett framsynt tillvägagångssätt för att möta de ständigt föränderliga behoven i byggbranschen. Denna information baserades på ett företag för småhusutvecklare i Arnråde (totalentreprenad) utfört av Liljewalls., som skisserar den omfattande processen från förstudie/planering till konstruktion och återanvändning. Den omfattar aktiviteter som sträcker sig över kundanalys,

behovsbedömning, designiterationer och konstruktionshantering över olika projektfaser.

Utmaningar som visar sig under resans gång inkluderar behovet av att övertyga kunder, marknadsorientering, antagande av okonventionell teknologi och kunskaps-/verktygsluckor för underhåll. Dessa hinder understryker komplexiteten i att navigera kundförväntningar, marknadskrav och tekniska framsteg. Dock finns det möjligheter för innovation och förbättring mitt i utmaningarna. Kartan identifierar outnyttjad potential, som flexibilitet i planering, partnerskap för materialval och anpassning i arkitektur för klimatfördelar. Dessa vägar erbjuder möjligheter att förbättra hållbarheten, minska kostnader och förbättra övergripande projektresultat.

Kartan understryker betydelsen av hållbarhetsinsatser, inklusive initiativ som klimatdeklarationer och anpassning av arkitektur för att maximera klimatfördelar. Dessa insatser bidrar till miljöbevarande och har potential att spara kostnader och säkerställa långsiktig livskraft.

Trots det finns det ihållande utmaningar, såsom saknade specifikationer, behovet av kontinuerligt att övertyga kunder och osäkerheter kopplade till antagande av otestade material och teknologier. Att adressera dessa utmaningar kräver kontinuerlig anpassning, innovation och samarbete mellan intressenter.



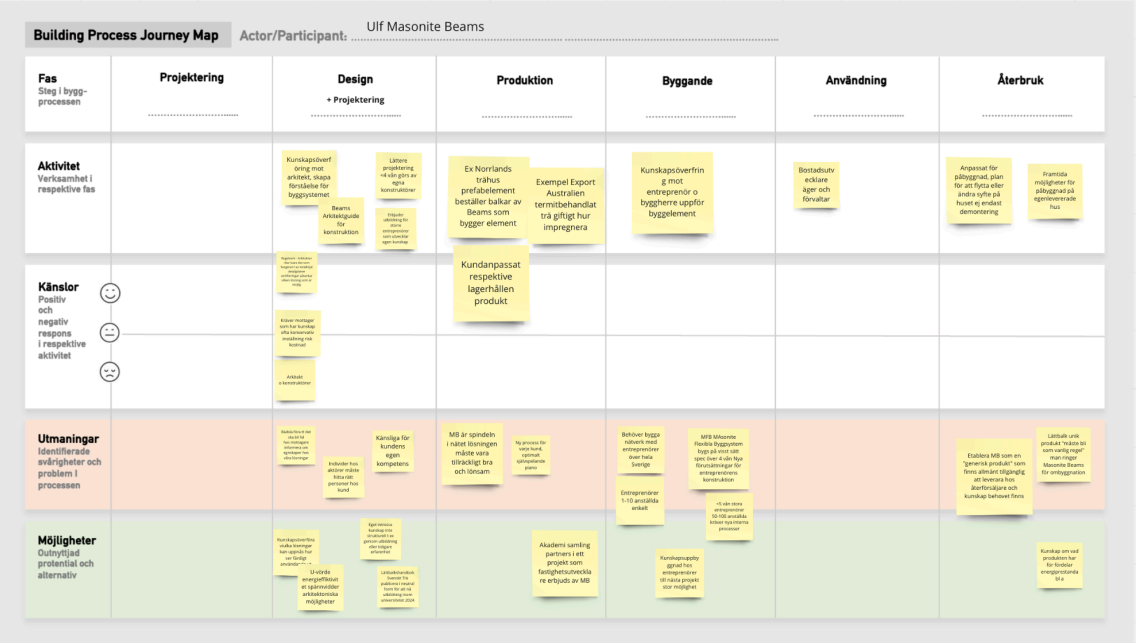
Figur 5. Project Journey Map (projektresa) för Liljewalls Arkitekter.

Workshop 3: Producentperspektivet

Byggprocessens karta för Masonite Beams belyser den dynamiska samverkan mellan utmaningar och möjligheter inom byggbranschen. Genom att ta itu med utmaningarna direkt och utnyttja möjligheterna till innovation och utbildning kan leverantörer av delsystem positionera sig som en ledare inom hållbara bygglösningar och driva positiv förändring inom branschen. Masonite Beams presenterar framstegen inom byggaktiviteter, som sträcker sig över planering, design, produktion, byggande, användning och återanvändning. Det understryker utmaningar som att identifiera svårigheter och säkerställa konservativa installationspraxis på grund av produktsensitivitet. Producenterna, de som levererar delsystem till byggindustrin, spelar en avgörande roll för att hantera dessa utmaningar och kräver strikta kvalitetsstandarder för att effektivt möta kundkrav. Dock finns det möjligheter till förbättring mitt i utmaningarna. Genom att utnyttja outnyttjad potential för lösningar och dra nytta av kundkunskap kan resultatet förbättras avsevärt. Att etablera sina produkter som generiska och delar i en större helhet öppnar möjligheter för bredare användning och marknadsinträde, vilket främjar tillväxt och hållbarhet.

Utbildning framträder som en avgörande komponent, där ansträngningar fokuseras på att informera partners och kunder om fördelarna och alternativen som erbjuds av Masonite Beams. Utbildningen inkluderar att främja energieffektivitet och belysa de arkitektoniska möjligheter det presenterar. På så sätt kan Masonite Beams attrahera intressenter genom att sprida neutralt, informativt innehåll, inklusive fastighetsutvecklare och entreprenörer.

Projektresan i Figur 5 betonar vikten av kunskapsöverföring och kontinuerlig förbättring för att möta kundernas ständigt föränderliga behov och branschstandarder. Samarbete över byggsektorn är avgörande för att säkerställa att Masonite Beams förblir anpassningsbar och lyhörd för marknadens krav.



Figur 6. Project Journey Map (projektresa) för Masonite Beams.

5.2 Resultat från fallstudier

Fallstudie 1: Utveckling av koncept för infrastrukturoberoende hus

Projektet genomfördes utifrån ramen för BRIC med målet att undersöka hur möjliga nya tekniska lösningar för ett Off-Grid hus skulle kunna implementeras, samt kartlägga vilka hinder och svårigheter detta medför med hänsyn till befintliga processer.

Resultatet, i form av ett Boundary Object, presenterades som en modell för hur en process skulle kunna gå till. Genom metoden prövades hur Boundary Object skulle kunna fungera som metod för att samla olika intressenter kring olika förslag och underlätta kommunikation genom objektet. Genom resultaten testades om en lösningsinriktad metod skulle kunna användas för att pröva nya idéer, väcka diskussion om hållbarhetsfrågor och innovation inom byggsektorn.

Resultatet redovisas i en studentrapport publicerad på Jönköping University och återfinns i Bilaga 1.

Fallstudie 2: Integrering av standardiserade industriella produktutvecklingsmetoder inom byggsektorn

Denna studie genomfördes parallellt med samma problemställning av tre av varandra oberoende studentgrupper. Grupperna hade till uppgift att skapa ett modulbaserat boendekoncept som fungerar som studentboende, tillfälligt flyktingboende eller arbetarboende på en byggplats.

Totalt gav projekten tre diametralt olika lösningar. Koncepten togs fram genom användning av industriella produktutvecklingsmetoder (se t. ex. Cross, 2008) och Double Diamond-modellen. Användardata samlades genom intervjuer och efter en prioritering skapades en konstruktionskriterielista (första diamanten). Denna lista låg sedan till grund för den andra diamanten där studenterna tog fram en mängd olika koncept som sedan med hjälp av valda kriterier och konceptvalsverktyg reducerades till ett slutligt koncept.

Med tanke på likadana ingångskriterier och ingenjörsmässiga metoder för funktionsdesign skulle man kunna förvänta sig likformiga lösningar. Detta var dock inte fallet utan trots den starka standardiseringen finns det en stor varians av lösningar som uppfyller ovannämnda kriterier. Resultaten av dessa uppgifter redovisas i form av rapporter som återfinns i Bilaga 2-4.

Fallstudie 3: Utveckling av hjälpmedel för lärande inom akademin och byggindustrin

Projektet genomfördes utifrån ramen för BRIC och projektets mål är att undersöka vilka de mest kritiska hindren för innovation inom byggindustrin var, samt hur attityden till hållbarhet inom byggindustrin kan förändras. Det slutliga målet var att skapa ett fysiskt/visuellt koncept som utökar medvetenhet och väcker diskussion kring hållbarhet och innovation inom byggindustrin.

En studie bestående av litteraturstudier och intervjuer genererade information som analyserades och delades in i olika kategorier av insikter. Baserat på denna information genomfördes idégenereringssessioner och flera koncept utvecklades. Lågfidilitetsprototyper av olika koncept skapades och därefter användes konceptgranskning för att välja det slutgiltiga konceptet som producerades som en högfidelitetsprototyp.

Det slutgiltiga konceptet "EcoBuilding Challenge" är ett brädspel avsett att användas i workshopmiljöer. Spelet syftar till att skapa medvetenhet och

transparens inom byggindustrin genom att adressera hinder, möjligheter och väcka diskussioner. Målet är för spelarna att bygga ett hus med så låg miljöpåverkan som möjligt, samtidigt som de möter vanliga utmaningar och får perspektiv som påverkar dessa val. Resultatet redovisas i en rapport på Linköpings universitet samt i Bilaga 5.

Figur 7. "EcoBuilding Challenge" är ett brädspel avsett att användas i workshopmiljöer.

Fallstudie 4. Cirkulära processer för återbruk av överblivet byggmaterial

Den globala byggsektorn är en kritisk komponent i vårt moderna samhälle och sysselsätter många människor globalt. Tyvärr spelar den också en betydande roll i förbrukningen av energi och utsläpp av växthusgaser. Enligt FN:s miljöprogram statusrapport 2022 stod bygg- och anläggningssektorn för 34 procent av energianvändningen globalt (FN:s miljöprogram, 2022).

Mer än hälften av det avfall som produceras runt om i världen kommer från material som används inom byggsektorn och mycket av avfallet hamnar på soptippar. Dessutom kommer 32 procent av avfallet som hamnar på soptippar från byggarbetsplatser. Mycket material som beställs för konstruktion kommer aldrig till användning, varvid 13 procent skickas direkt till soptippar (Brady et al, 2021). Genom att anpassa ett cirkulärt ekonomiperspektiv på byggsektorn kommer investeringar att generera värde på lång sikt eftersom de kommer att ses som återanvändbara. Dessutom kan 25 procent av materialkostnaderna reduceras genom att återanvända material som asfalt och betong (Brady et al, 2021).

Projektet föreslår en lösning i form av en app som fungerar som en plattform där leverantörer och byggföretag kan köpa och sälja material som inte används från byggarbetsplatser. Genom att använda appen får aktörer inom byggindustrin ett konto efter att ha verifierats som ett legitimt företag. De kan sedan söka efter material som de behöver eller vill sälja. Om materialet är tillgängligt kan de se kvantitet, kvalitet, fraktinformation och få kontaktinformation till säljaren. Materialet kan sedan köpas i appen.

Appen kan implementeras på några olika sätt. Den mest lovande metoden är att introducera appen för en stor leverantör. Ett annat alternativ är att introducera appen för ett eller flera stora byggföretag. Detta kan vara fördelaktigt eftersom de kan se denna innovation som en konkurrensfördel och inkorporera den i sin affärsmodell. Slutligen kan appen introduceras för ett nätverk av mindre sammanlänkade företag, som LMF30 (Jansson, 2023). Resultatet redovisas i en rapport på Lunds universitet samt i Bilaga 6.

6. Diskussion

Fem huvudteman har identifierats som centrala faktorer för denna studie: kunskap, kommunikation, regelverk, process och miljö. Projektets övergripande mål har varit att främja en omställning inom byggsektorn mot en mer resurseffektiv och hållbar framtid genom införandet av designbaserade innovationsmetoder. Målet har varit att stärka branschens förmåga att anpassa sig till förändringar och skapa en grund för hållbar utveckling. Det är dock viktigt att notera att detta systemiska problem inte kan lösas genom ett enstaka projekt. Framtida lösningar och arbetssätt kommer att behöva utvecklas genom samarbete mellan olika aktörer inom nya projekt. Införande av innovativa metoder inom arbetsprocesser, metodik, digitala tjänster och systemlösningar kommer att krävas för att uppnå en hållbar byggsektor, som tar hänsyn till ekonomiska, sociala och miljömässiga aspekter. Det är också av yttersta vikt att sträva efter klimatneutralitet, resurseffektivitet, energieffektivitet och cirkularitet i byggprocessen.

6.1 Kunskap

Diskussionen om kunskap inom byggsektorn är central i de tre presenterade fallstudierna. Den första studien, genomförd av Engström et al. (2023) betonade betydelsen av att skapa och sprida kunskap genom användning av Boundary Objects och lösningsinriktade metoder för att underlätta kommunikation och samarbete mellan intressenter. Liknande insikter framkom i den tredje studien, utförd av Koshkooi et al. (2023). Genom en kombination av litteraturstudier, intervjuer och idégenereringssessioner utvecklades konceptet "EcoBuilding Challenge", ett brädspel som avser att öka medvetenheten och väcka diskussioner kring hållbarhet och innovation inom byggindustrin. Denna ansats betonar vikten av att sprida kunskap och skapa delaktighet för att främja förändring. I studien av Alsterberg et al. (2023) adresseras problemet med överflödigt avfall och ineffektiv resursanvändning och en app utvecklades som en plattform för köp och försäljning av oanvända material på byggarbetsplatser. Denna innovation kräver emellertid kunskap om både teknologi och affärsprocesser för att kunna implementeras framgångsrikt.

I de tre första workshoparna framkom en gemensam insikt om behovet av utbildning och kunskapsspridning för att möta utmaningarna och främja innovation inom byggbranschen. Sunda Hus identifierade kunskapsklyftor inom

områdena säkerhet, material och hållbarhet. De betonade behovet av uppdaterad utbildning för att åtgärda dessa brister och föreslår investeringar i utbildning och kompetensutveckling för att höja medvetenheten och skapa en mer hållbar och säker byggmiljö. Likaså poängterade Liljewalls Arkitekter vikten av att informera och utbilda intressenter om de mångfacetterade fördelarna med innovativa lösningar och hållbara byggmaterial. För att adressera dessa behov krävs konkreta åtgärder, såsom att erbjuda utbildningsmaterial och workshops, för att öka förståelsen för hållbara byggmaterial och därigenom främja deras användning. Även Masonite Beams lade stor vikt vid utbildning och kunskapsspridning för att övertyga sina kunder och marknaden om värdet med deras produkter.

Kunskapsbristen inom byggsektorn framstår som ett utmanande problem med låg prioritet. Endast ett fåtal aktörer visar det nödvändiga intresset och engagemanget för att aktivt lära sig och implementera nya lösningar. Trots en allmän vilja att bygga hållbart och effektivt saknar många den nödvändiga kunskapen för att ta till sig och dra nytta av de senaste innovationerna. Kravställning och policy kan fungera som stödstrukturer för att introducera och främja nya lösningar, men det är avgörande att aktörerna har tillräcklig kompetens för att förstå och tillämpa dessa riktlinjer i praktiken.

Sverige noteras vara något efter Danmark när det gäller lagstiftning inom hållbart byggande, vilket indikerar en bristande förståelse och brådska att anpassa sig till de senaste hållbarhetstrenderna. Endast ett fåtal företag och entreprenörer visar sig vara öppna och insatta i att omfamna och förstå nya tekniker och metoder. Majoriteten, närmare 90%, upplever svårigheter och föredrar att hålla sig till konventionella lösningar.

I tider av lågkonjunktur är det vanligt att verksamheter nedprioriteras, vilket kan leda till att innovativa projekt, som exempelvis Veideckes höga trähus, hamnar i skuggan. Däremot finns en liten grupp modiga beställare som vågar ta steget mot att utforska och implementera nya, mer hållbara lösningar. Det är viktigt att komma ihåg att trender och behov i byggbranschen förändras över tid och att det är avgörande att vara lyhörd och anpassningsbar för att möta dessa förändringar på ett framgångsrikt sätt.

Slutligen är det viktigt att notera att kunskapen inte bara handlar om tekniska färdigheter utan också om förståelse för hållbarhetsfrågor och sociala aspekter av byggprocessen. En mer holistisk syn på kunskap och kompetensutveckling är avgörande för att skapa en mer hållbar och framgångsrik byggsektor på lång sikt.

6.2 Kommunikation

I de presenterade fallstudierna manifesteras kommunikation genom en strukturerad spridning av forskningsresultat utförda av olika författare (Engström et al. 2023, Koshkooi et al. 2023, Alsterberg et al. 2023). Dessa resultat, förmedlade genom rapporter, fungerar som budskapet och behandlar hållbara lösningar och innovationer inom byggbranschen. De avsedda mottagarna av detta meddelande omfattar forskarkollegor, branschexperter, beslutsfattare och individer intresserade av hållbar utveckling. Syftet med denna kommunikation är att dela insikter, föreslå lösningar och väcka diskussioner med syfte att främja hållbara metoder och innovationer inom byggsektorn. Mot bakgrund av byggindustrin upprätthåller kommunikationen en professionell och informativ ton, vilket driver diskussioner som är relevanta för hållbara byggpraxis och avfallshantering. Genom denna strukturerade kommunikation navigerar fallstudier effektivt mellan akademi och industri och underlättar utbytet av kunskap och idéer som är avgörande för att möta samtida utmaningar inom byggsektorn.

Workshoppar betonar betydelsen av effektiv kommunikation mellan olika intressenter inom byggbranschen. Dessa workshops identifierar utmaningar relaterade till kommunikation, såsom bristande förståelse mellan olika parter, behovet av övertygande och ömsesidig förståelse för att övervinna hinder. Skapandet av en öppen och transparent kommunikationskanal mellan entreprenörer, arkitekter, kunder och andra aktörer kan överbrygga kunskapsglapp och förbättra samarbete för att möta gemensamma mål och utnyttja innovationsmöjligheter. Samtidigt, att uppmuntra till aktivt deltagande, kunskapsdelning och en kontinuerlig dialog kan olika intressenter inom byggsektorn arbeta mer effektivt tillsammans och säkerställa framgångsrika projektutfall.

Det krävs samverkan för att realisera hållbart byggande. Olika parter i byggprocessen har svårt att samarbeta med varandra. Mjukvaror och program är inte kompatibla vilket låser information i olika domäner. Simulering för att säkra kvalitet och kravuppfyllnad kan nyttjas i högre grad. Det krävs tydliga mål som är nedbrutna och kommunicerade till samtliga parter.

För att öka branschens konkurrenskraft krävs att nya samarbeten och nätverk formas för att utforska innovativa lösningar inom hållbart byggande. Initiativ som det regionala nätverket NFM30 i Västra Götaland tar tid att etablera, men när de väl är på plats blir de en kraftfull plattform för utbyte av information och kunskap. Genom långsiktig utveckling och regionalt fokus kan sådana samarbeten vara

effektiva i att skapa övergripande system som kan tillhandahålla marknaden med de mest relevanta och hållbara lösningarna.

Aktörer med framåtblick, såsom rikstäckande entreprenörer, efterfrågar hybridlösningar som kan kombinera olika lösningar för att passa specifika behov. Det är avgörande att underlätta för att rätt lösning kan väljas för rätt behov. Mindre projekt kan vara lättare att samverka kring, medan större projekt såsom bostadsområden kräver mer komplex samverkan med fler faktorer att beakta. För att möta dessa utmaningar behöver branschen investera i samarbetsstrukturer och metoder som kan hantera den ökande komplexiteten i hållbart byggande.

Byggprojekt är komplexa och involverar många olika intressenter som i sin tur har olika prioriteringar och målbilder. Det är ofta svårt att åstadkomma en gemensam målbild. Det är ofta som det föreligger konkurrens mellan olika intressenter i ett projekt, vilket försvårar samarbete.

Ofta fungerar nätverk på en relativt lokal nivå, men det saknas övergripande nätverk för kunskapsöverföring på nationell nivå. Danmark nämns ofta som ett gott exempel där man kommit längre i dessa frågor. Samarbete för att skapa övergripande system krävs för att kunna erbjuda marknaden rätt lösning

6.3 Regelverk

Framför allt fallstudie 4 berör regelverk och policy inom byggsektorn. Genom att identifiera problemet med överflödigt material som hamnar på soptippar och ineffektiv resursanvändning föreslår projektet en innovativ lösning i form av en app. Denna lösning, som presenteras som ett alternativ till att skicka material till soptippar, har potential att minska avfallet och främja återanvändning av material, vilket kan vara en viktig faktor för att främja hållbarhet inom branschen.

Alla tre workshoppar belyser vikten av samverkan mellan olika intressenter inom byggsektorn. Dessa workshops visar på behovet av att effektivt hantera och samordna kommunikation mellan olika parter såsom entreprenörer, arkitekter och kunder för att lösa gemensamma utmaningar och utnyttja möjligheter till innovation och hållbarhetsintegration. Genom att identifiera och adressera utmaningar som brister i kommunikation och kunskap samt främja en öppen dialog och kunskapsdelning kan olika intressenter inom byggsektorn arbeta tillsammans för att uppnå bättre resultat och främja hållbar utveckling.

En jämn spelplan med höga kravställningar är viktigt för att ge alla samma möjligheter. Det noteras att bristen på en branschorganisation för att driva frågor kring regelverk är en utmaning och incitament behövs för att minska material- och energiförbrukningen inom byggsektorn.

Samhället har ansvar att uppfylla klimatöverenskommelser och därmed incitament att driva på utvecklingen. Användare och slutkunder har ofta intresse av hållbart byggande men lösningar är ofta dyra och svåra att hitta. Policy måste fungera i samklang med denna ambition genom att skapa incitament för hållbart byggande, skapa stödjande regelverk som tydliggör och förenklar för samtliga parter. Branschstandarder saknas för bedömning av material. Vissa aktörer drivs inte av hållbarhetsfrågor. Olika certifieringar har olika krav och är inte kompatibla vilket tvingar aktörer att välja, vilket i sin tur skapar en fragmenterad marknad.

Innovation kräver en tydlig kravställning. Projekt i Uppsala har krav på max 160 kg CO2/kvm, men ofta är kraven otydliga och öppnar för olika tolkningar. I Danmark prioriteras ibland miljön före pris och certifieringar, men eftersom det finns så många olika certifieringar kan det vara svårt att bedöma värdet av dem för olika intressenter. En gemensam certifiering för träbyggnation skulle kunna vara en bättre lösning, men det kräver både tid och kostnader för att hålla certifieringen uppdaterad. Bredare kunskap behövs ibland för upphandlare med fokus på hållbarhet, särskilt när det gäller produkter, jämfört med områden där det finns tydliga standarder, som exempelvis våtrumssäkerhet. Incitamenten för skogsindustrin att avverka kan påverka implementeringen av vissa material, som lättbalkar, i svenska träkonstruktioner. En omvärdering av viktningen av olika kriterier, till exempel 15% av den totala vikten, kan vara en del av lösningen.

Kommande lagstiftning är avgörande för en hållbar framtid inom byggsektorn, och olika grupper som Svenskt trä (TMF) kan bidra, men en gemensam certifiering saknas fortfarande. Behovet av policyarbete i byggsektorn lyfts fram som viktig för att få till förändring på nationell nivå. Det finns många organisationer som arbetar med policyarbete, men då utifrån sina egna behov och förutsättningar. Ett nationellt policyarbete skulle kunna stärka och supporta nya, innovativa och hållbara lösningar.

Ett ytterligare hinder för innovation i byggsektorn är att introduktion av nya icke-etablerade lösningar upplevs förenade med stor risk. Byggare och entreprenörer väljer hellre kända lösningar enligt branschpraxis, eftersom långsiktiga konsekvenser av fel som kan upptäckas i senare delar av en byggnads livscykel fel kan innebära stora ekonomisk risk för en mindre aktör. Eftersom nya

lösningar ofta är väl testade och motståndet ofta består av okunskap och konventionellt tänkande, kan en lösning kan vara att introducera en gemensam försäkring för branschaktörer som vill satsa på hållbart och innovativt byggande genom användning av nya metoder och material. En branschägd försäkringslösning skulle kunna öka incitamenten att pröva mer hållbara och cirkulära lösningar och skulle ge trygghet för både kunder och utförare.

När det gäller detaljplaner för bygglov kan dessa utgöra hinder för träbyggnation på grund av specificeringen av totalhöjd istället för antal våningar, vilket gynnar betongbyggnader. Det är viktigt att kommunerna reviderar sina riktlinjer för att undanröja sådana hinder och prioritera miljöaspekter. Dessutom behövs andra incitament för att uppnå hållbarhetsmålen, eftersom ekonomiska överväganden ofta styr beslutsfattandet och kan leda till mindre hållbara alternativ trots bästa intentioner. Ett tydligt exempel är Växjö, där kostnadsaspekter ledde till betongbyggnation istället för trä, trots fördelarna med det senare för hållbarheten.

6.4 Process

Fallstudierna undersöker olika aspekter av byggprocessen. För det första utforskar de nya tekniska lösningar och undersöker innovativa teknologier som Off-Grid-huslösningar (omfattas av Fallstudie 1). Dessutom identifierar de hinder och utmaningar inom byggbranschen, med syfte att övervinna hinder som bromsar innovation för att främja hållbarhet och innovation (omfattas av Fallstudie 1 och Fallstudie 2). Vidare betonar studierna främjandet av hållbarhet och innovation, vilket främjar diskussioner och medvetenhet inom branschen, exempelvis genom initiativ som "EcoBuilding Challenge" brädspel (omfattas av Fallstudie 3). Slutligen diskuteras praktiska lösningar, inklusive förslag som en app för att köpa och sälja oanvända byggmaterial, med syfte att förbättra byggprocesserna (omfattas av Fallstudie 4).

Workshoppar ger också perspektiv på hur innovativa processer kan integreras i byggprojekt. Dessa workshops belyser vikten av att identifiera och utnyttja innovativa lösningar för att möta utmaningar och förbättra effektiviteten i byggprocessen. Sunda Hus utforskar möjligheter till innovativt samarbete mellan olika intressenter för att effektivisera kommunikationen och främja hållbarhet. Med integration av hållbarhetsaspekter tidigt i planerings- och designfasen kan man optimera byggprojekten för att uppnå miljömässig och ekonomisk hållbarhet. Liljewalls Arkitekter betonar vikten av proaktivt problemlösning och engagemang

från alla intressenter för att främja innovation och framsteg. När man är öppen för nya idéer och teknologier kan man hitta innovativa lösningar för att möta kundernas behov och öka projektekonomins hållbarhet. Dessutom utforskar Masonite Beams möjligheter till innovativ produktutveckling och marknadsföring för att positionera sig som ledare inom hållbara byggmaterial. Att investera i forskning och utveckling av nya material och teknologier kan företaget skapa innovativa produkter som möter kundernas krav på hållbarhet och prestanda.

Workshopar belyser att olika intressenter har olika ansvarsområden och roller i byggprocessen. Sunda Hus fokuserar på att agera som en länk mellan entreprenörer och projektägare, medan Liljewalls, Klara Byggsystem och Masonite Beams betonar behovet av att hantera och övervinna utmaningar relaterade till klientövertygelse, marknadsorientering och implementering av ny teknik. För att förstå och tydligt definiera ansvarsområden och roller för varje intressent i byggprojekt kan man öka effektiviteten och minska risken för missförstånd och konflikter. Till exempel, inom Sunda Hus-projektet kan en klar definition av entreprenörens roll och projektägarens förväntningar minska förvirring och främja smidig kommunikation. Liljewalls visar på vikten av att tydligt kommunicera med klienter för att övertyga dem om fördelarna med nya tekniker eller material. Samtidigt framhäver Masonite Beams och Klara Byggsystem betydelsen av att etablera sig som en generisk produkt och därigenom fördela ansvar och roller på ett tydligt sätt för att underlätta samarbete och uppfylla kundbehov.

När ansvarsfördelningen är klargjord, kan man också främja samarbete och kunskapsdelning mellan olika parter, vilket i sin tur kan leda till bättre projektresultat och ökad möjlighet att uppnå hållbarhetsmål.

Ett hinder för att åstadkomma mer hållbara byggprocesser är ansvarsrollen. Att införa nya hållbara, men ibland oprövade material innebär en risk. Det är många gånger mindre riskfyllt att använda beprövade material och metoder, och det utgör ett hinder för att pröva nya innovativa lösningar. Då dyker frågan om vem som tar den risken upp. En lösning som diskuterats är en form av branschråd. Fördelningen av risk i ett projekt är aktuellt att hitta en bra lösning på.Trygghet i beslut är tydligt korrelerat till risk. Om det fanns ett policynätverk att luta sig på skulle risken kunna delas mellan flera aktörer.

Processen för byggande karaktäriseras av sin komplexitet och involverar många aktörer över en lång tidsperiod. Denna komplexitet ger upphov till osäkerhetsfaktorer som kan leda till ökade kostnader och förseningar i projekt.

Introduktionen av nya lösningar och material är särskilt utmanande på grund av bristen på kompetens hos de involverade parterna, vilket skapar en ovilja att ta risker och hindrar nyskapande tankesätt. Den nuvarande situationen där byggfel som orsakas av beprövade metoder kostar samhället stora summor varje år, saknar incitament för att utforska och införa ny teknik och innovationer. Det är också svårt för nya aktörer att etablera sig på marknaden med sina innovativa lösningar, och steget från att demonstrera en ny teknik till att få den implementerad i praktiken är ofta stort.

En viktig del av att förbättra processen är att skapa strukturer som underlättar och stödjer hållbart byggande. Detta kan innefatta samarbetsformer och styrning som främjar en mer hållbar byggd miljö. En participativ process där flera aktörer samverkar kan underlätta Det betonas också att införandet av nya lösningar och material kräver förändringar i lagstiftning och kommunala regelverk för att underlätta introduktionen av dessa lösningar.

Exempelvis kan bygglovsprocessen och detaljplaner utgöra hinder för träbyggnation på grund av regler som fokuserar på totalhöjd snarare än antal våningar, vilket skapar olika förutsättningar för betong- och träbyggande. Dessa hinder behöver adresseras genom ökad medvetenhet om miljöaspekter och en ökad prioritering av hållbarhetsmål hos kommuner och andra beslutsfattare. Incitament behövs också för att säkerställa att ekonomiska överväganden inte prioriteras över hållbarhetsmål, som i fallet med Växjö skola där ekonomiska överväganden ledde till valet av betongbyggnation trots fördelarna med träbyggande.

En lösning på bristande kommunikation mellan aktörer i byggprocessen, kan vara att skapa ett nätverkande ekosystem för ökad kunskapsspridning där parter i hela processen samverkar. Ytterligare ett sätt att kommunicera hållbara lösningar kan vara koncept som utvecklats med fokus på hållbarhet, där dessa kan fungera som demonstrator eller "boundary objects” (Leigh Star and Griesemer, 1989). Det finns många databaser som skulle kunna utvecklas till att bli mer tillgängliga och transparenta för att skapa en marknads ”pull” för mer hållbara val.

Diskussionen kring komplexiteten i tillståndsprocesser och detaljplaner, som ofta gynnar betongbyggnader och därigenom begränsar entreprenörers möjligheter att välja andra material, är av stor vikt. Det framhålls att det behövs tydliga krav eller egna direktiv från kommuner för att främja hållbara byggnationer

6.5 Miljö

Kopplingen till miljön i fallstudierna är tydlig genom flera centrala aspekter. För det första fokuseras på att utforska nya tekniska lösningar och innovationer som syftar till att främja hållbarhet inom byggbranschen. Detta inkluderar initiativ såsom att undersöka Off-Grid-lösningar för bostäder (Fallstudie 1) och utveckla ett brädspel, "EcoBuilding Challenge", för att öka medvetenheten och stimulera diskussioner om hållbarhet och innovation (Fallstudie 3). Dessutom finns det en erkänsla för byggverksamhetens miljöpåverkan, vilket belyses genom statistik om energiförbrukning, utsläpp av växthusgaser och avfallsproduktion inom sektorn (Fallstudie 4). De föreslagna lösningarna, såsom appen för handel med oanvända byggmaterial, syftar till att adressera miljöutmaningar genom att främja resurseffektivitet och minska avfallet. Sammantaget visar fallstudierna en samlad ansträngning för att integrera miljöhänsyn i byggprocessen och främja hållbara metoder inom branschen.

I dessa tre workshops framställdes miljön som dynamisk och föränderlig, med olika utmaningar och möjligheter som uppstår under byggprocessens resa. Varje workshop belyser olika aspekter av byggindustrin och visar på de komplexiteter och nyanser som är involverade i att leverera hållbara och innovativa bygglösningar.

Workshop 1 betonade behovet av uppdaterad kunskap och träning inom säkerhet, material och hållbarhet. Resultaten underströk vikten av att adressera kunskapsklyftor för att säkerställa en säkrare och mer hållbar byggmiljö. Till exempel identifierades utmaningar som bristen på formella krav för hållbarhetsinsatser under planeringsfasen. Exempel på föreslagna lösningar inkluderade investeringar i utbildningsprogram och initiativ för kompetensutveckling för att öka medvetenheten och kompetensen hos intressenter. Genom att överbrygga dessa kunskapsklyftor ville Sunda Hus skapa en mer välinformerad och kapabel arbetskraft som kan navigera kraven inom hållbar byggverksamhet effektivt.

I Workshop 2 var fokus att informera intressenter om fördelarna med innovativa lösningar och hållbara byggmaterial. Workshopen betonade betydelsen av utbildning och medvetandehöjande insatser för att driva användningen av hållbara metoder i byggprojekt. Till exempel framhölls behovet av att utbilda kunder om hållbarhetens värde och betydelsen av att integrera det tidigt i designfasen. Exempel på föreslagna initiativ inkluderade att erbjuda utbildningsmaterial och workshops för att öka förståelsen och främja

användningen av hållbara material i byggprojekt. Genom att främja en kultur av hållbarhet och innovation ville Liljewalls katalysera positiv förändring inom byggindustrin och uppmuntra intressenter att omfamna hållbara byggmetoder.

Workshop 3 underströk vikten av att utbilda intressenter om fördelarna med deras produkter för att övertyga kunder och marknaden om deras värde. Workshopen belyste rollen som utbildning och kunskapsspridning spelar för att främja användningen av hållbara byggmaterial. Till exempel diskuterades initiativ som att erbjuda utbildningsresurser för att öka medvetenheten om fördelarna med innovativa produkter och deras tillämpningar. Genom att tillhandahålla intressenter med den nödvändiga informationen och resurserna ville Masonite Beams och Klara Byggsystem öka acceptansen och användningen av sina produkter i byggprojekt.

En utmaning med lösningar som är utformade för att passa cirkulära system inom byggbranschen idag är att kontext och system som kan göra dessa lösningar möjliga ofta saknas. Detta är en av de stora utmaningarna med byggsektorn, dvs att skapa cirkulära system som kan hantera lösningar som är resurseffektiva, miljömässigt hållbara och återbrukbara.

För att möta utmaningarna med klimatförändringar och miljöpåverkan behöver byggbranschen omfamna en omfattande förändring mot koldioxidneutrala och icke-toxiska material och processer. En central del av denna förändring är att öka graden av återbruk av byggmaterial, vilket inte bara minskar avfallsmängderna utan också diversifierar byggkomponenter och ställer nya krav på arkitektur och byggmetoder. Dock möts detta av utmaningar, inklusive behovet av uppdaterade krav och regelverk kring återbrukat material samt skapandet av incitament för tillverkare att prioritera återbruk och reparationsprocesser över nyproduktion. Trots detta finns det en optimistisk framtid där produkter designas för demontering och återanvändning, och där möjligheterna till återvinning ligger nära i tid. Detta skulle inte bara minska avfallet utan också öka tillgången på cirkulerade material och minska miljöbelastningen från tillverkning och produktion. Det är avgörande att branschen tar dessa steg mot en mer hållbar framtid.

7. Slutsatser, nyttiggörande och nästa steg

Slutsatser

Nedan sammanfattas projektets slutsatser kopplat till de fem centrala utmaningar som identifierades i projektet. Resultaten från detta projekt har bidragit till en ansökan till ett fortsättningsprojekt med syfte att utforska lösningar genom samarbete i ett hållbart, cirkulärt byggprojekt där hållbara och resurseffektiva lösningar utvecklas och testas i branschsamverkande processer.

Kunskap:

- Det finns en tydlig brist på kunskap och kompetens inom byggsektorn, vilket utgör ett utmanande problem med låg prioritet för många aktörer. Trots en önskan att bygga hållbart saknar många den nödvändiga kunskapen för att implementera nya lösningar och dra nytta av de senaste innovationerna.
- Fallstudierna visar olika metoder för att sprida och skapa kunskap, såsom användning av boundary objects, utveckling av pedagogiska verktyg som brädspel, och implementering av teknologiska lösningar som appar.
- Utbildning och kompetensutveckling är avgörande för att överbrygga kunskapsklyftorna inom byggsektorn. Genom att erbjuda utbildningsmaterial, workshops och andra pedagogiska aktiviteter kan förståelsen för hållbara byggmaterial och innovationer förbättras.
- Kunskap inom byggsektorn handlar inte bara om tekniska färdigheter utan också om förståelse för hållbarhetsfrågor och sociala aspekter av byggprocessen. En holistisk syn på kunskap och kompetensutveckling är avgörande för att skapa en mer hållbar och framgångsrik byggsektor på lång sikt.
- Det finns ett behov av nätverksekosystem för att förbättra kunskapsdelning mellan intressenter i byggprocessen och kommunikation av hållbara lösningar genom koncept som exempelvis "boundary objects".

Kommunikation:

- Effektiv kommunikation mellan olika intressenter inom byggbranschen är centralt för att övervinna hinder och maximera innovationsmöjligheter.

- Samarbete och nätverksbildning är avgörande för att realisera hållbart byggande. Initiativ såsom regionala nätverk kan vara kraftfulla plattformar för kunskapsutbyte och främja utveckling av övergripande system för hållbara lösningar.
- För att öka branschens konkurrenskraft krävs investeringar i samarbetsstrukturer och metoder för att hantera den ökande komplexiteten inom hållbart byggande. Flexibilitet och anpassningsförmåga till olika projektbehov är avgörande för att möta utmaningarna i byggsektorn.
- Strukturerad kommunikation, effektivt samarbete och nätverksbildning är nödvändigt för att främja hållbar utveckling inom byggsektorn och möta dess utmaningar.

Regelverk:

- Samverkan mellan olika intressenter inom byggsektorn är en nyckelfaktor för att lösa gemensamma utmaningar och främja innovation och hållbarhets-integration. Kommunikation och kunskapsdelning är avgörande för att uppnå bättre resultat och främja hållbar utveckling.
- Utmaningar är bristande samarbete på nationell nivå och hinder för att införa nya hållbara lösningar, bland annat på grund av riskuppfattningar och bristande kunskap.
- Lagstiftning och policyarbete spelar en avgörande roll för att främja hållbarhet inom byggsektorn. Behovet av en gemensam certifiering och ett nationellt policyarbete betonas för att stödja innovativa och hållbara lösningar på nationell nivå. En gemensam försäkringslösning kan öka incitamenten för att pröva mer hållbara och cirkulära lösningar.
- En helhetsansats som integrerar olika intressenters perspektiv och främjar innovativa lösningar är nödvändig för att adressera de utmaningar som branschen står inför.

Process:

- Tydliga ansvarsroller och kommunikation mellan olika intressenter i byggprojekt är avgörande för att främja samarbete och kunskapsdelning, vilket i sin tur kan leda till bättre projektresultat och hållbarhetsmål.
- Utmaningar som begränsad kunskap och motstånd mot förändring i branschen identifieras, och det föreslås att skapa strukturer som

underlättar och stödjer hållbart byggande genom samarbetsformer, förändringar i lagstiftning och kommunala regelverk.
- Kommunikation kring hållbara lösningar och skapandet av nätverkande ekosystem för kunskapsspridning lyfts fram som viktiga strategier för att främja hållbarhet inom byggbranschen.
- Förbättringar i tillståndsprocesser och detaljplaner behövs för att gynna hållbara byggnationer och minska hindren för att välja alternativa material och lösningar.
- En omfattande förändring inom byggbranschen krävs för att främja hållbarhet och innovation, vilket innefattar både tekniska lösningar och förändringar i arbetssätt och regelverk.
- De förändrade trender och behov som finns inom byggbranschen måste synliggöras och driva anpassningar. I detta ingår förståelse för hållbarhetsfrågor och främjande av holistisk kunskap och kompetensutveckling för långsiktig hållbarhet.
- Branschen behöver göra en omprövning av kriterieviktning vid projekt och utveckling av nya klassificeringar. Detta görs lämpligt innan eventuell kommande lagstiftning, och betonar betydelsen av nationellt politiskt arbete för att driva hållbara förändringar inom byggsektorn.

Miljö:

- Initiativ som Off-Grid-lösningar för bostäder och utvecklingen av brädspelet "EcoBuilding Challenge" syftar till att öka medvetenheten och främja diskussioner om hållbarhet och innovation.
- Föreslagna lösningar, såsom en app för handel med oanvända byggmaterial, strävar efter att adressera miljöutmaningar genom att främja resurseffektivitet och minska avfallet.
- Utbildnings- och medvetandehöjande insatser är avgörande för att främja användningen av hållbara metoder och material i byggprojekt.
- Byggbranschen behöver omfamna omfattande förändringar mot koldioxidneutrala och icke-toxiska material och processer för att möta utmaningarna med klimatförändringar och miljöpåverkan.
- Ökad återbruk av byggmaterial är centralt för att minska avfallsmängder och diversifiera byggkomponenter, men det kräver uppdaterade krav och regelverk samt incitament för tillverkare.
- En framtid där produkter designas för demontering och återanvändning skulle minska avfall och miljöbelastning från tillverkning och produktion, vilket är avgörande för en mer hållbar framtid.

Nyttiggörande

I projektet har följande grundläggande hypoteser prövats:

1. Det finns potential att effektivisera byggsektorns processer för att åstadkomma mer resurseffektivt byggande genom metoder och arbetssätt från design och innovationsområdet
2. Det finns behov av processer, mekanismer och regelverk som stödjer innovation och underlättar introduktionen av mer hållbara lösningar i byggsektorn
3. Det finns behov av mer samverkan för att sprida kunskap och demonstrera innovativa, resurseffektiva och cirkulära lösningar i byggsektorn för att realisera omställningen mot hållbart byggande

Resultat och slutsatser som presenterats i föregående kapitel visar tydligt att dessa hypoteser är stärkta. Genom samverkan med deltagande aktörer och parter har projektet utvecklat kunskap om arbetssätt, metoder och lösningar som bidrar till omställningen mot en cirkulär och hållbar byggsektor.

Genom att skapa lösningar och implementera resultaten från en sådan process kommer samhällelig nytta som kommersiellt värde att uppnås. Det är tydligt att omställningen inte endast handlar om nya tekniska och organisatoriska lösningar, den handlar minst lika mycket om en mental omställning, en omvärdering av djupt rotade värderingar och om ett enormt behov av ny kunskap.

Genom samverkan mellan akademi, industri och samhälle kan lösningar och incitament såsom kunskap, hållbar resursanvändning och regelverk skapas. I ett planerat nästa projektsteg avses sådana lösningar prövas för att visa på dess potential och nytta.

Nästa steg

I nästa steg planeras ett fortsättningsprojekt som bygger på resultat och slutsatser från detta projekt. Projektets mål är att utveckla och demonstrera designprocesser och lösningar för innovativt cirkulärt byggande. I projektet tas nästa steg i Double Diamond-processen genom att skapa nya lösningar som prototypas, utvärderas och testas.

Syftet är att visa hur förändring kan ske i byggbranschens arbetssätt, metodik, digitala tjänster och systemlösningar. Målet är att åstadkomma ett byggande som är ekologiskt, ekonomiskt och socialt hållbart, klimatneutralt, resurs- och energieffektivt och cirkulärt och accepteras hos byggare, beställare och användare.

Projektets parter kommer genom co-design ta fram en demonstrator i form av en mikrobostad som utvärderas med avseende på resurseffektivitet och boendekvalitet. Prototypen ska demonstrera nya metoder och lösningar för att bygga hållbart, cirkulärt, modulärt, självförsörjande, konfigurerbart, resurssnålt, demonterbart, flyttbart och återbrukbart. Projektet kommer utmana etablerade tankar kring byggprocess, samverkan, material, byggsätt och boende. Resultaten kommer bidra till ny kunskap, metoder, arbetssätt och lösningar i omställningen mot en hållbar byggsektor.

För att främja kunskapsutbyte, kommunikation, regelverk, byggprocess och miljö är det avgörande att implementera olika strategier och aktiviteter. En viktig åtgärd är att anordna regelbundna workshops och seminarier där projektets deltagare kan mötas för att diskutera gemensamma intressen och utmaningar. Genom att utveckla och implementera partnerskapsbyggande aktiviteter kan långsiktiga samarbeten etableras, vilket ökar projektets framgång. Att delta i och arrangera nätverksevenemang såsom konferenser, seminarier och branschmässor är också en effektiv metod för att öka synligheten för projektet och skapa nya möjligheter till samarbete och kunskapsutbyte. För att underlätta informationsdelning och effektiv kommunikation är det viktigt att skapa digitala plattformar och verktyg som främjar informationsutbyte mellan projektets deltagare.

Samtidigt är det centralt att integrera genusaspekter i arbetet för att adressera en mångfald av behov, perspektiv och erfarenheter inom projektet. Det inkluderar att utföra en bedömning av hur olika hållbarhetsinitiativ påverkar kvinnor och män på olika sätt, samt att analysera könsspecifika konsumtionsmönster och preferenser inom byggsektorn. Genom att förstå och beakta dessa aspekter kan kommunikationsstrategier och aktiviteter anpassas för att bättre möta de olika behoven och öka projektets hållbarhetsprestanda. Genom att integrera dessa överväganden kan arbetet bli mer inkluderande och effektivt, vilket i sin tur bidrar till projektets framgång och positiva miljöpåverkan.

En insikt från detta projekt är att byggsektorn är mycket komplex, med många aktörer och en ofta fragmenterad kunskaps- och processorganisation. En begränsning i det genomförda projektet som vi vill adressera i nästa projekt är betydelsen av policy och regelverk för att skapa incitament och styrning mot hållbar omställning i byggsektorn. Denna omställning behöver omfatta arbetssätt, samverkan och kunskapsbyggande samt beteendeförändring hos samtliga aktörer i branschen.

8. Publikationslista

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9. Projektkommunikation

I projektet har information och resultat kontinuerligt kommunicerats och spridits genom ett antal aktiviteter:

- Ett kontinuerligt kunskapsutbyte mellan deltagarna har skett genom planering och genomförande av olika workshops, samt genom diskussion och handledning av studentprojekt.
- Branschaktörer, tillverkare och akademiska deltagare har genom hela projektet samverkat, utforskat möjligheter och hinder, och identifierat faktorer för omställning av byggsektorn.
- Studenter har genom medverkan i fallstudier bidragit till informationsspridning, kunskapsutveckling och kommunikation av resultat till deltagande parter.
- I arbetet med projektets fortsättning har resultaten och utmaningar från detta projekt sammanställts i en pitch som har kommunicerats till nya aktörer.
- Denna slutrapport kommer att publiceras och distribueras av konsortiets medlemmar för att utöka nätverket för framtida forskningssamarbeten och finansieringsansökningar.
- En nyhetsartikel som belyser projektets genomförande och resultat planeras att publiceras i en branschtidning inom byggsektorn för att sprida kunskap och engagera nya aktörer.
- Projektet kommer att publiceras på respektive lärosätes webbplats under aktuella händelser och nyheter.
- En artikel planeras för konferenspublicering under 2024-25.

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Bilaga 3: Fallstudie 2b

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Bilaga 4. Fallstudie 3

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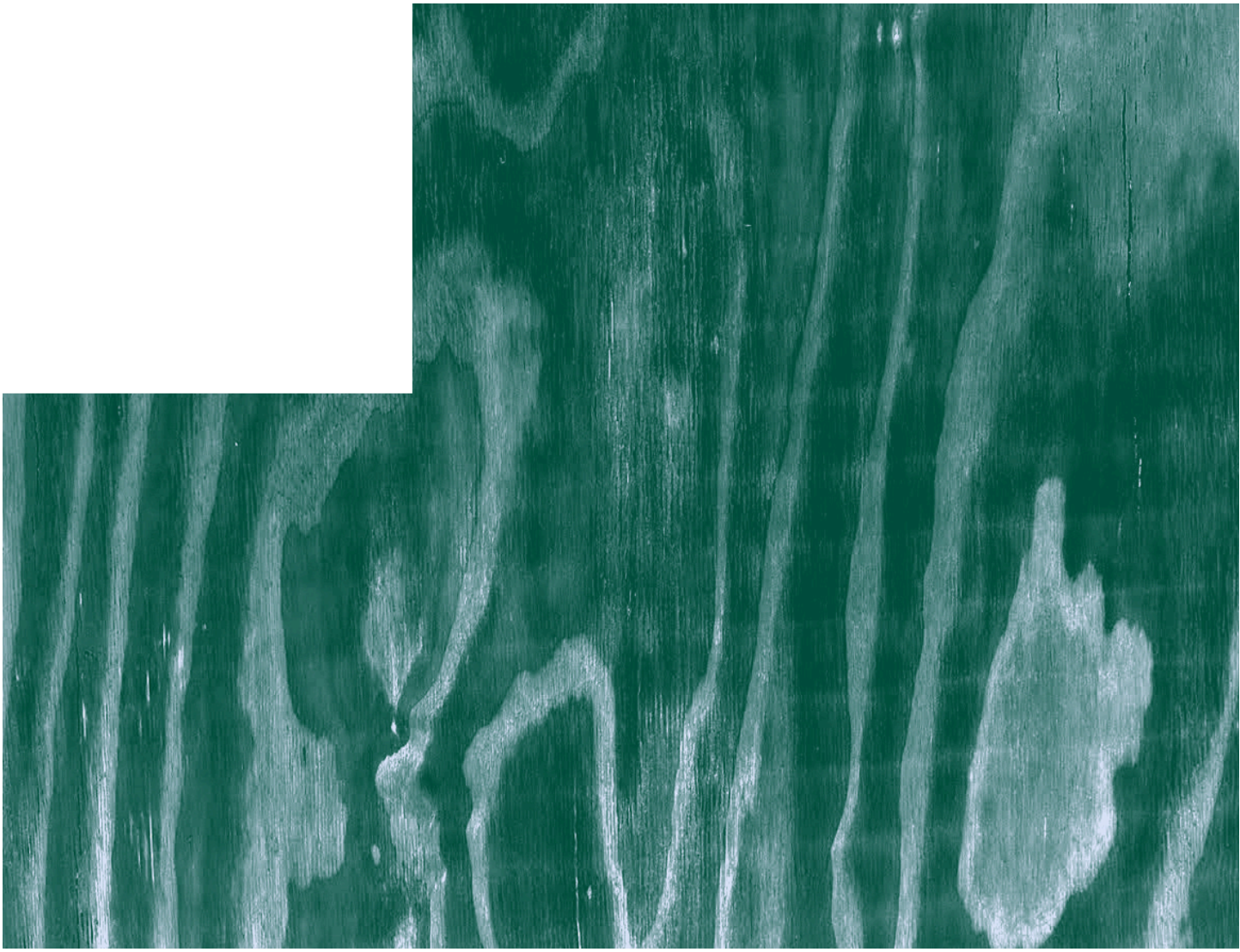

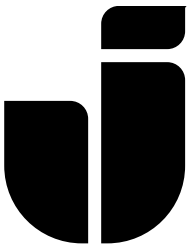

JÖNKÖPING UNIVERSITY

School of Engineering

Development of off-grid, self-sufficient Attefallshus for increased sustainability

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Abstract

This report explores the design, technologies, and methodologies required for creating a self-sufficient, sustainable, remote off-grid Attefallshus. The introduction provides relevant background information for the project and the research questions. The theoretical background dives into resource demand and sourcing, house design and technologies needed to support the off-grid house. The researched technologies are hygroelectricity, windmills, anaerobic digestion, nanomembranes to name a few. By using the methods, boundary object, Double Diamond, and TAIDA framework a comprehensive approach eased the research. The approach involves individual research, meetings, and trend analysis to help improve the project. The results highlight the effectiveness of the integrated system for the Attefallshus, covering energy, water, waste, and air. The TAIDA framework are presented in the results as an outcome from a visit to a subcontractor fair. Discussion and conclusion addresses the research questions and will give suggestions for future research. Based on the research questions, the resource demand will be covered by the technologies chosen for the Attefallshus. The boundary objects helped to develop the solution in the specific context of the Attefallshus which increases the details for the real-world implementation. The boundary objects also contributed by making it easier to share knowledge and communicate both between group members as well as to external parties. The solution is found to increase the circularity and lower the resource demand while providing the ability to live remotely, self-sufficiently and off-grid in Sweden. However, suggestions for future research include the total lifetime and maintenance requirement of the Attefallshus. With the goal of finding new ways of integrating secure maintenance with the current system option. Furthermore, these solutions should be done in an inexpensive way.

Sammanfattning

Denna rapport utforskar designen, teknologierna och metoderna som krävs för att skapa ett självförsörjande, hållbart och Attefallshus utanför elnätet på en avlägsen plats. Introduktionen ger relevant bakgrundsinformation för projektet och frågeställningarna. Den teoretiska bakgrunden fördjupar sig i behovet och källorna för resurser, husdesign och de teknologier som behövs för att stödja det avlägset placerade huset. Dem undersökta teknologierna inkluderar hygroelektricitet, vindkraftverk, anaerob digestion, nano membran med flera. Genom att använda metoderna boundary object, Double Diamond och TAIDA-ramverket som kompletterar varandra underlättades forskningen. Tillvägagångssättet omfattar individuell forskning, möten och trendanalys för att förbättra projektet. Resultaten belyser effektiviteten hos det integrerade systemet för Attefallshuset, inklusive energi, vatten, avfall och luft. TAIDA-ramverket presenteras i resultaten som ett resultat av ett besök på en underleverantörsmässa. Diskussion och slutsats tar upp forskningsfrågorna och ger förslag på framtida forskning. Baserat på frågeställningarna resursbehoven täcks av dem valda teknologierna för Attefallshuset. De utvecklade boundary objects, bidrog med utvecklingen av lösningen i det specifika sammanhanget av ett Attefallshus, vilket ökar detaljnivån för implementering i verkligheten. Boundary objects förenklar även spridningen av kunskap och kommunikationen dels mellan gruppmedlemmarna och till externa intressenter. Lösningen bedöms öka cirkulariteten, minska resursbehovet samt erbjuda möjligheten till boende på en avlägsen plats och vara självförsörjande och bortkopplad från elnätet. Exempel på framtida forskning inkluderar den totala livstid -och driftskrav för Attefallshuset. Målet är att hitta nya sätt att integrera säker drift med det nuvarande system föreslagen. Dessutom, borde dessa föreslag på drift vara billigt som möjligt.

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1 Introduction

The introduction introduces the background to the problem, describes the problem and the purpose and aim of the project. The purpose and aim form several research questions that are then posed. The delimitations limit the scope, and the disposition describes how the rest of the report is organized. Some text is reused from the research plan written by Engström & Pasovic (2023)for the course Research Methodology in Product Realization at Jönköping University.

1.1 Background

The research project is part of a larger on-going multi-university pre-study called Building right in collaboration for circularity (BRIC). The BRIC pre-study aims to find and understand conditions and obstacles for the construction industry to radically change the possibilities for ecologically sustainable user-centric construction.

In today's construction industry both development and construction of new housing follows a traditional workflow in terms of methods and practices (CBM, 2021). This results in a barrier of entry for inexperienced players looking to improve the construction industry from a sustainability viewpoint, increasing cost and resource demands connected to finding and implementing sustainable solutions. The property sector was responsible for 21 % of Sweden's greenhouse gas emissions in 2020 through carbon dioxide equivalents (Boverket, 2023). The total greenhouse gas emissions rise even further if imported materials are accounted for and therefore, there is room for improvement and innovation. Currently, modern housing requires many public utilities that require being intricately connected with communal infrastructure. This limits the freedom to live wherever possible.

An innovation opportunity presents itself to improve sustainability and the ability to live in a remote location in Sweden while being self-sufficient and off-grid. Small housing offers greater freedom since regulation is more relaxed (Boverket, 2021a). A specific type of small housing is the "Attefallshus", which is defined as a small house with a maximum building area of 30 m^2 and a maximum ridge height of four meters above the ground (Boverket, 2021a). The European Commission's waste hierarchy (n.d.) can be used in conjunction with the Eco cycle house defined by Bokalders & Block (2010) to determine that a sustainable house, minimizes the consumption of both material and energy while also maximizing the circularity. Circularity, meaning the priority of reuse, recycling, and recovery of resources before disposal as a last resort. Maximizing circularity while minimizing the consumption should still allow for comfortable living.

1.2 Purpose

The purpose is to increase the sustainability of a self-sufficient off-grid Attefallshus through minimizing the material, energy, air, and water usage, increasing the circularity,

while still allowing for comfortable living in a remote location. The idea is to design a sustainable integrated system regarding energy, air, water, and material that enables comfortable off-grid living. Also, to identify limitations for realization of this. Additionally, it is important to assess how well the system fulfills the criteria.

1.3 Aim and research questions

The aim is to identify the resource demand of a single person living in an Attefallshus in Sweden, develop an integrated, self-sufficient, off-grid solution that fulfill these needs and to assess the solution while documenting the issues for realization.

The purpose and aim lead to the following research questions.

- What is the resource demand for one person living in an Attefallshus?
- What is a solution that fulfills the identified demands?
- How well does the solution fulfill these demands?
- What are the limitations for real-world implementation?

1.4 Delimitations

To research this project within the required time limit, scope limitations are required. These limitations are:

- Limiting factors for the possibility of implementing the different technological solutions for the Attefallshus are documented but not necessarily solved. Meaning, if there are conflicting dimensions or advanced calculation required for in-depth analysis of a solution, it cannot be solved.
- The structural integrity of the structure will not be evaluated, and common thicknesses of various house structures will be assumed to be sufficient to carry loads they are subject to.
- The intricacies of house construction will not be designed but standard dimensions for various house components will be assumed to be representative for how a house could be constructed.
- The material choice for several aspects will be ignored.
- The material consumption and sourcing will be ignored other than the bodily fluids.
- The accessibility requirements for people with disabilities such as mobility impairment will not be regarded in the house design.
- There is no specific location for the placement of the Attefallshus other than the general location of somewhere in Sweden.
- The lifetime of the Attefallshus and its subcomponents will not be investigated.

1.5 Disposition

The rest of the report is organized in the following order, theoretical framework, method, approach and implementation, result, conclusion and discussion, references followed by attachments.

The theoretical frame lays the theoretical foundation for the work to answer the research questions and includes the necessary information for the reader to comprehend the result. The method describes the methods used to achieve the result. The approach and implementation describe how the methods were used in the project, how information was collected, and the work structured. The result shows the results of the project and highlights the decisions made based on the information in the theoretical framework and the approach and implementation of methods. The discussion and conclusion discusses the results based on the research questions posed and then conclusions are drawn based on the discussion. The references list all the sources for the information and knowledge retrieved from various places. The attachments provide additional information and work done.

2 Theoretical Background

The theoretical foundation contains the necessary knowledge for the reader to understand the subject matter and result.

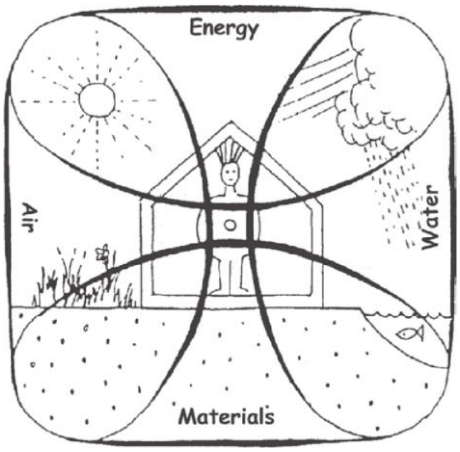
2.1 Sustainable housing

The waste framework directive (European commision, n.d.) lays down basic principles for reducing waste and minimizing the waste's ecological damage by introducing the waste hierarchy shown in Figure 1. The framework prioritizes prevention of waste, while declaring disposal as the last resort.

Figure 1. Waste hierarchy (European commision, n.d.)

The framework stresses the importance of prevention and reuse, recycling, and recovery before disposal. The sustainability considered in the project can be split into circularity and efficient use of resources. The waste hierarchy's division between prevention, reuse and disposal can be used to define the term circularity. Circular house, meaning to maximize the reuse, recycling and recovery of material and energy and minimizing the disposal of said material. The resource demand for a house can be categorized according to Figure 2. The resource demand for water, energy, air, and material can be considered both in terms of circularity and prevention which lowers the waste of a traditional linear household. Maximizing circularity and prevention should still allow for an acceptable living standard regarding consumption of resources.

Figure 2. Ecocycle house (Bokalders & Block, 2010, p. 225)



2.2 Demand and sourcing of resources

The resource demand for a single person living in an Attefallshus is separated into energy, water, materials, and air in accordance with Figure 2.

2.2.1 Energy

Attefallshus typically consumes between 2 000 and 5 000 kWh annually (Gustafsson, 2022). While the energy required to heat up water is proportional to the average warm water usage for one person. According to Energimyndigheten (n.d.) an average swede uses around 875 to 1 625 kWh/year. 1 000 kWh can be assumed for simplicity.

2.2.2 Water

The Swedish national average for daily water consumption per person overall, is 140 liters (Svenskt vatten, 2021), with

- 60 liters for personal hygiene
- 30 liters for toilet flushing
- 15 liters for dishes
- 15 liters for washing
- 10 liters for drinking and cooking
- 10 liters miscellaneous consumption.

This amount can be halved through different technologies (Bokalders & Block, 2014, p. 256) without sacrificing comfort and hygiene and the UN pushes for 50 liters/day/person consumption (Bokalders & Block, 2014, p. 254). This would mean a yearly consumption of 18 250 liters of water per person.

It is possible to divide the water used by humans daily into three subcategories which can be kept separate from one another. First there's drinking water. Drinking water most often requires purification (Bokalders & Block, 2014, p. 271). About 3 to 5 liters per day

per adult is needed (MSB, 2023). Although the Swedish average is 10 liters per person per day for drinking and cooking (Svenskt vatten, 2021). Next is the graywater category. This water is water that has been contaminated by anything other than fecal matter. This water can be used for chores such as cleaning and is also for keeping personal hygiene. This water could be sourced and used without prior purification (Bokalders & Block, 2014, p. 275). Lastly, blackwater. Blackwater is water contaminated with fecal matter and urine and toilet paper which makes it enriched with nutrients from partially digested food, bodily fluids, and bacteria. (Bokalders & Block, 2014, p. 354)

The typical Swedish sewerage system collects both blackwater and graywater without separation (Svenskt vatten, 2023). Furthermore, drinking water is used for every purpose within the household and subsequently disposed of to a purification facility as waste immediately after being flushed down the drain (Svenskt vatten, 2023). Water infiltration or ground beds (Avloppscenter, n.d.) is another common way to purify water and works by first separating the sludge in a container for later disposal and letting the rest of the impure water pass through. Then letting the ground purify the water naturally.

Sources for circular self-sufficient, off-grid water are shown in Figure 2. Precipitation and groundwater have the potential individually for sufficient supply depending on the location's particular circumstances. The ground water quality is good with a few exceptions that require purification different to each type of pollution and combination of pollutions (Bokalders & Block, 2010, pp. 271–274). Precipitation collection should be safe if the proper precautions are taken to avoid contaminations while also purifying the water appropriately, although it could be appropriate for low quality domestic use as is (Bokalders & Block, 2014, p. 275; Villarreal & Dixon, 2005). Precautions could be to collect the water away from areas with low air quality or other strong sources of pollution and choose appropriate roof material (Villarreal & Dixon, 2005). The first precipitation to fall between dry periods also needs to be flushed away to avoid the accumulated pollution on the roof (Villarreal & Dixon, 2005).

The available supply of water from a well varies but about two million households have wells for drinking water (Sveriges geologiska undersökning, n.d.-b) and they can be found throughout Sweden with the aid of the interactive map by Sveriges geologiska undersökning (n.d.-a) meaning that virtually anywhere could be suitable for a well. Nine out of ten provide enough for a standard household (Bokalders & Block, 2014, p. 264) and the widespread practice today is a to install a drilled well deeper than 60 m. The cost for a drilled well can be costly with 70 000 SEK (Villaägarnas Riksförbund, n.d.) for the drilling and the pump alone could cost 20 000 SEK (VVSbutiken, n.d.). Availability of precipitated water depends on the Swedish climate which can be assessed through SMHI (n.d.) and the size of the collection area. The precipitation in Sweden is stable with a minimum of about 1 mm in March and a maximum of about 2,5 mm in August. (SMHI, 2021).

2.2.3 Air

Proper ventilation is necessary to maintain a safe and healthy environment for the well-being of the people inside a building and the building itself. (Svensk Ventilation, n.d.-c) Without proper ventilation of a building there is an increased risk of health issues such as allergies, asthma, or even chronic diseases. It is estimated that in Sweden alone, roughly 5 000 people die prematurely due to polluted air (Svensk Ventilation, n.d.-b). Households consume about 27% of the total energy within the EU, where most of that energy is used for heating (Eurostat, 2023).

For houses designed for single families, there are three main systems to achieve proper ventilation (Svensk Ventilation, n.d.-a). The first solution is natural ventilation, which is more common for older buildings. Natural ventilation relies on the warm air within a building rising and is lead out through airducts at the roof. The dissipating heated air creates a low pressure within the building, forcing new air into the building often through less isolated areas like windows. Improving the insulation of the building could therefore decrease the ability for the building's ventilation.

A more common solution for modern buildings with better isolation is to use a Mechanical Ventilation Heat recovery (MVHR) system (Svensk Ventilation, n.d.-a). This system forces the air circulation within a building using fans and ducts for a more controlled air flow and better climate with more even temperature. A MVHR system recycles the heat from the exhaust air leaving the building and applies for the intake air, resulting in a decrease in used energy. It is estimated that a MVHR system could reuse 50-80 percent of the heat energy, resulting in a decrease of 5000-7000 kWh for a normal sized household. MVHR system is more expensive than natural ventilation, but it is estimated that it could provide a net gain after 3-5 years. The last category is mixed-mode ventilation that is like natural ventilation, however, it uses some mechanical functions to circulate the air, typically fans for the exhaust air section.

2.3 House design

There are several aspects to designing an Attefallshus, some legal requirements (Boverket, 2021a) and others meant to ensure a quality house both regarding low resource consumption and comfort for the inhabitant (Boverket, 2020c).

The vertical height of a room in a house is regulated (Boverket, 2020a) as well as the placement of a room for sleep and rest (Boverket, 2021b). Though the room height requirement is only applicable to rooms meant to be used often, such as the bedroom while the bathroom is exempt. The requirement for a secluded space for sleep and rest is removed for houses smaller than 35 m^2.

There must be a certain amount of access to view the outside world from the interior of the house and access to direct sunlight to ensure a comfortable and legal house (Boverket,

2020b, 2020c). Every room that is meant to be used often is subject to this requirement while other rooms are exempt.

The house foundation helps to stabilize the ground while also carrying the loads of the house (Svenskt Trä, 2020a). A foundation needs to be sufficiently deep or stable enough to prevent movement due to ground frost if the foundation is placed on soil with risk such as moraine. The moraine covers 75 % of Sweden's surface (Bokalders & Block, 2014, p. 264), meaning that the pad foundation must be sufficiently deep. For certain foundations, the foundation must be deep enough for the soil to never freeze, which varies between 1,1 m to 2,5 m in the soil with risk for movement due to ground frost.

Depending on the chosen foundation, different heights for the rooms are possible since some foundations are the same level as the ground while others elevate the house and thus limit the vertical space available to residents (Asp-Tjällden, n.d.-a). Furthermore, the amount of preparation that must be done to the ground before constructing the foundation on top can vary along with the material and equipment required (Villaägarnas Riksförbund, 2022). The main considerations for comparison between foundation types are elevation above ground, ground preparation, required equipment and material to achieve an energy efficient home that lasts a long time without complication.

Basement foundation works by having a slab below the ground upon which walls are placed that can carry the house (Svenskt Trä, 2020b). Because the basement can be fully submerged, the extra space does not affect the building area requirement of 30 m². This solution serves as the most expensive, complicated to build and least environmentally friendly due to the required amount of material which is often concrete. A concrete slab foundation has a big slab of concrete upon which the house is placed (Asp-Tjällden, n.d.-e). This solution serves the next to least expensive complicated and least environmentally friendly for the same reasons as for the basement foundation. However, it saves the most amount of vertical living space since it can be submerged completely.

The pad foundation provides support through individual feet that are partially submerged in the ground (Asp-Tjällden, n.d.-f). Upon which the house can be placed. At least 20 cm above the ground is required to create adequate airflow to avoid damage due to moisture. This reduces the interior height of the Attefallshus. It is the easiest to construct and often requires the least amount of ground preparation before construction of the foundation while requiring the least amount of material to construct.

Crawl space foundations have a space between the ground and the house (Asp-Tjällden, n.d.-c), like the pad foundation although the space is a bit smaller above ground (Asp-Tjällden, n.d.-a).

The hybrid between crawl space foundation and the concrete slab foundation enables the crawl space to be filled with insolation and thus enabling more vertical living space without increasing the ridge height above the ground while at the same time reducing the required material (Asp-Tjällden, n.d.-b).

The overhang of the roof cannot be larger than 50 cm which otherwise adds to the calculated building area (Österåkers kommun, n.d.). However, the more the overhang the better since it protects the façade (Thomsson, 2018). The incline of the roof helps to remove precipitation from the roof and mitigate the risk of damage due to moisture (Plåt och Ventföretagen, n.d.). A minimum recommendation of a 5,7-degree incline for corrugated metal sheets can be found in AMA Hus 21 (Plåt och Ventföretagen, n.d.). A steep incline reduces the available living space by lowering the roof on at least one side depending on the roof configuration. The reduced interior space has a greater effect the smaller the house. Certain roof materials can release toxic material into the environment which stresses the need to choose an appropriate material such as clay tile, certain felt roofing materials, stainless steel and treated cement tile that have shown no toxicity in certain tests (Andersson-Wikström et al., 2015).

2.4 Technologies

There are several technologies that can fulfill the demand and criteria for the Attefallshus. They are described here.

2.4.1 Photovoltaic (PV) Panels

Solar panels convert sunlight to electrical energy either through mirrors that concentrate solar radiation or by photovoltaic (PV) panels. The energy generated can be immediately used as electrical power or stored in batteries or as thermal energy. In theory, Solar energy can be an excellent source of power for off-grid houses for self-sustainability (U.S. Department of Energy, n.d.-a). However, there are multiple challenges in the current day landscape of the industry. Primarily, batteries that can hold and store the amount of energy required are expensive. Furthermore, special climates with a lot of sunlight are required to be able to generate more energy. Meaning, that some climates may not be able to consistently produce enough energy all year round to supply a self-sufficient living.

Photovoltaic (PV) panels work by using semiconducting materials to convert sunlight into electrical power. A single PV device is called a cell and usually multiple cells are used to generated power, known as modulus or panels. Individually, cells are small and do not generate much power (usually around 1 or 2 watts) (U.S. Department of Energy, n.d.-d). Cells are sandwiched between protective materials of glass and plastics to be able to withstand years of outdoor usage.

Efficiency of PV is the percentage of the sunlight shinning on the panel that is converted into energy. Most of the sunlight shining on the panel is usually lost, and there are several factors that contribute to this (U.S. Department of Energy, n.d.-c).

- Wavelength, depending on the wavelength when hitting different reactions occur. Some of the photons get reflected while others are absorbed.
- Recombination reverses the process from which electricity is generated by having electrons recombining.

- Temperature, higher temperature affects the properties of semiconducting materials leading to lower efficiency.
- Reflection, higher reflection of the panel leads to lower efficiency.

2.4.2 Anaerobic Digestion

Anaerobic digestion (AD) occurs in space without oxygen, where a breakdown of organic matter results in production of biogas. The produced biogas consists of methane and carbon dioxide. The AD process has been widely used for the treatment of various organic waste as food waste, including toilet paper (TP) and human feces (HF) (Kim et al., 2019).

The AD is sequences of process where microorganisms break down biodegradable material without oxygen, which involves four steps.

1. Hydrolysis is the first step, and are that bacteria break down organic materials into simple rounds, like sugars and amino acids (Uddin & Wright, 2022).
2. Acidogenesis is when bacteria convert these sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids (Uddin & Wright, 2022).
3. Acetogenesis is the third step and is when bacteria convert the rest of the organic acids into carbon oxide, hydrogen, and ammonia (Uddin & Wright, 2022).
4. Methanogenesis is the last step and occurs when methanogens convert these materials into methane and carbon dioxide (Uddin & Wright, 2022).

AD has two different ranges of favorable temperatures to maximize performance. Temperatures ranging from 55 – 60 °C are defined as thermophilic digestion. The high operating temperature requires an additional heat source but provides a higher biogas production rate. However, this process is often unstable (Uddin & Wright, 2022).

The other range of temperatures is between 35 – 40 °C and is called Mesophilic digestions and most commercial digesters are within that temperature range. Mesophilic digestion produces less biogas than thermophilic digestion but provides a more stable operation with lower costs (Uddin & Wright, 2022).

AD of HF and TP has been recognized as a promising approach for the treatment of household organic waste (Kim et al., 2019). The breakdown of organic matter involves the use of microorganisms. The biogas produced can be used as a source of renewable energy for various applications, including cooking, lighting, and heating. According to Professor Cho Jae-Weon (Ellichipuram, 2021), a singular person defecates upward of 500 grams a day. Hence, AD could be able to produce approximately 50 liters of methane gas which can produce 500 Wh.

There are several advantages to using AD for HF and TP. It can reduce the volume of waste, eliminate pathogens, and produce a valuable source of energy. Additionally, the process can be used by using simple and low-cost technologies, making it suitable for off-grid settings (Kim et al., 2019).

The anaerobic co-digestion of HF and TP has been shown to have synergistic effect on biogas production. The combination of both substrates can result in a higher methane yield compared to the sole digestion of each substrate. TP provides a source of carbon that can balance the carbon-to-nitrogen ratio in the waste leading to a more efficient AD process (Kim et al., 2019).

There are still some challenges with AD of HF and TP. A main challenge is the nitrogen content in the waste because it can lead to production of ammonia during the AD process. If ammonia is produced it can result in a decrease in efficiency of the process as well as the quality of the produced biogas. Therefore, it can be of interest to add TP as it is carbon-rich to balance the carbon-to-nitro ratio (Kim et al., 2019).

2.4.3 Nanonmembrane toilet

The nanomembrane toilet is a technology that can transform decentralized sanitation systems. The design is made to recover clean water from urine contaminated by feces in a single step. The technology uses a membrane distillation process to separate water from the urine, which then is purified and collected.

Membrane distillation is a process that uses hydrophobic membrane to separate water from a moving feed solution. The membrane used is designed to only let water vapor pass through. The nanomembrane toilet uses a specially designed membrane that has nominal pore size of 0.1 to 0.5 μm. In the case of this nanomembrane toilet, the feed solution is concentrated urine contaminated by feces. Which is heated to a hot temperature to create water vapor. The vapor then passes through and is collected as clean purified water. The membrane is designed to withstand elevated temperatures without degrading (Davey et al., 2021; Kamranvand, 2018).

In the Nanomembrane toilet, feces and urine are separated and the feces are transported to a chamber where the first step of the mechanical process is started. Firstly, the feces are broken down into smaller pieces, to increase the surface area and facilitate the drying step. Secondly, the feces are mixed with a bulking agent such as sawdust or ashes, that is made because of the need to absorb excess moisture and improve the drying step. The bulking agent helps with reducing odors and improving the characteristics of the final product (Davey et al., 2021; Kamranvand, 2018).

Now the thermal process begins, after the feces been broken down and mixed with the bulking agent, it undergoes a series of steps to remove moisture and kill pathogens. The first step involves heating the feces to a temperature around 70 degrees Celsius, which aims to evaporate excess moisture and reduce the risk of pathogens. The second step is also heating, but here its temperature rises to 90 to 100 degrees Celsius to completely ensure drying and pathogen inactivation (Davey et al., 2021; Kamranvand, 2018).

The final product is now a dry, odorless material that can safely be removed and used as a fertilizer or fuel source. As it is rich in nutrients, particularly nitrogen, phosphorus, and potassium, which makes it perfect food for plants (Davey et al., 2021; Kamranvand, 2018).

There are multiple advantages to using membrane distillation for urine treatment. Firstly, membrane distillation operates at lower working temperatures and pressures. Therefore, it results in lower operation costs and less stringent mechanical properties. The solution becomes more affordable and easier to maintain, which makes it a perfect solution for an off-grid setting (Davey et al., 2021; Kamranvand, 2018).

The membrane distillation makes the purified water safe for reuse in various applications, including irrigation, washing, and even drinking. Since distillation offers 100 percent retention for non-volatile dissolved matters theoretically. By that, this means the solution can effectively remove all contaminants such as bacteria, viruses, and other pathogens (Davey et al., 2021; Kamranvand, 2018).

2.4.4 Hygroelectricty

Hygroelectricty is a recent technology that has been proposed as a new green electricity form (Huang et al., 2018). As explained by Huang et al. (2018), it works by producing electric power from the air by absorbing gaseous or vaporous water molecules, which are present in the humidity. For Sweden, the humidity is around 80 % (SMHI, 2023), which is above the required 35 % for hygroelectric generation.

The tech is based on the principle of converting potential energy of water molecules into electricity, it can be done by using hygroscopic materials with a chemical-gradient structure as well as a pair of electrodes. The working principle of hygroelectricity is based on water molecules being absorbed by a hygroscopic material, which results in a generation of free charge carries by an ionization effect. The direct diffusion of the charge carries under the function of a gradient structure in the hygroscopic materials, creating electric potential between two electrodes. The electrodes induce a flow in an external circuit and therefore produce electric power. The special electrode of graphene oxide interface forms a well-matched charge zone. The zone acts as a gate to block free electrons trough the graphene oxide and regulates its flow direction, promoting the electric output.

Hygroelectric generators are scalable for practical applications as the output of a single generator unit is typically in the range of 0,035 Volt to 0,7 Volt. However, high voltage generators can be reached by scaling up the number of hygroelectric generators units in series (Huang et al., 2018). As scalability is the key feature, one company has plans to stack over 20,000 of the generators into the same humidity battery by 2024 (Ferrell, 2023). By stacking the generators, the company CascataChuva expects to have hygrolectric generator that can produce 10 kWh per day. The installation cost of that battery is expected to be between 14,000 and 18,000 euros.

2.4.5 Windmill

The energy harvested from wind is renewable and has been harnessed for centuries (U.S. Department of Energy, n.d.-b). Windmills especially have had several applications

throughout the centuries, such as grinding grains, pumping water, and in recent years as a source of generating electricity. The basic principles of small windmills used to generate electricity are described by the U.S. Department of Energy (n.d.-b). They work by converting the kinetic energy in the wind into mechanical energy. Then mechanical energy can be used to produce electricity and power. The components in a windmill are usually a rotor, blades, shaft, gearbox, generator, and tower. The rotor is the part of the windmill that captures the wind and makes blades turn. The aerodynamic design of the blades is angled to capture the most amount of wind energy. By the connection through the shaft from the rotor to the gearbox, the speed increases to a certain level which drives the generator. The generator converts the mechanical energy into electrical energy and could therefore be used to power houses. Lastly, the tower's task is to support the windmill and raise it from the ground to harness the maximum amount of wind energy.

One advantage of windmills is that they are scalable, as they can be built in a wide range of sizes (U.S. Department of Energy n.d.-b). The smaller one can provide electricity for a single home, where a farm of windmills could be able to provide for a couple hundred homes. Hence, the scalability makes windmills a flexible source of energy that could be adapted to fit the specific need. The smaller windmills are mostly used for single homes, and when the windmills are mounted on a tower it can generate upwards to 15 kilowatts of power per day (U.S. Department of Energy n.d.-b). Therefore, they are suitable for remote locations where the home cannot access the grid.

2.4.6 Energy storage

Using more environmentally friendly alternatives such as windmills to generate energy or electricity is a great method to push for sustainable living. However, some of these alternatives that harness the power from the environment create fluctuations in the amount of energy produced over time. These fluctuations could lead to both shortages and surplus of energy over time causing a waste. There are methods to counter to counter the varying energy supply by using energy storage systems such as electrical energy storage (EES) in batteries or to use pumped hydro energy storage (PHES) (Barnhart et al., 2013). PHES pumps water from a reservoir at a low level up to a higher level at time of large energy supply. When there are higher demands of energy, the water can be returned to the lower level while used to generate energy to be used. PHES is commonly used for a large grid where it can store and control energy flow at a lower cost than EES, however, EES is continuously falling in price. However, for shorter storage with faster output and smaller scale EES has the advantage over PHES (Barnhart et al., 2013; Blakers et al., 2021).

2.4.7 LifeStraw Community

One viable product that could be used to purify water for the Attefallshus is the LifeStraw Community (LifeStraw, n.d.). The LifeStraw Community can purify over 98 000 liters of water, after which it is possible to change the filter and continue to use. According to LifeStraw, this should be enough to provide purified water for 25 people for about 3

years. LifeStraw Community costs almost 400 USD and the replacement filter less than 80 USD.

2.4.8 Ventilation system

Swegon creates ventilation systems that can be used for buildings, including smaller houses (Swegon, n.d.). One solution, the CASA R2, is a small product typically mounted above the kitchen stove. CASA R2 is a Heating Ventilation Air Condition (HVAC) system that uses a rotary heat exchanger. This means that the HVAC system mechanically pushes the air with fans, and the thermal energy can be preserved by the heat exchanger, transferring the energy between the exhaust and supply air sections. This system ensures a controlled airflow, which is more suitable for modern buildings with better insulation, enabling energy saving. CASA R2 has an estimated price of 3 000 USD, plus installation costs (Swegon, n.d.)

3 Method

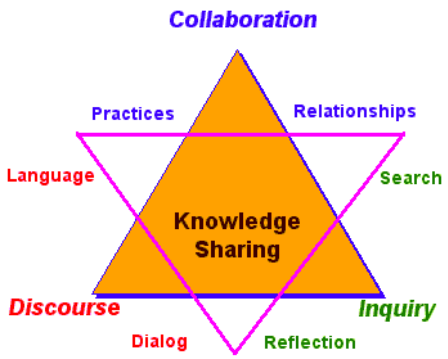
The methodology used to reach the result is described here. Chapter 4 will describe how the methods were implemented in the project.

3.1 Boundary object

A critical challenge in innovation management involves achieving efficient collaboration between experts from different departments (Caccamo et al., 2023). Literature suggests that boundary objects may be the key to solving this problem. Boundary objects act as a pivot in knowledge integration by bridging differences in expertise by being able to universally convey a meaning. Refer to Figure 3, to see how knowledge sharing through using boundary objects takes place.

Furthermore, a study by Gustavsson & Säfsten (2017) found that these challenges were founded in lack of communication and information sharing between departments in product development. By introducing boundary objects, it opens opportunities for boundary crossing providing valuable learning experiences to relevant departments. Resulting in further communication and knowledge cross-boundary integration (Gustavsson and Säfsen, 2017).

Figure 3. Knowledge sharing (Tapia, n.d.)



3.2 Double Diamond

The Double Diamond methodology by the (Design Council, n.d.)serves as a guideline for both designers and non- designers. It is a systematic approach for creative problem solving. The model tries to waver between divergent thinking and convergent thinking. Where exploring an issue extensively is divergent thinking and taking focused, decisive action is convergent thinking.

Discover is the first and initiates the process by prompting a nuanced analysis of the problem. There it is important to have a direct engagement with and observation of individuals affected.

Define is second stage and builds on the gathered insights from the first stage. It is about leveraging the information to try to redefine the problem.

Develop is generating diverse solutions to the defined problem area. This phase is about seeking innovative answers.

Delivery is the practical implementation of the solutions on a small scale, it could therefore be a boundary object. The objective of this step is to test the iterating solutions.

The core principles for the double diamond method are to put people first, communicate visually and inclusively, collaborate, and co-create and lastly iterate, iterate, iterate. Where it is important to understand the needs of the customer. By gaining knowledge of the needs, it creates an understanding of the problem and ideas. By working together and getting inspired by others will help with spotting errors, avoid risks, and build confidence (Design Council, n.d.).

3.3 TAIDA

The human brain is a scenario-generating organ, constantly taking in new experiences from the surroundings, identifying developments and taking the necessary steps. This procedure aligns with tracking, analyzing, imaging, deciding, and acting (TAIDA) (Lindgren & Bandhold, 2009).

The first step of tracking involves observing changes and detecting future threats and opportunities. As individuals, organizations must stay competitive and understand signals from the surroundings. Various methods could be used at this step like brainstorming, media scanning, and focus group for trend identification (Lindgren & Bandhold, 2009).

The second step is analyzing where the objective is to understand the consequences of change, identifying patterns and exploring the connections between them. It could be done by doing a cross-impact analysis to help identify the connections (Lindgren & Bandhold, 2009).

The third step is imagining where the organization creates a future vision to be able to reflect their aspirations. The scenarios must be realistic and have support within the organization itself (Lindgren & Bandhold, 2009).

The fourth step is deciding, and it involves linking the future scenarios and visions to the alternative strategies for the future. Trends and driving forces that were founded in the scenarios play a key role in generating a strategy.

The fifth and last step is acting, and it aims to implement the organization's strategy and its engagement in scenario planning. It involves identification of early warning signals by

new trends and changes in the existing scenarios. As establish short-term goals, monitoring, and adjust of the needed actions (Lindgren & Bandhold, 2009).

4 Approach and Implementation

This chapter will describe the project's work, how it was performed and how the result was reached with the aim and purpose in mind. The data collection and data processing will also be described along with how the tools and methods were used.

The methods used were as described in chapter 3, Double Diamond, boundary objects and TAIDA. The Double Diamond was used to develop the result while supported by the TAIDA and boundary objects. TAIDA was used for trend analysis, and the boundary objects supported the spread of knowledge internally within the group while conveying their idea to the external parties and stakeholders.

4.1 Individual research

In the pursuit of finding and understanding the technologies, systems, and principles relevant to the project, all four students conducted individual research tasks. This phase was important to gain knowledge necessary to address the complexity of creating a sustainable and self-sufficient Attefallshus. This was conducted throughout the Double Diamond process but was the focus during the discovering and developing phases, since these require both a wide understanding of the subject but also deep knowledge of the details.

Diverse subjects were studied, where technologies were explored related to energy systems, waste management, water supply and material sustainability. The research included both traditional and innovative solutions, ensuring an understanding of the options. By leveraging various sources, like academic literature, industry publications and online resources each student brought valuable insights to the collective knowledge.

Collaborative meeting or presentation from individual research findings occurred during group meetings. Where key discoveries were shared, joint evaluations of the integration of the technologies, and identifying potential challenges with them. This process allowed a refining of the collective understanding and improved decision making during all stages of the project. The individual research tasks served as an important part of the foundation, enabling an approach to the design and implementation phases with a full understanding of the technologies and systems needed to achieve the project's aim.

4.2 Meetings

The Double Diamond's core principles are collaboration with iterations of ideas and solutions, achieved through group meetings. These interactions between dynamic platforms for sharing insights, addressing current challenges, and collectively steering the project towards the aim. The core principles of the Double Diamond are collaboration in conjunction with iterations of ideas and solutions, was achieved through group meetings.

4.2.1 Meetings between group members and stakeholders

During the project frequent meetings were held to provide a forum for open discussion on project progress which allowed the exchange of ideas and alignment of individual efforts. Every Monday and sometimes more often meetings were held with the project supervisor to get valuable input and to ensure the alignment of the aim and expectations from the project owner. Throughout the project, these meetings helped refine the understanding and provided guidance on navigating obstacles.

4.2.2 Group meetings for problem-solving

Group meetings were recuring during the project to tackle specific challenges encountered. Through physical meetings and bringing together collective knowledge, these sessions fostered creative problem-solving. Whether it was addressing design options, technical integrations, or challenges, these group meetings provided an environment for brainstorming, idea generation, or consensus building. The nature of physical meetings and an open mind regarding innovative ideas allowed for the refining of solutions and improved decision making.

4.3 Trend analysis

As part of our approach to answering research questions and gathering knowledge, the Elmia subcontractor fair was visited. During this venture, the aim was to conduct a trend analysis using TAIDA, allowing new insights to be gained. This increased the customer focus on the development and discovery of the Double Diamond. This shaped the delivery phase of the Double Diamond by re-evaluating the project's priorities.

The fair provided experience, engagement with industry experts, exploration of innovative technologies, and identified potential components or solutions relevant to the project regarding the Attefallshus. During the fair it served as a dynamic platform for trend identification, involving activities such as brainstorming, media scanning, and observations.

The TAIDA framework was utilized during the trend analysis. It involved tracking changes in the industry, analysis of future consequences and identification of patterns in the market. This process facilitated the prediction of future scenarios, that also aligned with the aim for a sustainable and integrated system in the self-sufficient and off-grid Attefallshus.

4.4 Boundary objects

The boundary objects were designed in collaboration, from the beginning in the discovery phase and continued to be developed during each stage of the Double Diamond as the project matured and became more detailed. The boundary objects were first developed through quick sketches and diagrams such as ATTACHMENT/REFERENCE. This

gave an initial understanding of how the different technologies could be integrated into a system. During the delivery phase, the boundary objects were developed with a focus on the details.

The boundary objects for the Attefallshus are both digital through computer aided design (CAD) and physical. The CAD model could be built to scale, while the foamboard was built with the scale 1:20. A physical model prototype was created ahead of the digital model. The final digital model was built with the most detail and contains the correct proportions and dimensions. This was used to create the final physical model, which had to be changed due to limitations discovered during the creation of the final digital model. The interior floor plan did not have enough room to fit all the systems.

4.4.1 Physical model

The model was constructed using foamboard as the main component in the school's workshop, and this hands-on approach allowed visualization of ideas in a three-dimensional space. Therefore, it gave a feeling of how and where the Attefallshus could be spacious and not. This was an advantage when trying to locate where the technical systems and products could be placed.

4.4.2 Digital model

The digital model was built with aid from both the CAD programs of Catia V5 and SolidWorks. Catia V5 was used to create shape for all the components in the model which contains all the dimensions. Once the shape was finished, the model was converted to a SolidWorks file. SolidWorks was used to change the appearance of the model and the surrounding environment.

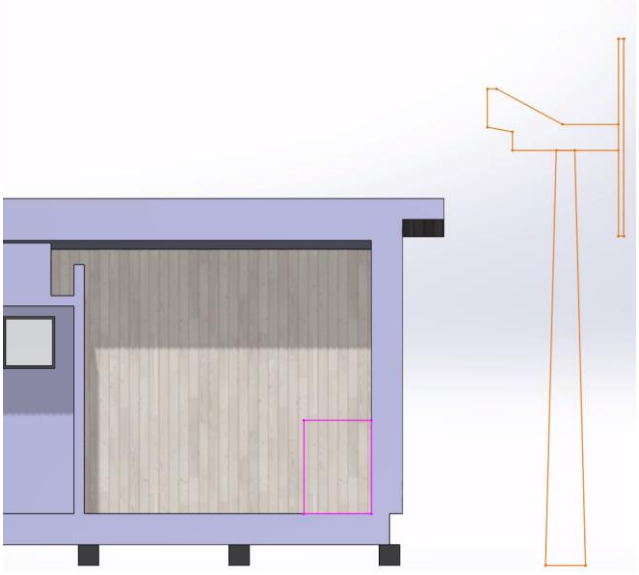
5 Result

In this chapter the result will be presented. It consists of the solution for the energy, water, material and air systems, the boundary objects developed and the trend analysis using TAIDA.

5.1 Energy system

The energy generation system is shown schematically in Figure 4.

Figure 4. Schematic view of the energy system



The examination of energy alternatives for the Attefallshus project culminated in the selection of hygroelectricity as the primary energy source, complemented in energy spikes by windmills as secondary. Hygroelectric generators can offer an innovative solution aligned with the specific energy needs of the project. As the new hygroelectric generators can produce up to 3650 kWh a year the energy demand is nearly met.

Windmills complement hygroelectricity as a secondary energy source. The scalability and flexibility in windmills allow for varying energy needs, making them an ideal power source for the Attefallshus. Where smaller windmills can generate 15 kWh a day, it offers a reliable backup for the primary energy sources.

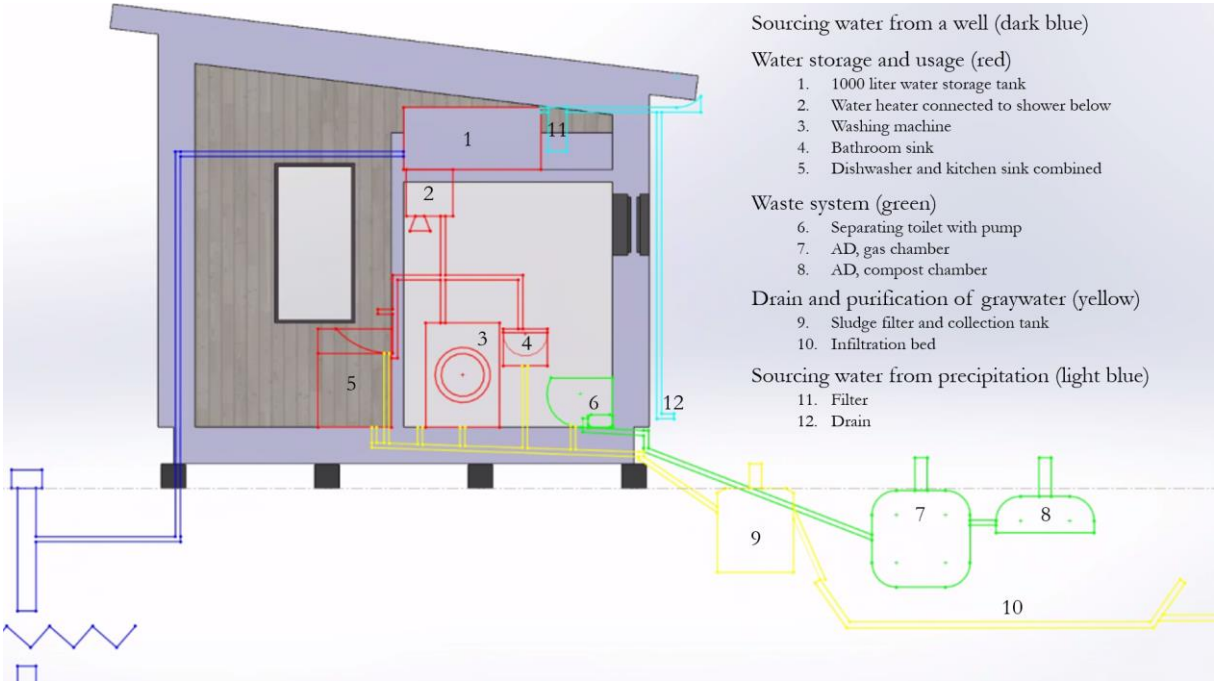
The strategic integration of hygroelectricity as the primary energy source and windmills as secondary reflects a sustainable approach to energy planning. The system should provide reliable and self-sustaining power solutions for the Attfallshus all year round.

5.2 Water and waste system

The water and waste system has been combined in the schematic representation of the intended solution shown in Figure 5. This is because of the possibility to integrate aspects

of them. Each subcomponent is numbered, and each section is color coded. The system is divided into five sections.

Figure 5. Schematic view of water and material system



5.2.1 Water

Water is used in different appliances that enable comfortable living. Namely, drinking water dispenser, tap, dishwasher, washing machine and shower shown in Figure 5. The drinking water purified through the LifeStraw mentioned in chapter 2.4.7 is not depicted. The system operates as a graywater system, meaning unsuitable to drink but should be enough to use for low level hygiene as described in chapter 2.2.2.

There are two sources, precipitation collection and a drilled well. A drilled well should supply enough water if installed correctly as described in 2.2.2 while, the available water from precipitation must be calculated. The roof's surface area and yearly precipitation determine the amount of water that can be collected. The roof surface area is 39,84 m² and is given by chapter 5.4 and a reasonable estimation of the yearly precipitation is 500 to 800 mm (SMHI, 2022), with 600 mm being common in many parts of Sweden. To calculate the collectable amount, the yearly precipitation [mm] is multiplied with the roof area [m²] (Rainwater Harvesting LTD, n.d.). 20 % could be assumed to be lost due to factors such as clogging and the initial flush that removes the first precipitation being collected after a dry period. This gives: 600 * 39,84 * 0,8 = 19 123,2 liters/year. This amount is sufficient for one person's need of about 18 250 liters/year. A backup or reserve could be needed for when temperatures drop below freezing for extended periods for the reasons described in chapter 2.2.2. This backup is the well.

The storage for the water uses a water tank of 1000 liters which is sufficient according to calculations made with the tank size calculator (Rainwater Harvesting LTD, n.d.) keeping the specific precipitation amount and demand in mind. A suitable water tank is long and rectangular considering the constrained shape of the Attefallshus described in chapter 5.4. The placement is on top of the bathroom as shown in Figure 5, which ensures that the water can fall naturally without requiring any extra energy input. A water tank with similar dimensions as 0,5 m * 1,8 m * 1,1 m (gowsalessvs, n.d.) would fit in the space shown in Figure 5. The water heater is situated as close as possible to the water tank to be as space efficient as possible.

The graywater is lastly purified through infiltration described in chapter 2.2.2, which utilizes a filter for the sludge and space for the water to spread on the ground as shown in Figure 5.

5.2.2 Waste management

The waste management strategy for the Attefallshus centers on the implementation of AD as the primary waste treatment method, incorporating a separation in the toilet of urine and feces.

The methane produced during the four-step process of AD holds significant value within the projects sustainable approach. Rather than being released into the atmosphere, the produced methane will be used for cooking purposes. This not only increases circularity but also provides a renewable and clean energy source for daily household activities.

Another aspect of the waste management strategy involves the separation of urine and feces at the source. This separation aligns with advancements in waste technology, such as the nanomembrane toilet, to optimize efficiency. The separate urine will be connected to the pipes that take care of the greywater for filtration and purification as depicted by the yellow pipes in Figure 5.

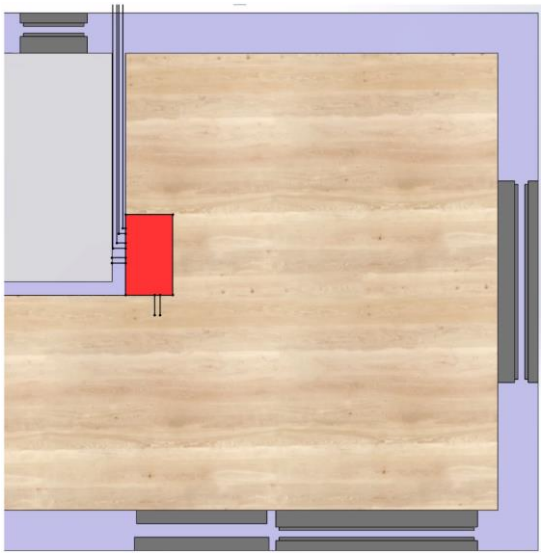
The advantages of urine-feces separation are many. Firstly, it addresses the challenge of nitrogen content in the waste, mitigating the potential production of ammonia that could occur during the AD process. This enhances process efficiency and improves the quality of the produced methane. Moreover, the separated urine can be utilized in the purification of greywater, closing the loop in a sustainable waste-to-resource cycle.

This waste management strategy, combining AD with urine-feces separation, shows commitment to an innovative and eco-friendly Attefallshus. By integrating advanced technologies and sustainable practices, the aim is to have a waste management system that minimizes environmental impact and contributes to the generation of renewable energy.

5.3 Air system

Figure 6 shows the schematic view of both the system for ventilation and heating of the air.

Figure 6. Schematic view of the air system



5.3.1 HVAC

The chosen option for HVAC system is Casa R2, with intended layout as can be seen in Figure 6. Casa R2, as described in chapter 2.4.8 is compact enough to be mounted above the stove in the kitchen and provides a good airflow with minimum installation costs in the form of ducts connected to the outside of the building. The fresh air will be pulled from outside to the kitchen area.

5.3.2 Heating

When it comes to heating, there are two main ones for the house in question. It is the amount of energy it takes to heat up the interior and water. The data for both are gathered in diverse ways. Since the house in question has its own unique dimensions, it is difficult to use reference data as a result. Instead, an approximate is calculated based on the requirements of the situation.

Calculation of heating up a 30 m^2 place starts with taking out the volume of air that needs to be heated. In this case it is 92,5 meters squared. Afterwards, the power required to heat up the air is multiplied with the amount of air (volume of air). In this case, 30 W is used to heat up air from -10 degrees to 20 degrees Celsius (Sonnenkönig of Switzerland, n.d.). In total, 2775 W is used to heat up 92,5 m^3 of air. Furthermore, this number increases based on the number of doors and windows because of poorer insulation. For every window 100 W is required, while every door requires 200 W (Greenmatch, n.d.). The total energy consumption to heat up the space increases to 5 362 W, based on the house design of 6 windows and one door.

Observe that this sum is only the amount of energy required to heat up the room once, afterwards there is a need to continuously input heat based on the loss of heat due to ventilation. The ventilation at use continuously outputs 0,1 liters per second of air for every meter of squared old space. In total, the room ventilates 360 liters of air per hour.

This new air needs to be heated again, which requires energy. Based on earlier calculations, 30 W is used to heat up. In summation, 324 W are used to heat up space every hour. Additionally, the heating will only need to be used during the colder months. This report assumes that seven months out of 12 will require heating, resulting in 1,524 kWh. Therefore, the total yearly output of energy required for both the water and air heating is 7 892 kWh.

5.4 Boundary objects

The resulting boundary objects will be described. First their shape will be explained.

The shape for Attefallshus shown in the digital boundary object in chapter 5.4.2 was decided to maximize the available space for an Attefallshus with 30 m² for the width and length and 4 m height. The shape was to be common and simple and the ratio between the sides easy to handle. Thus, 7,5 * 4 = 30 m² is suitable. This would potentially enable the system solution to fit a variety of different pre-existing houses with similar proportions such as found at (Asp-Tjällden, n.d.-d). The living room and kitchen area was deemed most important when deciding the floor plan, meaning that other rooms are minimized while still being able to perform their intended functions. The dimensions of construction components are estimated and not completely accurate to what could be built in real life. They are based on common dimensions by Svenskt Trä (2015).

The bedroom shown in Attachment 3 as the room farthest to the left, is given enough room to fit a common bed with a width of 120 cm (Ikea, n.d.). The bathroom is 3,5 m² which is judged to be sufficient for the intended appliances based on a small bathroom design by (Landqvist badrum, n.d.) that is even smaller at about 2,5 m².

The window placement is at least one per room which should allow for comfortable living and adheres to regulation regarding ability to see outside and gain direct sunlight described in chapter 2.3. To increase comfort further, the living room to the far right in Attachment 3 is given sunlight and the ability to see outside through big windows.

The limiting factor for the height of living space is the roof incline and foundation type. The incline was set to seven degrees. The incline was set to accommodate the suitable roof types regarding toxicity while ensuring the sufficient water flow described in chapter 2.3. The pad foundation type was chosen because of the ease of construction, low resource consumption and suitability for many types of terrain while sacrificing vertical living space described in 2.3. At least 20 cm of elevation is required for sufficient air flow. Furthermore, the pads must be sufficiently deep to avoid damage due to moving ground caused by ground frost. The depth is determined by the type of soil and the climate in which the house is placed. The wall thickness is a standard thickness of 30 cm. A certain margin was given to the total height of 3,95 m and the roof overhang to accommodate possible unforeseen limitations or necessary alterations. Resulting in the overhang of 40 cm for each side of the house which provides as much protection as possible without altering the building area requirement of 30 m² or less.

5.4.1 Prototype physical model

The prototype physical model shown in Attachment 1. By applying multiple methods such as boundary objects for crossing boundary dimensions and Double Diamond to define the problem and narrow down the solution a prototype was built. The prototype managed to make it easier to intuitively imagine the three-dimensional properties of the house to understand whether the solutions satisfy the research questions.

Through the properties minor defects were quickly detected, such as positions of windows and door so that they do not conflict with the room layouts.

Furthermore, optimal layouts were chosen after the prototype provided a visual representation of the space. Making it easier to decide where the integrated system should be placed to make it as efficient as possible. An example of this is placing the water tank as high as possible right above the washing room. Making use of the inherent pressure to transport the water. Additionally, the bathroom is placed wall-to-wall with the kitchen making it quite easy for the water to be transported to the kitchen.

5.4.2 Digital model

The digital model shown in Attachment 3 depict a potential shape and appearance that closely reflects what could be observed as described in chapter 5.4. The texture for the façade is used from Architextures (n.d.), the interior wall texture from (Architextures, n.d.-b) and the floor texture from (Architextures, n.d.-a). The bathroom had to meet the requirements for a sufficient water tank size described in chapter 5.2.1. This meant lowering the room height to 2 m based on the water tank height of 0,5 cm. The bathroom is not subject to room height law as described in chapter 2.3 and a person should be comfortable in the room anyway because of the average male height of 180 cm (Statistikmyndigheten, 2018).

5.4.3 Final physical model

The final model, shown in Attachment 1 mimicked the final digital model considering the floor plan, roof configuration and window configuration without considering the wall, floor, and roof thicknesses. The foundation is not included either and the framing is represented by single pieces of foam board.

5.5 TAIDA

Four main trends were identified through use of the TAIDA model that are relevant to the project with the Attefallshus. Each trend will be evaluated using the TAIDA model to identify how the trends can contribute to the project.

5.5.1 Tracking

The four relevant trends that were tracked are:

- Importance of boundary object for generating interest, creating discussion, and conveying information.
- Custom products in focus rather than mass-production.
- Environmental regulation regarding product passes and related documentation and implication for the industry.
- Integrating sustainability into all faucets of businesses.

Most booths had their own products on display and all other companies had some sort of other visual presentation or resorted to offering beverages or snacks. Alternative ways to garner interest among attendees other than through the company's own product were not as successful. Overall companies with their own products on display front and center were more likely to have attendees and exhibitors engaged in discussions.

A Suzuki Garphyttan spokesperson (personal communication, November 16, 2023) mentioned that they are new to the fair because of their need to get to know their customers while marketing their latest offerings. Reasons for the exhibitors to be at the subcontractor fair is not only to talk to attendees about their product and services but also, the fact that it is a physical meeting which provides opportunities for marketing both directly to interested companies but also toward competitors and other industrial partners that might not be possible through strictly digital forums for marketing.

A main area of difficulty for the industry is the adaptation to new ecological sustainability directives and laws that will be implemented. The subcontractor's environmental impact is also difficult for customers to change or assess, which is a need for a more sustainable future (Miljögiraff spokesperson, personal communication, November 16, 2023). Furthermore, a Liljas Plast spokesperson (personal communication, November 16, 2023) mentioned how vital cooperation between suppliers and customers through the whole value chain was for the development and production of a more sustainable product. They also mentioned how increased digitalization of their production system has led to an increasingly challenging task of using the data to improve production. Furthermore, knowing the ever-nearing regulatory demands for sustainability, subcontractors must position their strategic vision to match that of its customers, which are topics highlighted at multiple booths.

A Leden group spokesperson (personal communication, November 16, 2023) states that the secure and reliable supply of energy has become a critical issue and is leading their company growth, meaning that the threat of a lack of energy supply is worth major investments in infrastructure to ensure continual operation. Energy storage can also help alleviate the cost of electricity during high demand times when prices can spike. Energy storage might become even more important when considering that an Etteplan spokesperson (personal communication, November 16, 2023) mentioned that many

companies they are working with are moving toward electrification of products and components.

A trend recognized at the fair was a move away from mass production towards customization. Many exhibitors emphasized the shift from making products in huge quantities to creating a more person tailored solution. The exhibitors highlighted the importance of understanding the customer's needs and breaking away from the standard approach of one-size-fits-all. This change might suggest that customization is not just a trend but more of a crucial strategy that subcontractors need to have to be able to compete. This trend indicates a new era where flexibility and personalized solutions take the lead.

Another point of interest was the number of countries taking part in the event. It was common for countries' chambers of commerce to have their own booths. This could be a trend of further globalization or talent exportation/importation. The reason for having these booths may be to pay attention to the country's companies or skills within the area or attract potential talents.

5.5.2 Analyzing

The visual presentation aspect to generate interest, create a discussion and convey ideas and information seems essential when introducing a new concept. As such the boundary object, meant to connect many different disciplines within sustainable housing should be in focus when presenting results and findings. The boundary object becomes the primary representation of the project, and the results should be reflected in it. Furthermore, during presentation, the boundary object should be taken centerstage at the front so that the focus of the audience is first laid on it. Some exhibitors used their space by placing empty desks at the front while their products were placed behind in glass cases in some cases. Such an environment made it difficult to identify the obstructed product which hinders curiosity if interaction with company representatives is required first.

The increased focus of environmental impact both regarding laws and increased customer interest in the reduction of environmental impact requires that subcontractors know the necessary information and can provide thorough documentation and appropriate calculation. This does not only mean an increased complexity in IT systems and increased workload for engineers and the environmental department, but also that more and broader knowledge is needed to assess the product based on many different points of view. Such is the case for the self-sufficient, off-grid Attefallshus. It is not only a matter of evaluating every component of the house in and of itself, but also how these components interact with each other and their impact on one another. Such a systematic perspective allows for increased circularity.

The growing market of energy storage shows the trend toward increasing self-sufficiency both in case of power outage but also to balance the energy grid and reduce price spikes.

This correlates to the focus of the project to find appropriate technologies and systems to allow for complete energy independence from the grid.

With Sweden being one of the leading countries in sustainability, there is a lot of attention placed upon the quality of work produced here. Whether that is for international countries to establish ties and procuring new sustainability skilled sub-contractors or to attracted people that have the competence. This may be the reasoning behind the flourishing international presence of the event. Furthermore, exchanging of ideas or probing the marking are also reasons why attending the event is preferable.

5.5.3 Imaging

One of the first and most important things noticed at the fair was the importance of boundary objects. This adjusted the focus for the product itself, making it easier to establish contact between the company and potential customers. The boundary object also made it easier to create an understanding of the product itself. We often focus on the actual product and let it speak for itself, however, this event taught us the importance of both establishing contact in a more relaxed fashion and making it easier to "sell" the product to customers with better understanding. We did not manage to gain any new knowledge of products and systems, since most solutions had a specific use, rather than the broader use we try to achieve.

Based on the reasoning behind the international presence, we can establish a strategic vision for our project. Knowing the increasing international interest in sustainability and Sweden's ever-increasing edge, we can leverage that to make our project attractive to potential international actors. This can be achieved through integrating sustainability and design. It is of the utmost importance to keep the international aspect in mind when designing the house, and not be easily swayed by the traditional elements that are not as attractive to others. Design after customer segment.

5.5.4 Deciding

This experience highlighted the importance of heightening the priority of the model house to establish contact with customers and create an understanding. The boundary object itself has low use for us for the project, but it is vital to "sell" the product to the customer.

Some of the ways we may create designs to attract the international eye is to create different houses that have the same technical core but are accompanied by different aesthetics. Meaning, design the home after the customers preferred design. Whether that be traditional architectural from their native culture or new creative modern designs. Another way to tackle this problem is to focus on one design and make it synonymous with the project. Hopefully, this would make the project stand out in its own fashionable way. Furthermore, coupled with innovation, the project could be attractive to international eyes. However, such a focus on design might detract from the projects more technical parts that are important.

5.5.5 Acting

The boundary object is prioritized because of the boundary object's positive impact observed during the fair. Creating conversation and transferring knowledge becomes easier and more interesting with a boundary object.

6 Discussion and conclusion

During this chapter, a discussion will be an analyzing text from the chapter's result and theoretical background. Moreover, a conclusion and suggestions for future research will be presented.

6.1 What is the material and energy demand for one person living in an Attefallshus?

It is estimated that a person needs and uses roughly 18 250 liters/year. This is the total amount of water both for hygienic purposes and drinking. This assumes consumption of 50 liters, a difference from the average of 140 liters per day as described in chapter 2.2. Meaning that depending on the person and their desire and ability to save resources, the estimation can vary. As for the energy consumption, it is estimated that an Attefallshus in matching size will require 2 000 to 5 000 kWh. This energy demand must be supplied by alternative and self-generated sources since this house will be in an off-grid setting. The demand is expected to peak in the colder and darker winter months, that require more energy for heating and lighting.

A commonly overlooked energy potential is the energy that could be retained from biological waste such as fecal matter from toilets. This can be used to produce energy and as a fertilizer, increasing the circularity while reducing the potential consumption of other resources.

These calculations and estimations for demands are set at a low value, where the idea is that the person wants to live more sustainably, with increased circularity.

6.2 What is a solution that fulfills the identified demand?

The total amount of water needed for a person each day is 18 250 liters/year and according to our estimations our solution should supply just above 19 000 liters/year. This means that it should result in a surplus of water supply, providing better chances even during periods of drought. Since the idea is to collect and store the rainwater at an elevated level close to the roof, it should decrease the amount of energy needed to pump the water out for use in the household. However, the water must be filtered before storage to remove larger particles such as leaves that could clog the system and purified further to be safe for drinking. By using a solution like the LifeStraw Community, the

water can easily be purified to be safe for drinking. Another benefit with LifeStraw Community is that it is cheap as it should have the capacity to purify for the settings of Attefallshus for well over 20 years, and even have cheap replacement filters to further increase the usage.

Even if the water collection solution should be enough to meet the demand, it could have limitations during extreme periods of drought or during the colder seasons. If the temperature drops well below freezing point, it is possible that energy is needed to melt the snow and ice gathered on the roof. A drilled water well can be used to decrease or even eliminate the risk of water shortage. However, it is expensive to install and might be more challenging for an off-grid setting.

Since the colder and darker months are expected to require the highest amount of energy, some solutions like solar panels to generate electricity were eliminated early during the research phase. The project instead tried to identify state-of-the-art solutions that could generate energy at a more stable and reliable rate throughout the year or solutions that could decrease the amount of energy needed. Since the house should be well insulated it could be viable to use an HVAC system with heat exchanger to both meet the requirement of circulated air and to reduce the energy needed for heating. By using an AD toilet combined with a gas stove, it should be possible to cook food without having to add extra energy, further decreasing the energy demand.

There are a few viable candidates to generate energy that are presented in the report. The solution using hygroelectricity is an interesting candidate if the technology can be supplied to the general market as expected. The hygroelectricity should provide a stable supply of energy, decreasing the need for storage and provide peak performance during the colder months when needed. Another viable candidate to generate energy is windmills, which are a well-established method. Windmills can produce a stable supply of energy even throughout the darker and colder months. In our case, it should be enough with windmill, however, this might need to be used with some type of storage such as a battery.

The boundary object helped the project both for finding potential problems and solutions for the Attefallshus and to communicate the solutions for the stakeholders and interested parties. An example for how a problem was found and subsequently solved as a direct result of one of the boundary objects is that the constraints for the placement of the water tank made it necessary to lower the roof below the standard as described in chapter 5.4.2.. Overall, the boundary objects helped to make the solution more realistic by placing the different systems in a more realistic context.

6.3 How well does the solution fulfill these demands?

The solutions presented for the Attefallshus do enable sustainable off-grid living. With an integration of solutions that decrease the amount of energy needed by reducing waste and generating new energy and water, the demand is met in surplus. Some solutions, like the windmill, cannot always meet demand on their own, requiring other methods and

technology to create redundancy. Many of the solutions provided in this report are expensive both to purchase and install and might therefore prove less desirable for customers. However, the goal of the report was to find more sustainable solutions that could work in as a circularity to reduce wasted potential in energy and resources. Though the redundancy might be excessive since the heating of various systems might be lower than the averages used. For example, 5 000 kWh for initial heating from -10 to 20 is not realistic, more likely one a few degrees and then the 1500 kWh per year which is only value to be considered. It is found that the yearly drift of heating usage to be around 2 500 kWh/year based on the average numbers in chapter 2.2.1. With warm water taking up around 1000 kWh/year. However, it should be possible to cut down the usage of water down from 140 liters to 50 liters per day per person, meaning that it should also decrease the consumption of warm water.

The boundary object was helpful with visualizing layouts of the systems so that a more efficient one could be used. The more efficient the systems are designed; the less energy is used making it much more sustainable. Furthermore, it also reduces costs. The placement of the water system and the air system ended up close to each other as shown in chapter 5 which increases the efficiency.

6.4 What are the limitations for real-world implementation?

As mentioned, there could be some challenges with desirability for the solutions because of the high price. The viability of the systems has not been tested and could be problematic with different settings, providing more challenges for installation and function. Another aspect to consider is the possibility to maintain and repair the different solutions, that could be more problematic off-grid. The level of comfort can also be reduced depending on maintenance requirements. One of the more promising solutions is Hygroelectricity, however, this technology is still at an early stage but has so far been promising. Even if the technology is promising, there is no actual product of the size required for the Attefallshus at the moment. The goal was to create a system solution, using different systems like water and energy. However, this was a challenging task due to the vast number of options.

Hygroelectricity is especially desirable for customers in an environment with high year-round humidity like Sweden. Because it can thrive and consistently supply energy in an unstainable and comfortable way. The viability of the systems has not been tested and could be problematic with different settings, providing more challenges for installation and function.

Sadly, few options or solutions concerning system maintenance were considered for this research. Which can be a big problem especially when living off-grid, if the power goes out in a snow blizzard it could be disastrous considering the remote location that is hard to access. Therefore, this topic is especially important to look further into in future research. Additionally, it is not legal to have an Attefallshus detached from an existing house plot. A full building permit is required.

The true extent of sustainability improvement is difficult to answer without understanding the impact on the whole house's life cycle.

Observe, that the design was not intended for a specific location but rather the general or typical climate of Sweden, thus several factors unknown and the best solution would consider the specific environment in which the house is placed. Aspects such as wind, hours of sunlight.

6.5 Conclusion

In summary, a sustainable remote off-grid Attefallshus is possible with the technologies available today. However, that may not be desirable because many of the solutions require a substantial amount of investment. The actual resource demand for a person living in an Attefallshus is difficult to answer because of individual factors that contribute to the different demands.

Using boundary objects is effective when sharing and spreading knowledge to outside parties and within the group. It contributes well by concretizing the solutions by visualizing the problems. Observing these problems encourages creativity and can make problem solving easier.

The future of off-grid construction looks bright considering the rate at which innovative technologies are being developed that can fulfill demands in an inexpensive way compared to other existing options. This observation seems to go together with the trends noticed in TAIDA with increasing sustainability and the need of diverse ways to make up higher energy demands.

Future research should focus on assessing the viability and feasibility of the project's result. This should include all the laws and regulations that govern the construction of a house. Among them being accessibility laws that ensure that anybody can live anywhere. Furthermore, little has been investigated regarding in-depth research about the most optimal solution technological and economic. Therefore, it is recommended to investigate the relationship between Attefallshus and maintenance and the total lifetime compared to average houses in future research. A future research area could also be to investigate the manufacturing and supply chain that also should be more sustainable.

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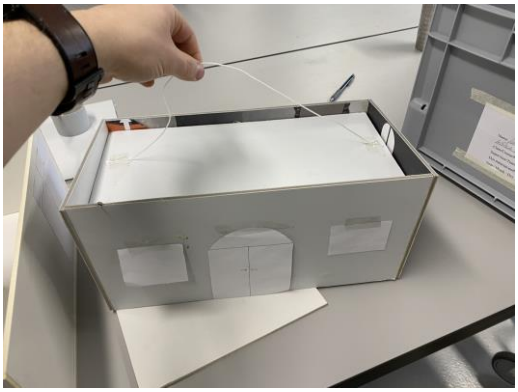
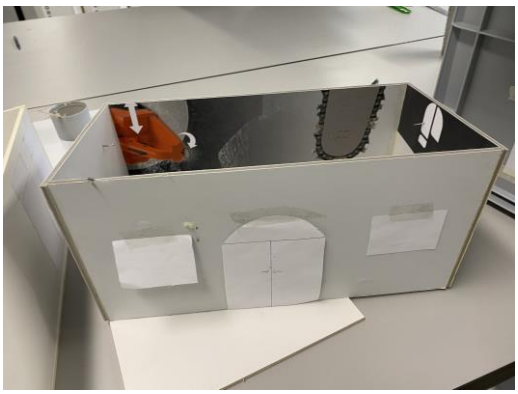
8 Attachments

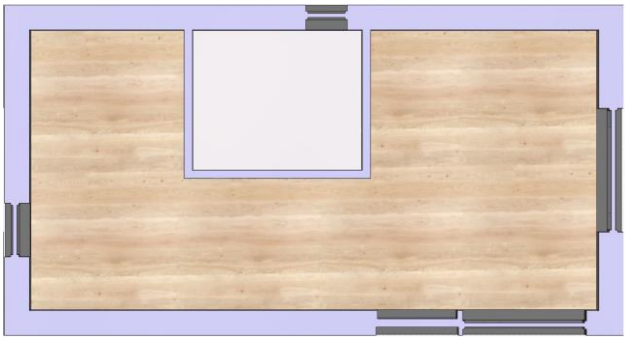
8.1 Attachment 1

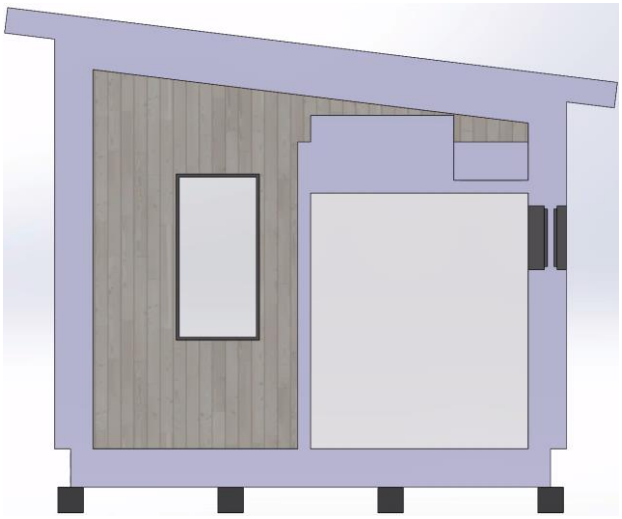




8.2 Attachment 2

8.3 Attachment 3





Linköping University | Department of Management and Engineering (IEI)
Report | TMKT78 Product Development
Autumn semester 2023

Product design and development

Applied to student accommodation.

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Abstract

This project created a concept for student accommodation according to the current needs of customers. It all started by gathering up all the necessities from the students via web survey. The answers were processed, organized, and decomposed to simplify understanding and facilitate the problem solution. Multiple brainstorming sessions were carried out both individually and as a group to define the best possible approach to the problems faced. At the end, a concept that fulfilled most of the necessities was developed and analyzed using FM/DFA and DFE Analysis which proof successful. This work was based on the methodology proposed by (Ulrich, 2012).

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1. Introduction

Rents are continuously rising, which leads to more and more young adults staying longer at home with their parents (Eurostat, 2023). However, a lot of these young people must move out from home because they want to study or start vocational training in a different town, that is often too far away from home.
Their biggest problem after finishing school then is to find affordable housing in convenient proximity to their school or university, so that they can get there without needing a car or equivalent. Hence, young adults often choose to live in student halls of residence or shared flats, where they share certain rooms, such as the kitchen or the bathroom.
But in many cities, the number of available living spaces is simply too low, which leads to the main task of this project: developing a concept to provide housing space quickly and inexpensively in areas where no or little infrastructure is in existence (Song, 2019). Therefore, the focus will be on student housing with the inclusion of sustainable aspects. Furthermore, standardized and module-based building blocks are to be designed to simplify production and reduce costs. In the following those are called student building blocks (SBBs).
The goal should be achieved by using standard methods of product respectively concept development. Accordingly, this work is structured in line with the scientific approach, that is also demonstrated in the project plan in figure 1.

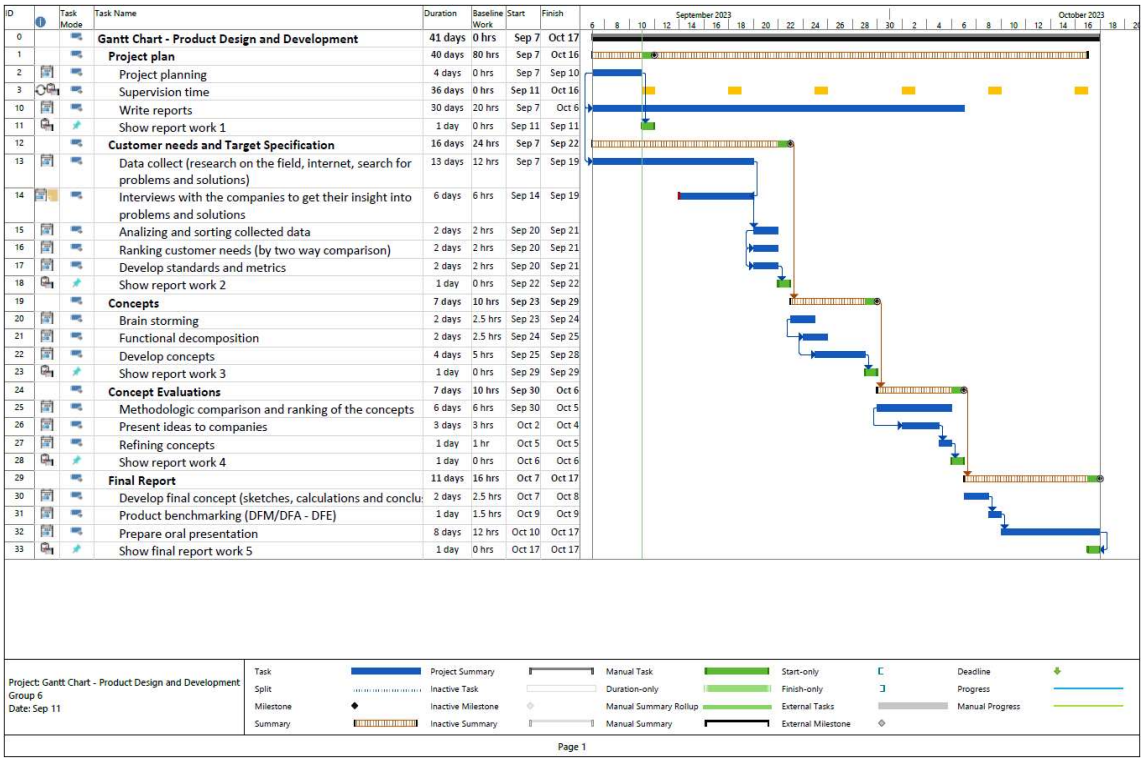


Figure 1: Project plan (own representation)

The first two weeks are allocated to do research and identify customer needs as well as target specifications by conducting surveys and interviews, which will then be covered in chapter 2. Various concepts for solving the task are then developed and designed in the following third chapter, before they are compared and evaluated in chapter 4, so that the final concept can be refined and realized. These two tasks are each scheduled for one week. After that the chosen concept will be analyzed for

manufacturing and its environmental impact, described in the fifth chapter, which takes up the remaining planned time. At the end, the work will be discussed in chapter 6 and conclusions will be presented in chapter 7.

2. Identifying Customer Needs

In the realm of student housing development, understanding and fulfilling customer needs is paramount. To ensure our project aligns with the expectations and preferences of our target audience, we adopted a systematic approach. Here is a breakdown of the steps we followed based on the book (Ulrich, 2012), with the obtained information in specific domains:

2.1 Gather Raw Data from Customers

We initiated the process by gathering customer data. This involved conducting surveys among the students, personal real-life observations combined with online research and an interview with the companies. We aimed to gain insights into student lifestyles, preferences, expectations, and pain points related to student housing.

During the meeting, we formulated 25 questions for the Internet survey and 14 questions for the interview with a potential housing company. Both lists of questions are included into the appendix as List 1 and 2. The survey was distributed among our friends, whose living conditions varied, starting from living with parents, through sharing rooms in dorms, ending up with living in their own apartments.

A chosen housing agency, Studentbostäder, is a dedicated company for student housing services. We have opted for this company because their focus is on providing affordable and convenient housing options for students, offering various types of accommodations such as student apartments, shared housing, or dormitories. They collaborate with universities and educational institutions to ensure that students have access to suitable living spaces in close proximity to their academic facilities. Despite the efforts to obtain written feedback on our questions, we did not receive an answer. Therefore, our data interpretation and analysis are based only on the student survey.

2.2 Interpret the Raw Data in Terms of Customer Needs

Once we had collected a substantial amount of data from the survey of 15 respondents, our team worked on interpreting this information. We categorized the needs into 14 general categories and standardized the data, identifying common themes and patterns among the responses. By doing that we were able to manage the data for example, searching for metrics, and choosing our final concept by scoring as presented in the upcoming chapters.

In this way, we obtained a classification consisting of 14 categories, which are:

- Basic needs
- Affordability
- Social interaction
- Proximity to campus
- Peaceful environment
- Enough space
- Security
- Privacy in general
- Eco friendly
- Easy move-in/ move-out
- Design
- Homely comfort
- Free time activities
- Access to services

The team also looked for hidden and latent needs during this step. This allowed us to transform raw data into clear and actionable customer needs. The work resulted in 62 needs that are shown on list 3 in appendix.

2.3 Organize the Needs into a Hierarchy of Primary, Secondary, and Tertiary Needs

After gathering what most people desire, we realized not all customer needs are of equal importance. To justify that our resources are allocated effectively, we ranked and identified needs based on their relative importance. This was done through an extensive discussion where every member of the group spoke his opinion on individual needs.

Through this dynamic exchange of ideas, we collectively shaped a prioritization framework that allowed us to pinpoint and concentrate our efforts on addressing the most crucial aspects. By focusing on these critical elements, we aimed to guarantee a targeted an impactful response, ultimately enhancing the overall satisfaction of our prospective residents. The needs were ranked into a hierarchy of primary, secondary, and tertiary needs, using the asterisk as a graphic indicator on list 3 in appendix.

2.4 Customer Needs

Trying to speak about customer needs, the first words should not be about anything else but basic needs. Uninterrupted access to electricity and clean running water is a fundamental necessity, providing seamless daily routines. A fast and reliable internet connection is sought after for the demands of modern living. The will for bright, warm, and comfortable living spaces, along with additional features such as underfloor heating, reflects people wishes for a cozy and welcoming home. Residents seek living spaces flooded with natural light, emphasizing the importance of a bright and invigorating atmosphere.

Customers also express the need for economic feasibility, and Student Building Blocks (SBBs), which were mentioned in the introduction, are intentionally crafted to be affordable for students. The ease of construction underscores the desire for a cost-effective yet high-quality living space.

Security is a desire that is going head-to-head with basic needs. Residents seek measures to ensure safety both from the outer door and within the building. Surveillance through camera systems, secure locks, and the presence of security guards align with the wish for a secure living environment.

Students prioritize comfortable living spaces. The design should accommodate desires for sufficient space for studying, cooking, and storage. Essential services of daily use, including laundry machines, shops, and a post office should be also included in the area of housings. Facilities for hanging and drying clothes, waste management, and secure bicycle storage align with customers space-related wishes. Students prefer private bedrooms and bathrooms. At the same time students want a connected community, especially spaces that foster social bonds. Public areas, common living rooms, and balconies cater to the desire for communal interactions. Beyond of that, living spaces, offering recreational options such as common gardens, play/hobby rooms, a public gym, and spaces for cafés could also be included as an excitement factor.

The need for proximity to educational institutions is evident, with SBBs strategically located near campuses to meet students' wishes for convenience and accessibility. Location is also an important thing in terms of tranquility, because people seek quiet spaces. Based on the survey, students try to minimize noises from neighbors and the surrounding environment in their current living conditions.

Modern, unique, modulable, and scalable designs characterize SBBs and fulfill for contemporary and adaptable living spaces. Homely comfort is an important factor, that can be appreciated by accessibility features, illuminated corridors, and scenic views that contribute to the overall ambience. Contribution to sustainability should be also present, constructing with sustainable materials, utilizing renewable energy sources and waste separation facilities.

2.5 Establish the Priority of the Categories

In this phase, we wanted to quantify the significance of different needs in the eyes of our potential student tenants. We approached this problem with a two-way comparison in a matrix shown in table 1. We assigned matrix scores to each category based on the conclusions from the discussion described in 3.3 and 3.4 chapters. The applied scale is from 0 (meaning that the need in column A is less important than the need in 1st row), through 1 (meaning that the need in column A is as important as the need in 1st row) to 2 (meaning that the need in column A is more important than the need in 1st row). Then, it was needed to divide the sum of points each row resulted with the maximum points available to get the weights. After that we knew the rank for individual categories. This resulted in categorized needs, with established weights.

Table 1. Weighting of the need by two-way comparison (own representation).

Need	security	social interaction	peaceful environment	affordability	proximity to campus	access to services	basic needs	homely comfort	privacy	design	eco friendly	easy move-in/ move-out	freetime activities	enough space	sum	max	weight	Rank
security		2	2	2	2	2	1	2	2	2	2	2	2	2	25	26	0,96	5
social interaction	0		0	0	1	2	0	1	0	2	1	2	2	0	11	26	0,42	2
peaceful environment	0	2		0	1	2	0	1	1	2	2	2	2	1	16	26	0,62	3
affordability	0	2	2		2	2	1	1	1	2	2	2	2	1	20	26	0,77	4
proximity to campus	0	1	1	0		2	0	2	0	2	2	2	2	0	14	26	0,54	3
access to services	0	0	0	0	0		0	1	0	2	2	2	2	0	9	26	0,35	2
basic needs	1	2	2	1	2	2		2	2	2	2	2	2	2	24	26	0,92	5
homely comfort	0	1	1	1	0	1	0		1	1	2	1	1	0	10	26	0,38	2
privacy	0	2	1	1	2	2	0	1		2	2	2	2	1	18	26	0,69	3
design	0	0	0	0	0	0	0	1	0		1	2	1	0	5	26	0,19	1
eco friendly	0	1	0	0	0	0	0	0	0	1		2	1	0	5	26	0,19	1
easy move-in/ move-out	0	0	0	0	0	0	0	1	0	0	0		2	0	3	26	0,12	1
freetime activities	0	0	0	0	0	0	0	1	0	1	1	0		0	3	26	0,12	1
enough space	0	2	1	1	2	2	0	2	1	2	2	2	2		19	26	0,73	4

2 means, that the need in column A is **more important** than the compared need from row 1
1 means, that the need in column A is **as important as** the compared need from row 1
0 means, that the need in column A is **less important** than the compared need from row 1

2.6 Reflect on the Results and the Process

With a comprehensive list of ranked customer needs described above, we took a step back to reflect on the data. This phase involved considering how various needs intersect and potentially influence each other. We also contemplated at the meeting how these needs aligned with our project's objectives and constraints mentioned in the introduction chapter.

When data from table 1 and list 1 were combined, the importance was finally found as shown in table 2. The importance is a result of multiplication of the rank (the weight of the category) and the hierarchy level of the defined needs. This step not only ensured that our project aligns with the highest priority needs of our target audience but also allowed us to make informed trade-offs when certain needs conflicted or posed budgetary constraints.

In conclusion, we found that to ensure customer happiness, housings need to fulfill all the security and basic needs. If any of these are not fulfilled, the rest of the needs do not make the living better or even a worth-noticing option to rent by students. Additionally, the affordability and space, contribute to performance attributes, the same way as basic needs and security. Performance attributes are fulfilling

the needs and raising the satisfaction of customer in a linear way. Other amenities shown in the table like access to services or design that we could name as excitement attributes, contribute to making very satisfied customer by fulfilling latent needs.

Table 2. Metrics related to the customer needs (own representation).

Need No.	Category	Rank	Weight	Importance	Need statement	Metrics related
1	Basic needs	5	3	15	The SBBs provide access to electricity at any time.	10, 19
2	Basic needs	5	3	15	The SBBs provide clean running water at any time.	29
3	Basic needs	5	3	15	The SBBs are warm in the winter and convenient in the summer.	14
4	Basic needs	5	3	15	The SBBs have fire exits.	18
5	Basic needs	5	2	10	The student building blocks (SBBs) offer much natural light.	9
6	Basic needs	5	2	10	The SBBs provide fast and reliable internet	17
7	Basic needs	5	2	10	The SBBs are bright inside.	12, 13, 9
8	Basic needs	5	2	10	The SBBs provide a pleasant indoor climate.	14, 27
9	Basic needs	5	1	5	The SBBs provide underfloor heating.	14
10	Basic needs	5	1	5	The SBBs bring clean air from the outside	27
11	Security	5	3	15	The SBBs are safe from the outer door.	10, 28
12	Security	5	3	15	The SBBs are safe inside.	10, 16, 28
13	Security	5	2	10	The SBBs provide secure locks.	10
14	Security	5	1	5	The SBBs are secured by camera systems.	21
15	Security	5	1	5	The SBBs have security guards.	not up to the builder
16	Affordability	4	3	12	The SBBs are affordable for students.	10
17	Affordability	4	2	8	The SBBs are easy to build.	10
18	Enough space	4	3	12	The SBBs provide enough space for living.	1, 2, 3, 6, 8
19	Enough space	4	2	8	The SBBs provide enough space for studying.	3
20	Enough space	4	2	8	The SBBs are big enough to cook simultanously with other students.	2
21	Enough space	4	2	8	The SBBs provide enough space to put personal belongings as well as fresh food.	2
22	Enough space	4	2	8	The SBBs deliver enough space for storage.	6
23	Enough space	4	1	4	The SBBs provide enough space to hang and dry clothes.	8
24	Enough space	4	1	4	The SBBs provide extra area for garbage.	6, 10
25	Enough space	4	1	4	The SBBs provide an own storage room for everyone.	6
26	Enough space	4	1	4	The SBBs provide a common bike cellar, that is closeable.	7
27	Peaceful enviroment	3	3	9	The SBBs block noises from the neighbours.	15
28	Peaceful enviroment	3	2	6	The SBBs provide quiet spaces.	15
29	Peaceful enviroment	3	2	6	The SBBs block noises from the street/ the environment.	15
30	Privacy in general	3	3	9	The SBBs include private rooms for everyone.	1
31	Privacy in general	3	2	6	The SBBs provide private bedrooms.	1
32	Privacy in general	3	2	6	The SBBs provide private bathrooms.	20
33	Privacy in general	3	1	3	The SBBs provide private kitchens.	2
34	Proximity to campus	3	3	9	The SBBs are placed near to campus.	10
35	Proximity to campus	3	2	6	The SBBs provide reaching the campus within a reasonable time.	10
36	Access to services	2	3	6	The SBBs provide access to services of daily use.	23, 24, 25
37	Access to services	2	2	4	The SBBs include laundry machines.	8
38	Access to services	2	1	2	The SBBs include a shop.	24
39	Access to services	2	1	2	The SBBs include a central post office packing station.	25
40	Homely comfort	2	3	6	The SBBs are disabled friendly.	22
41	Homely comfort	2	2	4	The SBBs are accessable through an elevator.	22
42	Homely comfort	2	1	2	The SBBs provide illuminated corridors.	12
43	Homely comfort	2	1	2	The SBBs provide a nice view to the environment.	10, 9
44	Social interaction	2	3	6	The SBBs are connected with each other.	5
45	Social interaction	2	2	4	The SBBs provide public areas.	5, 2
46	Social interaction	2	2	4	The SBBs provide common living rooms.	5
47	Social interaction	2	1	2	The SBBs provide public balconies.	5
48	Social interaction	2	1	2	The SBBs provide smoking areas.	5
49	Design	1	3	3	The SBBs are modulable and scalable.	10, 11, 16, 26, 28
50	Design	1	3	3	The SBBs are stackable.	10, 11, 16, 26, 28
51	Design	1	2	2	The SBBs inside is adjustable to accomodate specific needs	1, 2, 3, 10, 11, 13, 14, 16, 20
52	Design	1	1	1	The SBBs have design that is different from the standard	10, 11
53	Easy move-in/out	1	3	3	The SBBs are furnished.	not up to the builder
54	Easy move-in/out	1	1	1	The SBBs have large openings to get bulky objects through them.	4
55	Eco friendly	1	3	3	The SBBs are long lasting.	16
56	Eco friendly	1	2	2	The SBBs are made out of sustainable and regional materials.	11, 28
57	Eco friendly	1	2	2	The SBBs work with renewable energy.	11
58	Eco friendly	1	1	1	The SBBs make it easy to separate waste.	6, 10
59	Freetime activities	1	3	3	The SBBs provide common play/hobby rooms.	5
60	Freetime activities	1	2	2	The SBBs include a common garden for the students.	5
61	Freetime activities	1	1	1	The SBBs include a public gym.	23
62	Freetime activities	1	1	1	The SBBs include cafés or restaurants.	24

2.7 Target Specifications

When embarking on the journey of developing student housing, one of the first critical steps is to clearly define the target specifications and establish key metrics. This process not only sets the foundation for the entire project but also guarantees that the housing will cater to the specific needs and preferences of the student population. Metrics are essential for measuring the success and effectiveness of your student housing project. Metrics help you track progress and adjust as needed, but the main goal is to express subjective feelings of customers into measurable values. We intend to predominantly derive our target specifications from comprehensive student surveys and extensive research.

Certain steps were executed to create our matrix:

- Prepare the metrics list based on analyzed customer needs.
- Match specific needs with metrics.
- Set different kinds of units (e.g., m^2, SEK, Lux).
- Compare the data to set ideal and marginal values.

Table 3. Metrics matrix (own representation).

Metric No.	Metric	Need Nos.	Importance	Unit	Ideal value	Marginal values
1	Area of sleeping	18, 30, 31, 51	12	m^2	14	10 to 20
2	Area for making food	18, 20, 21, 33, 45, 51	12	m^2	~5	3 to 10
3	Area for living	18, 19, 51	12	m^2	~10	8 to 20
4	Entrance to the building area	54	1	m^2	~4	3 to 5
5	Area of common spaces	24, 44, 46, 47, 48, 59, 60	6	m^2	30 to 40	20 to 50
6	Area for storage	18, 22, 25, 58	12	m^2	~5	2 to 10
7	Area for bike cellar	26	4	m^2 per unit	2	0 to 5
8	Area of laundry room	18, 23, 37	12	m^2	~5	2 to 10
9	Windows area	5, 7, 43	10	m^2	3 to 6	2 to 8
10	Price	1, 11, 12, 13, 16, 17, 24, 34, 35, 43, 49, 50, 51, 52, 58	15	SEK	<4500	3000-8000
11	Sustainable material	49, 50, 51, 52, 56, 57	3	CO2 per ton	0,5 to 1,8	0,3 to 4
12	Ilumination on the corridors	7, 42	10	Lux	~400	300 to 600
13	Ilumination on the rooms	7, 51	10	Lux	~300	150 to 400
14	Needed temperature per room	3, 8, 9, 51	15	C	20 to 22	17 to 24
15	Acceptable noise	27, 28, 29	9	dl	35 to 40	30 to 55
16	Durability of the module	6, 12, 49, 50, 51, 55	15	years	~25	10 to 50
17	Internet speed	6	10	Mb/sec	100 to 500	10 to 1000
18	Number of fire exits	4	15	# per appartment	2	1 to 3
19	Electrical power needed	1	15	KWh/y per appartment	~2000	1000 to 3000
20	Bathroom area	32, 51	6	m^2	~4	3 to 10
21	CCTV coverage in public spaces	14	5	%	~80	0 to 100
22	reachable appartments for disabled persons	40, 41	15	%	~80	10 to 100
23	Gym area	36, 61	6	m^2	10 to 20	0 to 50
24	area for stores	36, 38, 62	6	m^2	~15	5 to 20
25	Area of parcel station	36, 39	6	m^2	~2	2 to 5
26	height of the rooms	49, 50	3	m	~2,4	2,3 to 2,5
27	Air refreshement rate	8, 10	10	% per hour	50	30 to 80
28	Density of material	11, 12, 49, 50, 56	15	kg/m^3	~2000	200 to 8000
29	number of water connections	2	15	# per block	>= 1	1 to 3

The table contains a comprehensive set of 29 metrics, each assigned to corresponding needs. The importance parameter was selected by considering the most crucial requirement within each category. When assigning units and specific values, the process adhered to law, stakeholder's opinions, existing buildings, and, of course, student needs. Units consist of m^2 for the space, SEK for affordability, Lux for light coming into the rooms, dB for the acceptable noise etc. For the noise and temperature in the buildings the data was taken from government laws setting the standards (Led rise, 2023) (Folkhälsomyndigheten, 2022) (Folkhälsomyndigheten, 2019) (Boverket, 2020) (Boverket, 2023) (BMAS, 2022). For the metrics regarding materials, web-based data bases where used, for the carbon footprint of materials (Circular Ecology , 2019). Adding to it, when determining the required space, the focus was primarily on gathering user opinions regarding their current living conditions.

The ideal value was determined through thorough discussion. Marginal values represent the range of acceptable figures, with the ideal value indicating what should guide the creation of a new concept, making it approachable and likable for everyone.

Next step was to develop a few concepts – each with a different approach. Also, it was important to keep in mind the needs, ideal values set in metrics and real-life limitations in terms of constructing buildings.

3. Concept Generation

3.1 Functional Decomposition

To fractionate the task of developing modular houses we have used a combination of two methods. First, we divided all the categories with functional decomposition into smaller segments. With a clearer picture, we started brainstorming at individual and group level. We thought about solutions that are broad enough to have “artistic freedom” when developing concepts but narrow enough so we know where to put focus on. From those ideas we created classification tree and from that we started to think about concrete solutions for each problem/need (Figure 2). Because of how broad this task is we came to the conclusion it is best to develop five different concepts to get more variety of solutions.

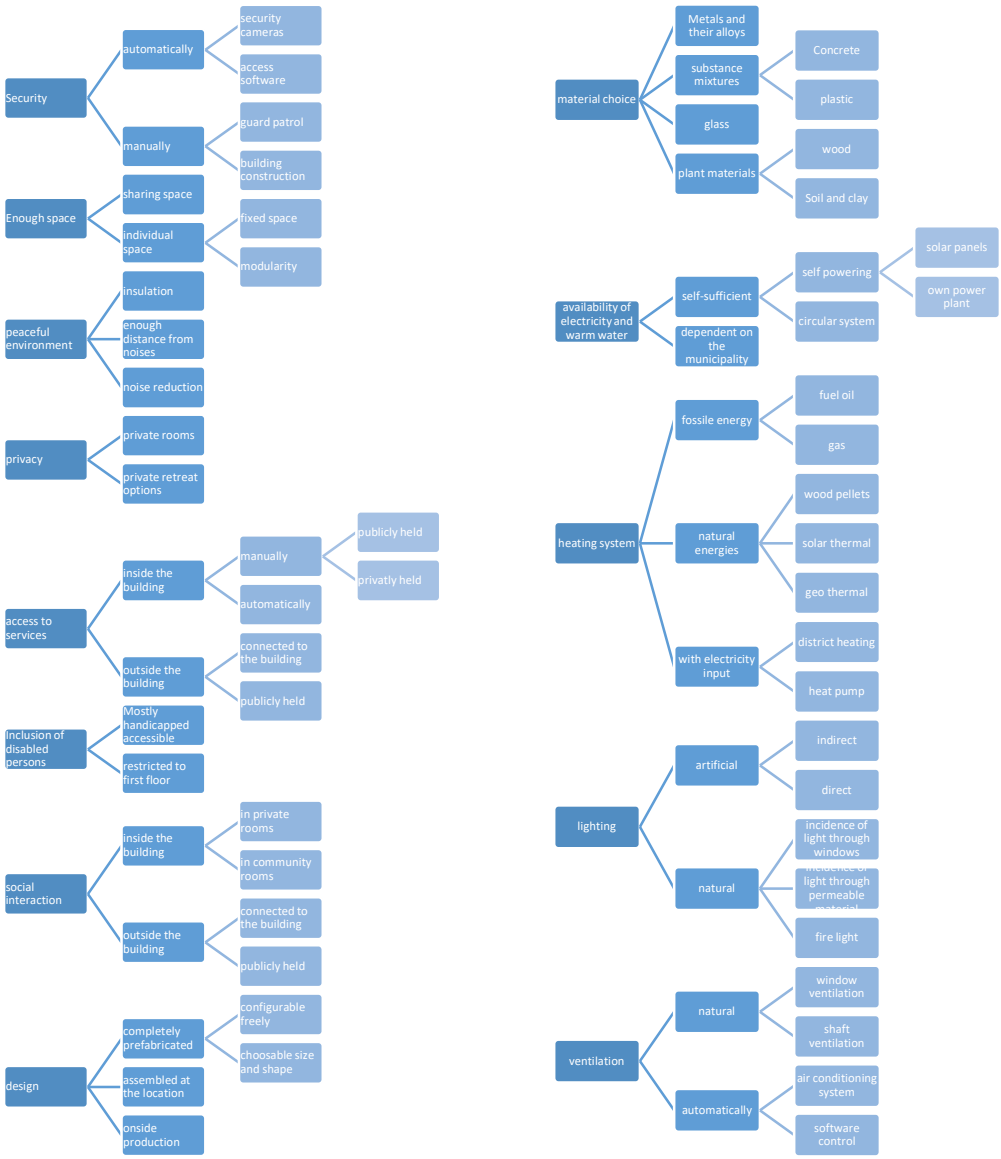


Figure 2: Functional decomposition per category (own representation)

3.2 Concept one

This concept is based on sustainability and how to combine it with comfort and price. Materials that will be used are not conventional, and some are work in progress but with promising results for the environment and the future of building materials.

To reduce time of building and CO_2 emissions, foundation will not be made of concrete but from steel pillars (Aalborg University, w.y) that are screwed into the ground. This way the building process can start the next day.

Materials used for the walls and floors of the house are going to be wood and mycocrete (Gillham, 2023.). Wood is well known building material, but mycocrete is something new. It is a concrete made of fungi mycelium, paper powder, paper fiber clumps, water, glycerin, and xanthan gum. It is renewable, compostable, fire-resistant, and entirely sustainable material.

This building will be composed out of modules (Figure 3), every apartment will be module for itself, and they will be connected like LEGO bricks. Houses will be uniform, and they will come with manual how to connect everything in one building. Since building materials are quite new it is not yet known how much weight they can hold, it is for the best for building and residence not to be higher than four stories.

To reduce the costs of electricity and water and to take more eco-friendly choice solar panels and rainwater will be used. To fit more panels the requirement is to have a larger roof, this will be achieved by prioritizing the building layout instead of focusing on height, the focus will be to achieve larger roof area in combination with higher angle of the roof. They will be strategically placed to catch as much sunlight as possible. Since the roof will be larger, the attic can be fitted, it will be used as extra storage space. Rainwater will be collected and could be used in toilets, radiators, showers and washing machines. For showers it will be filtered and for radiators distilled. These sources of electricity and water will be prioritized but still the building will be connected to the city electricity grid and plumbing.

To have more natural light in the apartments big windows will be put in every room. During the winter big windows can cool down the temperature of the rooms, to reduce that, a thin film will be put on glass of the windows that works as an insulator and caulk to seal the cracks around the window.

Main source of heating will be radiators but to reduce the need for them good insulation is required. Insulation will be made of mycelium panels (BIOHM, 2021.). It is a natural material that has high efficiency as a thermal and acoustic insulator. Other biomaterial that will be used as an insulator is moss (Welch, 1948.) and it will be put on the outer walls of the building. It is a natural heat and noise insulator that is very light weight and low maintenance material. Moss also helps improve air quality, reduce CO_2 levels and shelters the material below it.

Regarding security, every building will be equipped with CCTV (Closed-circuit television), security doors and good locks. In addition to that every corridor will be illuminated, when necessary, with natural or artificial light and around the building streetlamps will be put.

Since most student have bikes as a main transport, around the building canopy will be put. On that canopy solar panels will also be installed.

Building will have an elevator, ramps in front for disabled people and some rooms will be suited for physically disabled people, for example more reachable furniture. To provide homely comfort and enough space, rooms will have storage spaces and will be equipped with light furniture. There will be enough room for personalization.

To provide privacy to the residence, every person will have at least a private bedroom and bathroom. For people living on the bottom floor, the windows will have a film so they won't be seen but they will be able to see outside.

As this is student housing, spaces for socializing will be provided. On the ground floor of the building will be one big living room, furnished with couches, bookshelves, coffee machine and kettle. It is a place for students to come hang out with friends or just relax.

As a part of the building a small garden just for students will be present. To motivate them to work in the garden and use it as a place to socialize and/or relax it will be free if they tend to it.

This concept is a bit unconventional and pricy in the beginning but in the long run it is worth it. Big part of it was to look at what people have been using thorough history as construction materials, like wood and moss. With usage of natural materials and renewable energy we reduce CO_2 emissions greatly, and when they serve their purpose, they can be either reused or decomposed without damage to the environment.

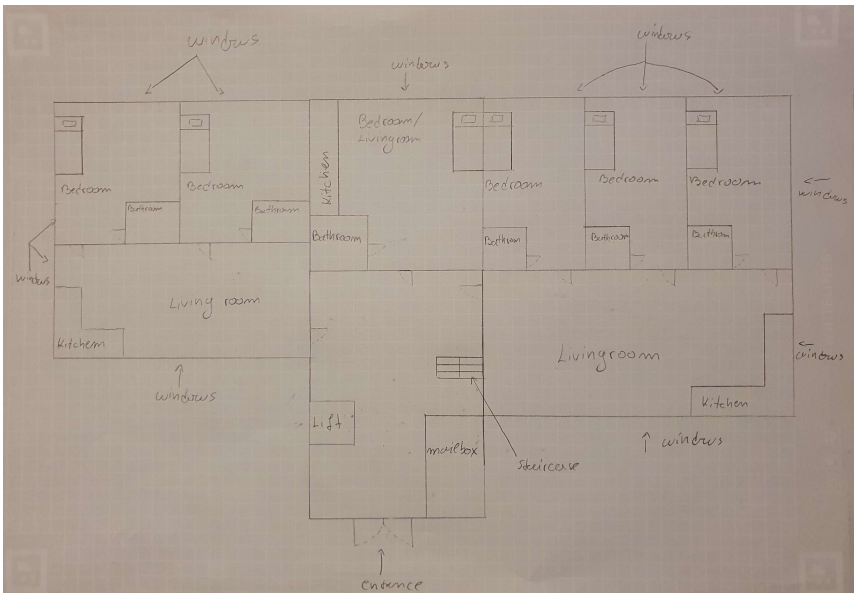


Figure 3: Layout for concept one (own representation)

3.3 Concept two

This idea is based on providing user comfort at a low cost. This solution is not only user-friendly for students who require certain standards without straining their budget but also for developers, as they can utilize proven patterns and readily available techniques. The architectural design of the building consists of simple, yet functional, rectangular blocks specifically crafted to house individual rooms. Within this design, residents benefit from the privacy of their personal bedrooms while sharing communal spaces such as kitchens and bathrooms. The building also includes a storage room, a laundry room, and a movie room. The blocks used for construction come finished.

From a bird's-eye view shown on figure 4, the building has a square shape with a courtyard in the middle, allowing for bicycle storage under shelters. The main entrance to the building is strategically positioned and branches out into three directions within the courtyard, ensuring efficient access for all people. Security is provided by a camera above the main entrance and in the courtyard, as well as secure, lockable doors.

The offered rooms are $12m^2$ in size but are taller than standard rooms, offering two levels of living, with the second one being a loft bed accessible by a ladder. This type of design is commonly used in big cities in Japan, where space-efficiency is crucial (neira, 2021). Various space-saving techniques are

employed, including compact shelving and concealed storage containers. Each room is equipped with a window and energy-efficient LED lighting with a more detailed view shown on figure 5.

The building is adapted for disabled individuals living on the ground floor. Students can socialize both in their own rooms and in common areas, whether it's during cooking or watching TV. Their external walls are insulated to provide a comfortable environment regardless of the season, reducing heating costs and soundproofing from outside noise. The building is connected to the municipal heating network, as well as to electricity, sewage, and water.

This holistic approach to design and construction prioritizes user comfort and community, making it an attractive and practical choice for both students and developers alike. For a better visualization, Adobe Firefly AI Image generator was used, as an addition to figure 4 and 5.

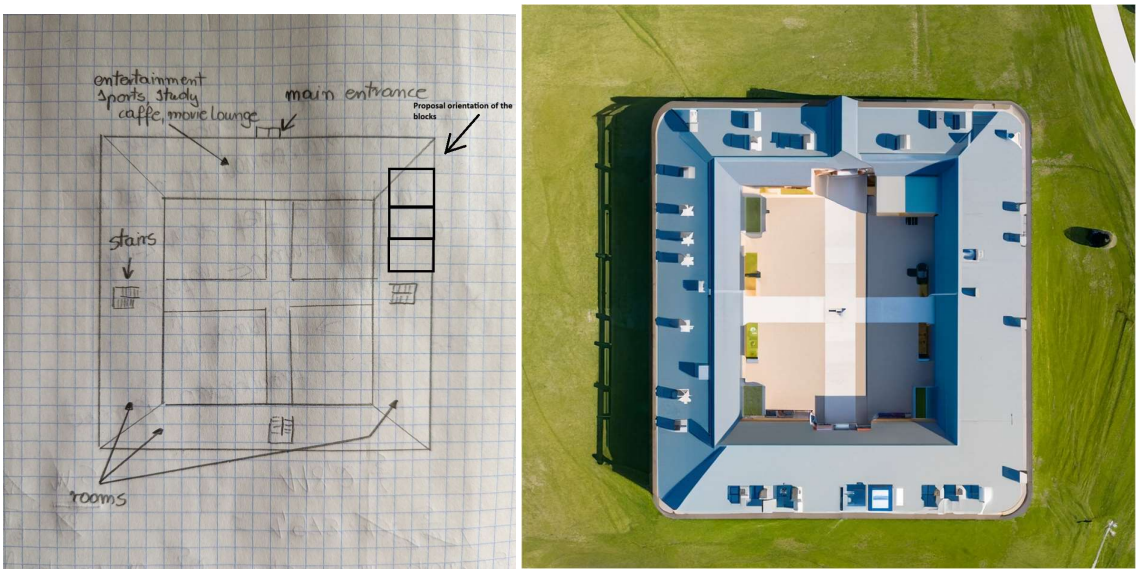


Figure 4: Layout of concept two (own representation, Adobe AI Image generator)

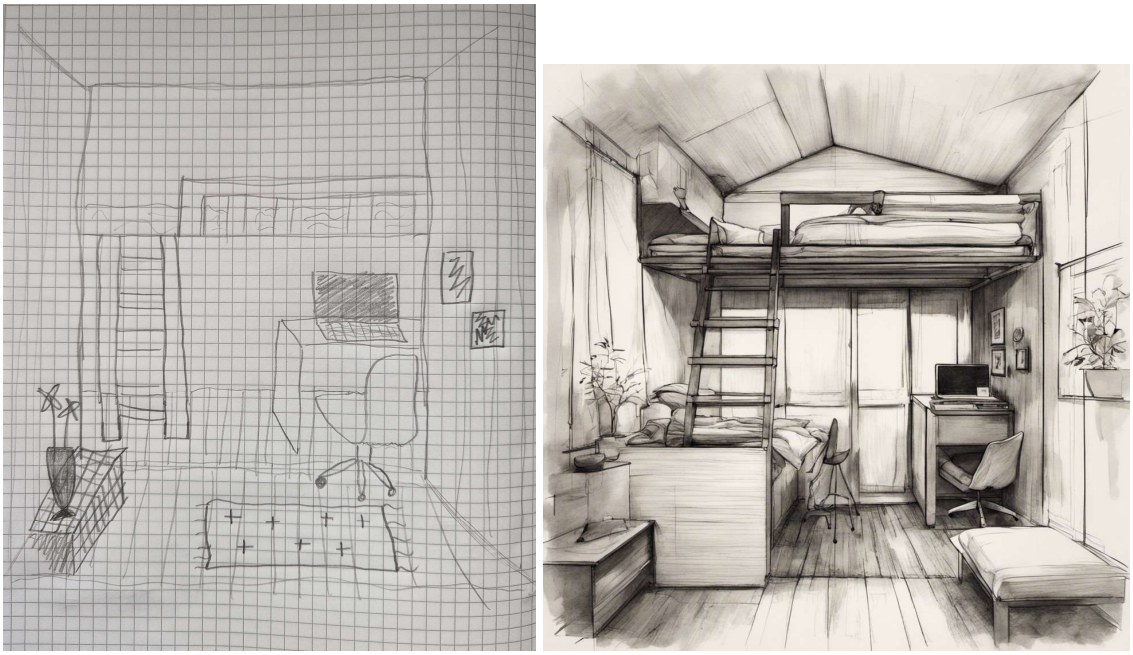


Figure 5: Concept two interior (own representation, Adobe AI Image generator)

3.4 Concept three

The following concept is made up from the point of privacy. Every apartment consists of three hexagonal rooms, that are connected to each other, shown in figure 6. So, every student has their own bedroom, own bathroom as well as their own living room, where the kitchen is included. The entrance to the apartment is located in the living room and from this room, it is possible to enter the bed or the bathroom.

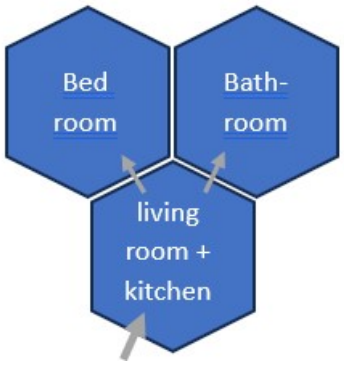


Figure 6: Layout of concept three apartment (own representation)

Then these apartments can be connected to other apartments in various ways. One example is shown in figure 7 and figure 8. You have an elevator in the middle of the whole building and the apartments are arranged around that. From the second floor on, one extra apartment can be stacked as the entry area is no longer needed.

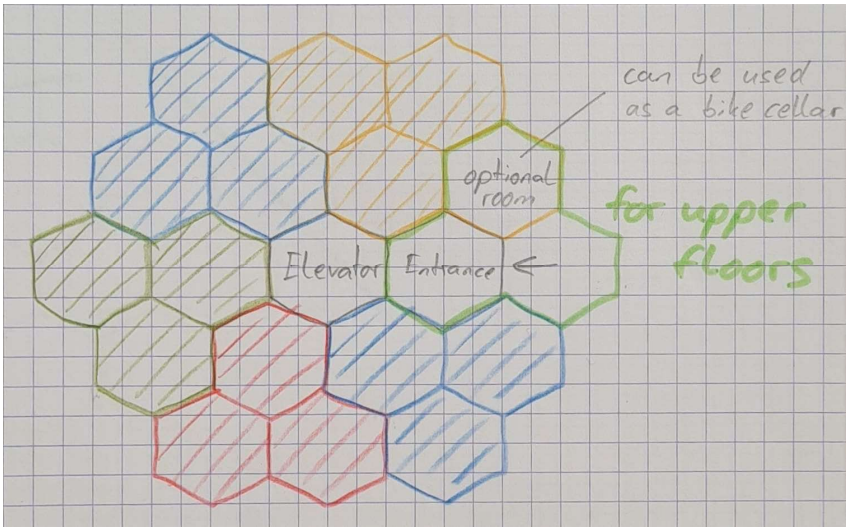


Figure 7: Layout of concept three building (own representation)

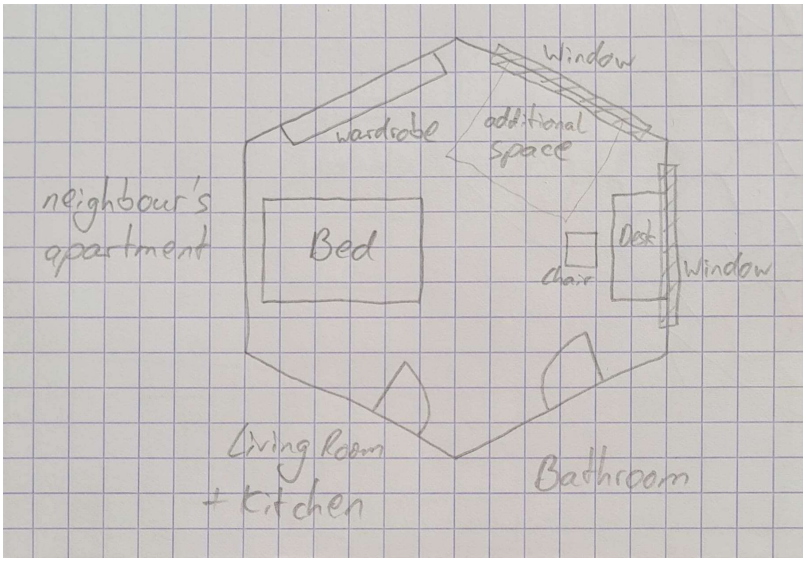


Figure 8: Top view of interior in concept three (own representation)

For security, access software (face scanning in particular) will be used to make sure only registered people can enter the building.

To make sure that everyone has enough space for his or her own stuff, depending on different interests and hobbies, there is a lot of space given within these three rooms with a predefined size. Furthermore, the walls are insulated to block noises from neighbor apartments as well as from the street. Any kind of services like shops or cafés as well as opportunities to interact socially with other people are not included in the building, because that would decrease the rate of privacy. Instead, there is enough space in the apartment itself. Handicapped people can access the whole building without any problem because of integrated elevators.

To lower the costs, the building blocks are prefabricated and available in defined sizes but can be assembled in various ways. The main used material is concrete because it provides good noise reduction and high durability (Paul, van Zijl, & Šavija, 2020). Electricity is gained through solar panels on top of the building and warm water is gained through a circular system with the usage of rainwater. A district heating system is chosen because of higher efficiency compared to other systems (Paiho & Reda, 2016). The more apartments are connected to this heating system, the more efficient it is.

The rooms are lit mainly by the incidence of natural light through big windows, but to secure privacy, so that no one can peak into the apartments, the windows have a special film layer. Also, artificial lighting in the form of LED lamps is supporting the natural incidence. In addition, the windows do not need to be opened to refresh the air because of an air conditioning system for the whole building (McQuiston, 2023).

3.5 Concept four

A Privacy focus with cost reduction by employing new proven techniques was chosen for this sketch. Figure 9 shows an isometric view of the apartment. It details that every apartment will have its own bathroom, kitchen, a window, and additional space to set a bed and study table.

In figure 10 the layout of the floor is shown. As communal space a living room is proposed, however, an additional apartment can be set on this space maximizing the number of apartments per floor. An additional communal space can be set in the outside to be shared by multiple buildings.

The access to the apartments would be via stairs or an elevator. Every floor has the intention to be accessible to disabled and non-disabled individuals. Space between the entry point and the hall is provided to comfortably move bulky objects moving. Access to the building will be granted with biometrics to ensure proper identification of the individuals eliminating the keys or cards for access. Also, cameras will be provided in each hall and the outside for vigilance and an extra layer of safety.

The cost optimization of this type of unit comes with several elements:

- Modularity: since each apartment will be the same, walls, floors and roofing can be manufactured and shipped to the building site, cutting the construction time by half. This also allows for easy expansion in case of it being necessary.
- For kitchens and bathrooms, the 3D printing of the modules on site is proposed to avoid extra costs and logistics in the transportation (Nick Bertram, 2019).
- Since the kitchen and bathroom will be made from compression resistant materials stack ability of the modules could be an option, hence the amount of apartments per square meter will be increased.
- The configuration of the kitchens and bathrooms allows for common piping between them.
- The modules will be blank when given to the students so it will be their responsibility to design/decorate the space.

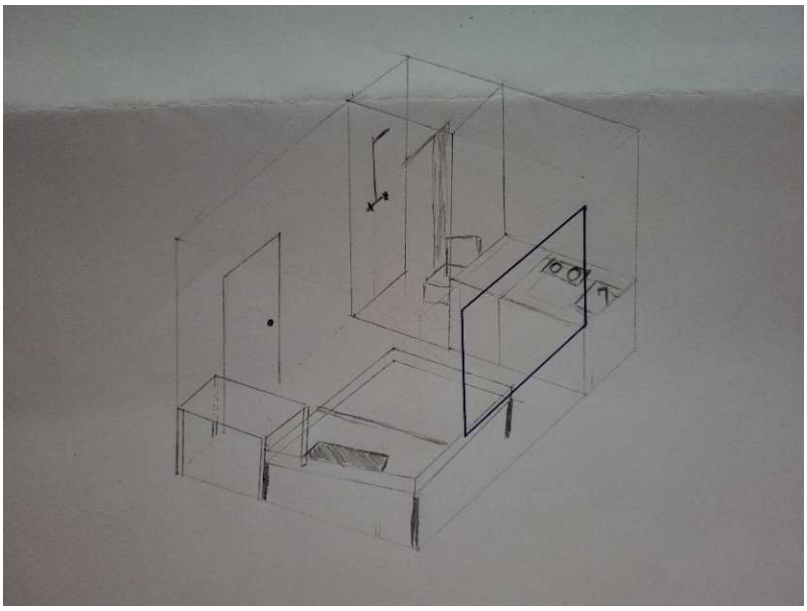


Figure 9: Isometric view of concept four apartment (own representation)

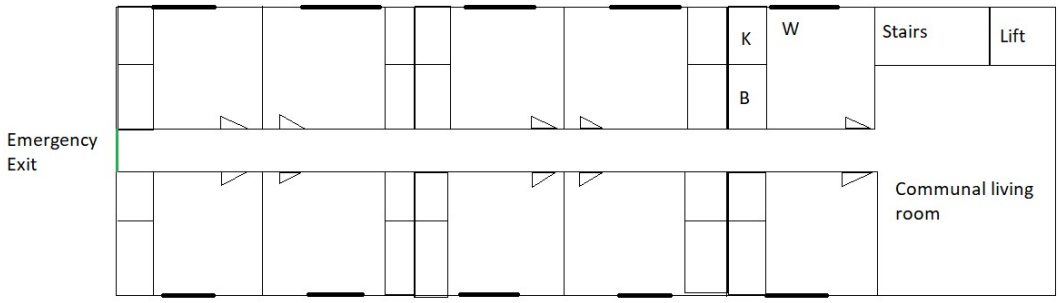


Figure 10: Top view of the concept four building (own representation)

3.6 Concept five

This housing concept presents a forward-thinking approach to address students' housing need for efficient and adaptable modular living spaces. For more information on the solution selected for this concept please refer to figure 11.

The design principle revolves around modular concrete modules, where each floor apartment is structured into a functional L-shaped layout comprising three cubic volumes. Seamlessly integrating a living room, kitchen and bathroom, and a bedroom block within a single semi-prefabricated concrete module. This compact yet comprehensive arrangement maximizes both space and functionality, providing a comfortable living environment tailored to the needs of the occupants. For a more detailed view see figure 12.

Privacy is a paramount consideration in this design. Each module stands independently, ensuring that the residents' personal space remains undisturbed. This design caters for the specific needs of students, fostering a sense of security and tranquility who often seek solitude for studying and relaxation.

The structural components, including walls, floors, and roofs, are constructed from pre-cast concrete, providing durability and longevity. The interiors are meticulously insulated for both thermal comfort and noise reduction, ensuring a peaceful and comfortable living environment.

Adequate ventilation is crucial for the health and comfort of residents. This design concept addresses ventilation through the following means:

Large, operable windows in each module allow for natural cross-ventilation, bringing in fresh air and reducing cost and reliance on mechanical ventilation. Moreover, mechanical systems with air exchange and filtration can also be integrated to maintain indoor air quality.

Ensuring that housing is accessible to all individuals, including those with disabilities, Ramps and Elevators; If the building is multi-story, ramps or elevators can be incorporated to guarantee access to all levels.

One of the standout features of this concept is that the L-shaped design allows for easy reconfiguration of rooms, offering students the flexibility to customize their living spaces. While the kitchen and bathroom remain constants within a single cube, the living and bedroom areas can be interchanged to meet individual preferences. This versatility is a game-changer (latent need) for students who may have varying space requirements or wish to collaborate with roommates to optimize their living conditions. for a more detailed view see figure 12

Moreover, scalability is a key advantage of this concept. By altering the scale-size of each apartment or eliminating living rooms altogether, these modules can be tailored to accommodate different

student needs and budgets. This cost-effective approach ensures that housing solutions remain accessible to a wide range of students.

From a construction standpoint, the production speed and ease of assembly would be remarkable. Modules are prefabricated at the contractor's yard, eliminating the need for daily operation of heavy-duty construction equipment on the building site, except for installation. The assembly process relies on efficient hooking and unhooking of floor, wall, and roof joints, promoting the reuse of building parts, such as concrete walls. This not only streamlines construction but also reduces the environmental impact associated with traditional building methods.

Imagine these modular units as sleek, contemporary living spaces characterized by clean lines and minimalist aesthetics. The prefabricated concrete components provide an industrial yet elegant exterior, while the interior is designed for maximum comfort and functionality. Large windows introduce an abundance of natural light, making the living spaces feel inviting and spacious. The interchangeability of walls and customizable layouts empower residents to make their apartments truly their own.

In conclusion, this housing concept presents a well-rounded solution that addresses the multifaceted challenges of student housing in a rapidly evolving urban landscape. Its efficient use of space, construction speed, adaptability, and sustainability measures make it a strong candidate for providing comfortable, cost-effective, and environmentally friendly housing options for students and potentially other urban populations.

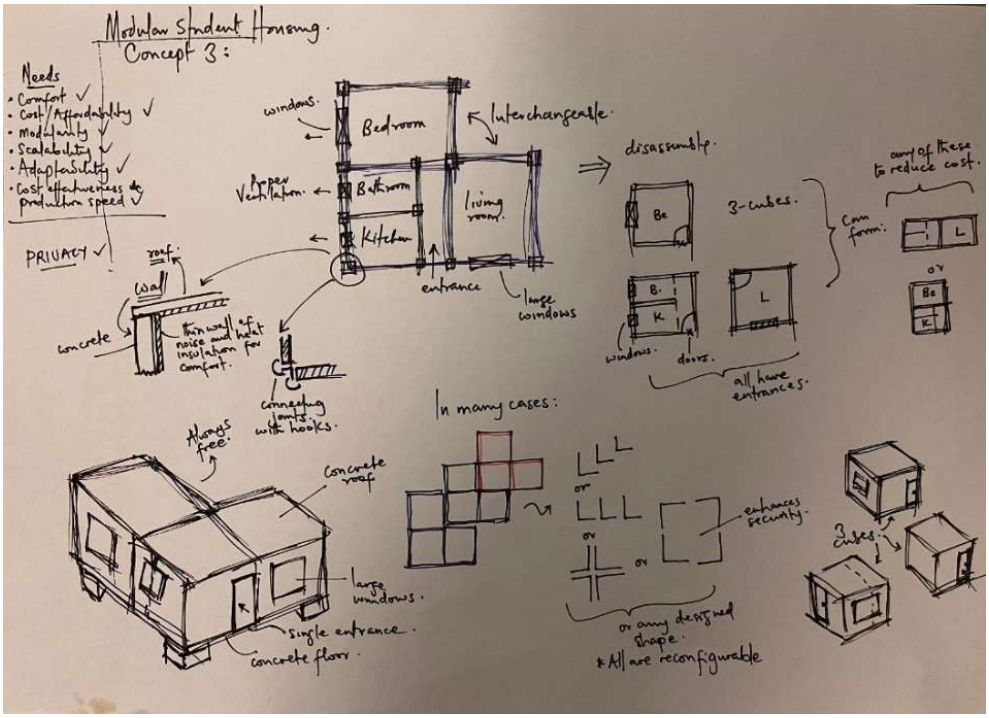


Figure 11: Layout and isometric view of concept five (own representation)

Figure 12: Room layout (own representation)

4. Evaluation

The five product concepts we generated in the preceding concept development stage, as depicted in figure 13 of the process chart, have been subjected to a rigorous evaluation process, taking into consideration the needs of our primary stakeholders - the students, which were identified in the initial stages of our product development process. Additionally, we assessed each concept against predefined criteria, thereby scrutinizing their respective strengths and weaknesses in relation to the target specifications we had established. Subsequently, after a thorough evaluation, a final concept was chosen. This selected concept underwent further scrutiny for potential improvements and refinements before being formally endorsed for further development.

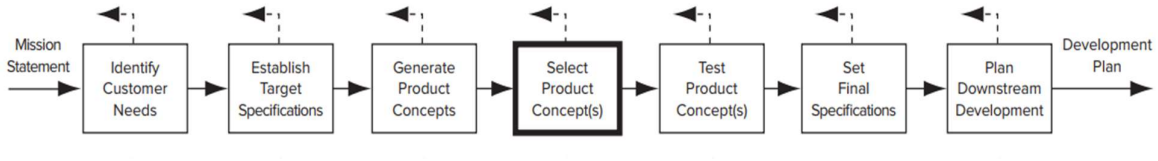


Figure 13: Concept selection as part of the concept development phase. (Ulrich, 2012)

During the concept selection phase, it became apparent that a single method was insufficient for making effective choices due to the intricate nature of the design decisions and the multitude of student needs that needed to be considered. Consequently, the project team decided to employ a combination of established methods. Initially, the team utilized a decision matrix, wherein the five concepts were systematically evaluated against a predefined set of primary student needs, each carrying significant weight in the decision-making process. Subsequently, the selection process was further refined through the application of the Pros and Cons method.

The following section elaborates on the specific process employed during the concept-scoring task within this concept selection phase.

4.1 Preparing the Screening/Selection Matrix:

In an Excel spreadsheet, we structured the selection criteria, aligning them with the primary hierarchy of customer needs that were determined during the decomposition phase. These criteria were chosen based on the weightiest needs identified in that phase. The primary focus in generating the concepts was placed on addressing the core objectives of affordability, privacy, and sustainability for the student housing solution.

To ensure clarity and precision in our decision-making process, we carefully evaluated and, where necessary, removed any criteria that were deemed unimportant or ambiguous from the screening matrix. This step was taken to prevent any undue complexity that might obscure the differentiation of concepts concerning the very important criteria.

4.2 Rating the Concepts:

Following this, we entered the importance weights into the matrix and proceeded to assess each concept by inputting ratings based on how well they performed compared to the reference concept for each criterion.

The reference concept, representing the ideal product, received equal ratings across all criteria to establish reference performance weightings. We also assigned distinct reference points for each criterion to maintain an accurate evaluation scale.

During the rating process, the team discussed the merits of each concept, focusing on one criterion at a time and using a 1 to 5 scale for assessment. This allowed for an evaluation in relation to the reference concept and alignment with the need's criterion.

4.3 Ranking the Concepts:

Once we had entered the ranks and weights for the concepts, we proceeded to calculate the percentage net scores for each concept. These scores were determined by summing the weighted scores, which were calculated by multiplying the concept ratings by the corresponding criteria weights. This calculation was performed relative to the ideal concept, as expressed in the equation below:

$$S_j = \sum_{i=1}^{n} e_{ij} w_i$$

e_{ij} = raw rating of concept j for the i^{th} criterion
w_i = weighting for i^{th} criterion
n = number of criteria
S_j = total score for concept j

We now assigned rank-orders to each concept based on their net % scores. In the table below, it's worth noting that the two highest-ranked concepts are 2 and 1, indicating their superior quality in terms of meeting the selection criteria.

Table 4: Concept-scoring Matrix for concept selection of a modularized student housing (own representation)

e = rating		Concepts											
w = weighted score		0		1		2		3		4		5	
		Reference Concept		Privacy (Tomas)		Affordability (Bartlomiej)		Sustainability by (Mia)		Privacy (Oscar)		Affordability (Juan)	
Selection criteria	w	e	w	e	w	e	w	e	w	e	w	e	w
security	5	5	25	5	25	3	15	3	15	4	20	5	25
social interaction	2	5	10	1	2	3	6	5	10	1	2	1	2
peaceful environment	3	5	15	4	12	4	12	5	15	4	12	4	12
affordability	4	5	20	1	4	5	20	3	12	4	16	2	8
access to services	2	5	10	2	4	1	2	4	8	1	2	3	6
homely comfort	2	5	10	4	8	2	4	5	10	3	6	4	8
privacy	3	5	15	5	15	2	6	4	12	5	15	5	15
eco-friendly	1	5	5	3	3	1	1	5	5	3	3	2	2
enough space	4	5	20	5	20	3	12	5	20	4	16	3	12
			130		93		78		107		92		90
Net score					72%		60%		82%		71%		69%
Rank					2		5		1		3		4
Continue?					Yes		No		Yes		No		No

4.4 Combining and Improving Concepts:

In another brainstorming session, we employed a method to evaluate each concept based on our team's opinions, highlighting their strengths and potential for refining and improvement through combination.

We selected the top two concepts for further development and identified key features from other concepts to incorporate:

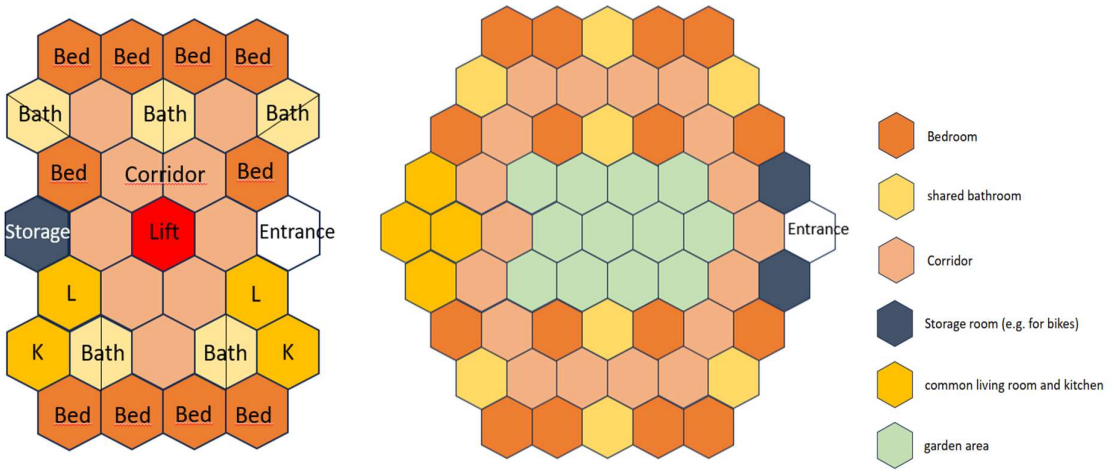
- We acknowledged the promise of the 3D printing technology from Concept 5.
- For sustainability and environmental impact reduction, we chose Mycocrete over concrete for 3D printing walls.
- We integrated the central garden space from Concept 2 into our chosen Concept 1.

These decisions aim to enhance the chosen concept by incorporating valuable elements from others, improving overall design quality.

4.5 Selecting a Final Concept:

Concept 1 was ultimately chosen for development, despite Concept 3 achieving the highest ranking in the decision matrix. Our decision was influenced by insights from a stakeholder regarding emerging trends in manufacturing technology related to 3D printing in construction and the notable sustainability benefits of Mycocrete—an innovative material with the potential to address significant challenges in the construction industry.

As a result, we're moving forward with Concept 1, which offers promising features. Below is a refined sketch of the selected concept. The Honeycomb concept consists of modular rooms that can be interconnected in various ways to create student housing units. Figure 14 shows two assembly examples, and Figure 15 illustrates room layouts.

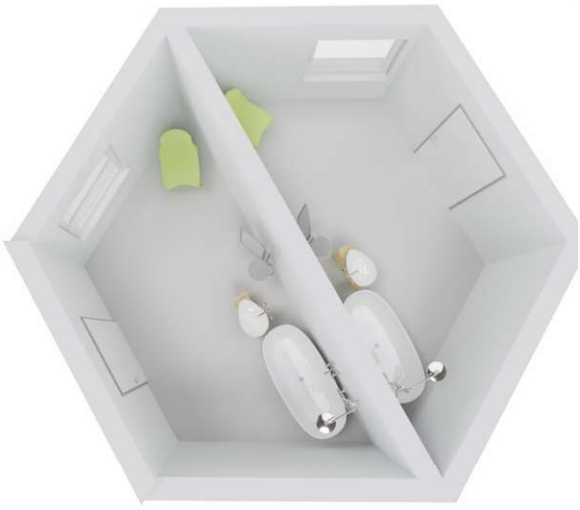


Solution A

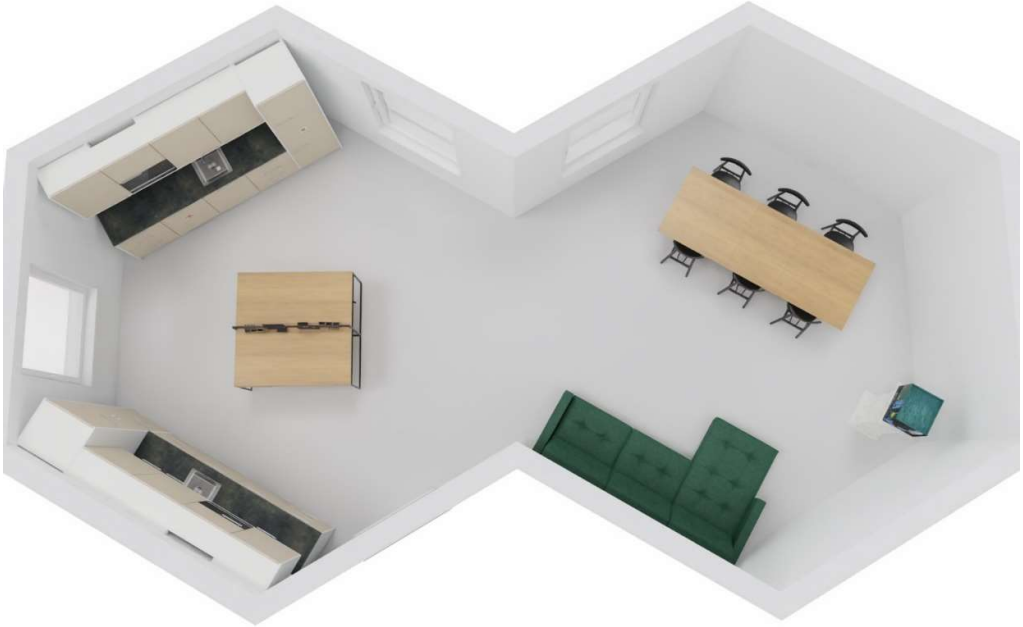
Solution B

Figure 14: Two out of many possible ways the building can be configured for the Honey-Comb Concept (own representation)

Bedroom layout



Bathroom layout



Shared kitchen (left) and Living room

Figure 15: Basic layouts to describe the various rooms of the concept under consideration (own representation with the use of pCon.planner STD)

4.6 Reflecting on the Results and Process:

As a final step, our team conducted a comprehensive review of the selected concept to ensure that it aligns with the majority, if not all, of the student needs.

During this review, we meticulously examined the metrics and target specifications. As a result, we have generated and selected the final criteria that will serve as our solution. The table below provides an overview of these selected criteria:

Table 5. Needs covered by the final solution (own representation)

Basic Needs	**Proposed solution in selected concept**
price	between 3000 -8000SEK
temperature	solar panels on the roof in addition to district heating
Durability	we have chosen mycocrete materials for the walls, which is much more durable. Coated wooden frames for the windows and doors.
No of fire exits	2 fire exits have been provided. Also, the chosen wall material is fire-proof.
Electricity	Would be provided by solar panels and augmented with power from electricity the national power grid.
Size of rooms	We considered three size options (16, 20, & 24 sq. meters) for each of the hexagonal rooms.
Illumination	Energy conserving LEDs, sensor lights and natural lighting has been considered for room illumination.
Internet	A wireless router per every floor would be the means for internet connectivity for the students. More can be added if need be.
Air refreshment	Natural ventilation for room air refreshment. Shaft ventilation can also be employed.
Insulation	Walls to be insulated with mycelium plates, this has advantages for both warm and cold climatic conditions.
Security	CCTV to be installed outside the housing, especially at corners and hidden pockets of space. Also, secure locks and biometric security access doors would be employed.
Parking spaces	Separate modules, provided close to the entrance would serve as storage rooms for bikes and scooters.
Water	Connected to the municipality for kitchen and drinking purposes. Collected rain water for toilet use
Study rooms	An apartment can be provided on the ground floor for studying
Garden area	A green area considered at the centre of the housing, also can serve for purposes of outdoor social activities.

These criteria will play a crucial role in guiding the development and refinement of our chosen concept to ensure it effectively meets the needs of the student population.

5. DFM/DFA and DFE Analysis

The main goal of DFM is to optimize the design to minimize manufacturing costs, improve efficiency, and ensure that the product can be produced with high quality and reliability. On the other hand, the primary goal of DFA is to reduce the number of parts, minimize the complexity of assembly, and enhance the ease with which components come together during manufacturing (Ulrich, 2012). Both principles are integral parts of concurrent engineering, where design, manufacturing, and assembly considerations are integrated early in the product development process to achieve an optimal balance between functionality, cost, and manufacturability.

The Honeycomb shaped student housing concept underwent some refinement during the concept selection process, considering the principles of Design for Manufacturing (DFM), Design for Assembly (DFA), and Design for Environment (DFE). Here's a brief analysis of how the concept performed:

5.1 DFM/DFA

- Modular components: the concept adopts a modular approach, with each apartment consisting of three hexagonal rooms that serve as individual modules. Initially, we had eliminated the need to 3D print the walls of the modules, arguing about its cost-effectiveness. This was eventually integrated into the concept as future of manufacturing looks promising for innovative 3D printing technology.

The modularity therefore simplifies the manufacturing process as parts/components can be produced in a controlled and efficient manner.

- Ease of Integration: The hexagonal room modules are interconnected to form complete apartments. The modular design allows for simplified assembly operations, following DFA guidelines, as components are designed to fit together seamlessly. Also noteworthy, hexagonal form is more rigid than a square form, eliminating the need for added structure.
- Standardized connections: Standardized connectors would be employed to ensure that modules are easily assembled. This approach minimizes the potential for errors during the assembly process.

5.2 Design for Environment (DFE)

- Energy Efficiency: The design incorporates several environmentally friendly features, such as solar panels for electricity generation, rainwater harvesting, and a district heating system for higher efficiency. These elements align with DFE principles by reducing energy consumption and environmental impact.
- Noise Reduction: The walls are insulated with a mycelium-based product to block noise, promoting a more comfortable and environmentally friendly living space.
- Natural Light: The design prioritizes natural light through large windows, which reduces the need for artificial lighting. The use of special film layers on windows ensures privacy while allowing natural light to enter.

Due to the specific needs of hexagonal rooms, a new requirement arises for the creation of furniture tailored to such spaces. However, this is not a necessity due to the thoughtful design and size of the room, allowing for the use of currently available furniture, such as beds and wardrobes, that will not interfere with any other interior elements. This is possible thanks to the selection of an appropriate size for the hexagonal room, measuring $16m^2$, where each side of the hexagon is 2.5m long. Consequently, it is possible to place a bed both lengthwise and widthwise without any obstruction.

Designing furniture through 3D printing for hexagonal rooms introduces a novel and adaptable approach to interior aesthetics. The technology's innate flexibility allows for the creation of customized

pieces that seamlessly align with the unique geometry of hexagonal spaces. In this creative process, composable PLA and clay emerge as key materials, offering both environmental sustainability and design versatility. Composable PLA, derived from renewable sources, not only contributes to eco-friendly practices but also ensures the strength and durability required for functional furniture. If we use a composite e.g., PLA as a binder for wood particles or hemp, we can also get a unique structure, reminding users of real wood. Clay, with its natural aesthetics and thermal properties, adds an earthy touch to the 3D-printed pieces, creating an organic and visually appealing integration. Printing with clay could also be done by the same machine that puts on the walls after adjusting the nozzle size and parameters like layer height. That's one of the factors that will reduce the costs. The combination of these materials results in furniture that not only meets the spatial demands of hexagonal rooms but also embodies a sustainable and aesthetically pleasing design ethos, merging form and function seamlessly (Carolo, 2023).

As hexagonal rooms become increasingly popular to the extent that they become a certain standard, stores, in tandem with technological advancements, will adapt to this trend by offering custom furniture. This will be achievable through interior visualization programs, where each user will have the option to choose the dimensions and appearance of their furniture. The store will receive the corresponding G-code, and a CNC machine will cut all the components, providing precise fittings or holes for screws. These processed elements can be collected either in assembled form or for assembly at home, minimizing the carton size and costs of logistics.

Providing fully furnished rooms right from the start is very convenient for clients, especially in the case of students. This not only enhances comfort for residents but also shortens the construction timeline by enabling on-site production of elements by the company itself. This eliminates the need to engage other firms' services, reduces reliance on lengthy supply chains, and minimizes unnecessary paperwork. The company will also decide when to put the furniture into the building. With a machine printing the walls, it is possible to use the same gantry to place all the furniture inside the rooms without a lot of human work and power. It's an example of better assembly characteristics, which is a part of DFA.

In conclusion, the "Honeycomb"-shaped design concept for our student housing project demonstrates a strong commitment to DFM/DFA, and DFE principles. Its modular construction, prefabricated 3D printed building modules, and material selection enhance manufacturing efficiency. The design simplifies assembly and offers sustainability features to minimize environmental impact.

6. Discussion

The construction industry has remained unchanged for the last decades, partly because it has been proven useful and people just learn to live with the little annoyances. However, developments in building techniques and requirements due to fiercer competition have planted new challenges. Throughout this work we encounter obstacles such as finding the proper way to get a proper sample while keeping the options as open as possible so that the users could lay out what they really wanted. This posed a challenge from the statistical scope since the data was irregular and couldn't be easily categorized. Although we thought more interviews could be conducted to get even more defining results and find even more needs giving more possibilities to create competitive edges; the data collected was sufficient to make informed decisions and fix the problems that previous constructors did not anticipate.

Once the data was collected and categorized to make it readable to us the designers and future readers was a challenge due to the sheer volume of information that was collected. The process, however, was successful since the result could be presented in an easy and understandable way.
Since the earlier stages we saw a huge number of iterations that could solve the problems exposed in the previous face. Hence, we decided to systematize the problem solving and reduce the number of iterations decomposing the needs into the solutions and focusing on certain aspects such as cost, sustainability, comfort and privacy in between others. This meant that many solutions will be left out of the picture on purpose, but by following the decomposition as shown new solutions can be reached.

Our final concept mixes the best elements of the previous concepts so that the solution complies with the factors mentioned above. The solution utilizes new materials, new techniques and shapes to fulfil the needs of the students.

7. Conclusions

The methodology laid out by Ulrich, K. E., Et. al (Ulrich, 2012), has been successfully applied up to the scope of the project. It has been shown by the results of the survey that the needs for student accommodation have taken a shift from what the current standard. The measurements created will assure that if the solution is comprised in between the marginal values the necessities will be fulfilled. The Decomposition of the needs showed remarkable results in the simplification of the problem. Although the concepts generated are good, they are by no means the best options possible. By using new technologies, the price and construction time will be affected, current models show a reduction in both variables. However, more work is suggested in this regard to either by exploring more construction techniques or by reimagining existing concepts.
The last solution was conceived out of the combination of the positive factors on each of the concept models. However, a marketing study will be necessary to determine if the concept will be deemed as too disruptive for people to feel comfortable living in it.
The DfM/DfA analysis showed that the model has great potential to be easily manufacture and brough to market. Many of the components could be finished in an industrial/assembly line scale lowering costs and reducing times. Since many of the elements will be constructed ahead of time, the execution will show less uncertainty reducing the execution risks of the business.

Although our ideas are promising, we acknowledge that there's room for improvement, especially by exploring new construction methods. The selected product concept combines good ideas, but we need to study if people will accept it. Our analysis suggests that we can efficiently construct modular student housing and get it ready for the market, achieving our main aim to demonstrate how product development methods used in general product design can help the construction industry to standardize student housing without impacting the environment.

Since many of the elements will be constructed ahead of time, the execution will show less uncertainty reducing the execution risks of the business. All of this taken into account we can confidently say that the objective of the project was met successfully. Although we recognize that some work is yet to be done since our ideas are promising, there could be room for improvement.

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Appendix

List 1. Interview questions with students

1. How old are you?
2. With how many people do you want to live together?
3. How much money are you willing to spend monthly for housing? (SEK)
4. What is your current living situation?
5. Why do you live in this current situation?
6. Which rooms you don't want to share?
7. How much space do you need for the bathroom?
8. How much space do you need for the kitchen?
9. How much space do you need for the living room?
10. How much space do you need for the bedroom?
11. How much space do you need for the washing room?
12. How much space do you need for the storage room?
13. How much space do you need for the working room?
14. How much space do you need for the hobby/party room?
15. How much space do you need for the balcony/garden?
16. Rank the rooms mentioned in the previous questions based on your needs.
17. What do you like about your current living situation?
18. What don’t you like about your current living situation?
19. How many hours do you spend at home during a working day? (without counting sleeping hours)
20. Which floor do you prefer to live on?
21. Can you describe why do you prefer that floor?
22. Do you prefer more natural light during the day or artificial?
23. What do you use to warm up the room?
24. In which rooms do you want heaters to be?
25. If you would like to have a go, describe your ideas on improving student housing (affordability & sustainability)?

List 2. Interview questions with Studentbostader

1. What considerations go into the design and layout of your student housing properties to optimize space and comfort for students?
2. Why did you decide on corridor rooms instead of small apartments?
3. Have you thought of other shared rooms except the kitchen? (e.g. bathroom)
4. What amenities and facilities do you typically offer in your student housing properties?
5. How are private and shared spaces designed to meet the needs of students?
6. What improvements would you make to the existing buildings?
7. What is the primary consideration when selecting interior design elements such as doors, flooring, bathroom tiles, and furniture for shared spaces? Is it primarily based on factors such as quality, pricing, or the locality of the supplier?
8. How do you determine rental prices, and how do they compare to the local market rates?
9. How do you incorporate energy-efficient features into the design of your buildings, such as lighting, heating, and cooling systems?
10. Do you integrate renewable energy sources (e.g., solar panels) into the design to reduce the carbon footprint of your buildings?
11. What are your future sustainability goals for your student housing properties, and how do you plan to achieve them?
12. What trends do you see in the student housing industry that might impact your business?
13. What legal and regulatory considerations are important in the student housing industry?
14. How do you handle the sale or transition of student housing properties when needed?

List 3. Needs

Basic needs
Prioritization: 5
** The student building blocks (SBBs) offer much natural light.
*** The SBBs provide access to electricity at any time.
*** The SBBs provide clean running water at any time.
** The SBBs provide fast and reliable internet
** The SBBs are bright inside.
*** The SBBs are warm in the winter and convenient in the summer.
* The SBBs provide underfloor heating.
** The SBBs provide a pleasant indoor climate.
* The SBBs filter unpleasant odors.
*** The SBBs have fire exits.

Affordability
Prioritization: 4
*** The SBBs are affordable for students.
** The SBBs are easy to build.

Social interaction
Prioritization: 2
*** The SBBs are connected with each other.
** The SBBs provide public areas.
** The SBBs provide common living rooms.
* The SBBs provide public balconies.
* The SBBs provide smoking areas.

Proximity to campus
Prioritization: 3
*** The SBBs are placed near campus.
** The SBBs provide reaching the campus within a reasonable time.

Peaceful environment
Prioritization: 3
** The SBBs provide quiet spaces.
*** The SBBs block noises from the neighbors.
** The SBBs block noises from the street/ the environment.

Enough space
Prioritization: 4
*** The SBBs provide enough space for living.
** The SBBs provide enough space for studying.
** The SBBs are big enough to cook simultaneously with other students.
** The SBBs provide enough space to store personal belongings as well as fresh food.
* The SBBs provide enough space to hang and dry clothes.
* The SBBs provide extra area for garbage.
** The SBBs deliver enough space for storage.
* The SBBs provide an own storage room for everyone.
* The SBBs provide a common bike cellar, that is closeable.

Security
Prioritization: 5
*** The SBBs are safe from the outer door.
* The SBBs are secured by camera systems.
*** The SBBs are safe inside.
** The SBBs provide secure locks.
* The SBBs have security guards.

Privacy in general
Prioritization: 3
*** The SBBs include private rooms for everyone.
** The SBBs provide private bedrooms.
** The SBBs provide private bathrooms.
* The SBBs provide private kitchens.

Eco friendly
Prioritization: 1
** The SBBs are made of sustainable and regional materials.
** The SBBs work with renewable energy.
*** The SBBs are long lasting.
* The SBBs make it easy to separate waste.

Easy move-in/ move-out
Prioritization: 1
* The SBBs have large openings to get bulky objects through them.
*** The SBBs are furnished.

Design
Prioritization: 1
* The SBBs are modern designed.
** The SBBs are designed unique.
*** The SBBs are modulable and scalable.
*** The SBBs are stackable.

Homely comfort
Prioritization: 2
** The SBBs are accessible through an elevator.
*** The SBBs are disabled friendly.
* The SBBs provide illuminated corridors.
* The SBBs provide a nice view of the environment.

Freetime activities
Prioritization: 1
** The SBBs include a common garden for the students.
*** The SBBs provide common play/hobby rooms.
* The SBBs include a public gym.
* The SBBs include cafés or restaurants.

Access to services
Prioritization: 2
*** The SBBs provide access to services of daily use.
** The SBBs include laundry machines.
* The SBBs include a shop.
* The SBBs include a central post office packing station.

LINKÖPINGS UNIVERSITET

REPORT

Modularized Building

TMKT78
Product Development

Group 8

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LIST OF FIGURES

1. Introduction

In today's evolving landscape of healthcare and senior living, the demand for innovative solutions has never been more pronounced. As populations around the world age, the need for efficient, cost-effective, and personalized senior housing options becomes increasingly evident. In response to this challenge, our project explores the use of modular homes as a solution to meet the specific needs of elderly care facilities.

Given the growing elderly population, there is a need for more innovative approaches to senior care and housing. Traditional methods may not always provide the flexibility and uniqueness that seniors desire. Therefore, our project investigates the advantages of modular housing for elderly care, offering faster construction times and cost-effective solutions while allowing seniors to enjoy a more personalized and non-institutionalized living environment.

Modular homes, characterized by their prefabricated components and assembly-line construction, offer an intriguing solution to the challenges faced by the elderly care sector. These homes combine the advantages of customization, enabling tailored living spaces for seniors, with the efficiency of factory production, promising faster construction and cost savings. It is within this intersection that our project seeks to explore new possibilities for senior living.

In this report, we embark on an exploration of the potential of modular housing within the context of elderly care facilities. Our focus is on understanding target specifications, identifying customer needs, and developing product specifications. Throughout the process, we will generate multiple product concepts and, ultimately, select the most suitable one to address the specific requirements of elderly residents.

We aim to provide a comprehensive view of how modular housing can revolutionize senior living environments while keeping the needs of elderly residents at the forefront.

2. Project Plan

To effectively manage the complexities of this project, meticulous planning was essential. We began by creating a comprehensive project plan to gain a thorough understanding of the tasks and milestones ahead. This plan served as a clear roadmap, guiding us through the various stages of research, analysis, and design

In our pursuit of clarity and efficient project management, we utilized a Gantt scheme, a visual tool that enabled us to outline the project's timeline. This invaluable resource provided a transparent overview of project tasks, their dependencies, and anticipated completion dates. As shown in the appendix (Figure 17), the Gantt chart acted as a reliable compass, helping us maintain our course and ensuring a seamless project progression.

3. Customer Needs

First, a team investigation has been carried out on the basic elements of nursing homes, companies dedicated to modularized constructions and some examples of existing constructions to better understand what the important aspects are. After this, the identification of customer needs has been carried out.

3.1. Process for customer needs identification

For identifying customer needs, two interviews with experts in healthcare and construction and a survey have been made.

3.1.1. Interview with health expert

In our quest to gain comprehensive insights into the fundamental requirements of elderly care residences, we had the privilege of conducting an extensive interview with Nurse Lucía Álvarez, a seasoned healthcare professional with a wealth of experience in elder care. The interview consisted on us asking her questions about life inside an elderly care housing,

The key insights that the expert highlighted were:

- Well-Designed Common Areas: Nurse Álvarez emphasized the importance of thoughtfully designed common areas within the facility.
- Access to Outdoor Areas: Nurse Álvarez highlighted the need for secure, accessible outdoor spaces that allow residents to enjoy fresh air and nature, positively impacting their quality of life.
- Places for family visits: This involves creating welcoming and comfortable spaces within the elderly care residence where residents can receive visits from their family.
- Personalization of living spaces: This aspect focuses on allowing residents to customize their individual living spaces, such as their rooms, with personal items, decor, and furnishings.
- Privacy and comfort: Ensuring privacy and comfort means providing residents with a secure and tranquil living environment where they can have personal space.
- High-Quality Healthcare: Providing well-trained staff, proper medical equipment, and robust medication management systems is crucial for residents' safety and well-being.
- Nutritious and customizable meals according to the needs: Nutritious and customizable meal options that cater to individual dietary needs.

Our enlightening conversation with Nurse Lucía Álvarez has shed light on the critical components that should be incorporated into the design and operation of elderly care residences, and have been taken into account for then creating a survey for the potential customers.

3.1.2. Interview with construction expert

Furthermore, we understood that it would be essential to interview someone with expertise in modular housing, as this is an area we are not familiar with. This interview would provide us with valuable insights and knowledge that we can use to better understand and improve our project's overall vision. We interviewed Eloy Valverde, and this interview did not consist on us asking him questions, but rather we outlined the specifics of our project, in order to provide some context, and then he enlightened us about the advantages of modular homes and other elements that could prove invaluable in achieving our goals.

Mr. Eloy Valverde is a highly regarded engineer with a prominent career in the construction industry. While specializing in traditional construction methods, his extensive experience has made him a respected authority. His engineering firm has shown significant interest in emerging trends, particularly modular construction, recognizing its potential to revolutionize the sector, and that is why he was a good choice to talk to.

- Modular Customization: Mr. Valverde emphasized the strength of modular construction in customization. He stressed the importance of tailoring each module to meet the unique needs of elderly residents, allowing for adjustments. He even gave us examples for us to better understand his view, like window placement, skylights for top-floor modules, and accessibility features without compromising structural integrity.
- Adaptability: He highlighted the importance of designing modules that can adapt to changing care needs, ensuring that residents can age in place comfortably.
- Sustainability: Mr. Valverde emphasized the value of sustainable and energy-efficient design in modular construction, aligning with responsible construction goals.
- Collaboration: He recommended close collaboration with local architects, engineers, and healthcare professionals to meet regional standards and ensure resident safety and well-being.
- Sustainable and Smart Building: the integration of advanced technology into a sustainable building that enhances elderly healthcare. This encompasses eco-friendly materials, intelligent systems for health monitoring and comfort, as well as renewable energy sources.

Our conversation with Mr. Eloy Valverde offers crucial insights into modular housing for elderly care. His focus on customization, adaptability, sustainability, and collaboration aligns perfectly with our mission to create comfortable and independent living environments for elderly residents. We are grateful for Mr. Valverde´s expertise, which will undoubtedly inform our project moving forward.

3.1.3. Interviews

After that, we elaborated ten questions in order to identify the needs of the elderly people living in the nursing home. These questions were asked to ten of our grandparents between the ages of 75-85 and were intended to be open-ended with the intention to find hidden needs as well as the primary needs and were the following:

1. What is most important to you when you think about moving to a nursing home?

2. What amenities or services do you consider essential in a nursing home?

3. What activities or programs would you like to have available in the nursing home to stay active and socially engaged?

4. What type of medical or healthcare attention do you consider vital in a nursing home?

5. What are your preferences regarding the size and design of your living space in the nursing home?

6. Would you like to have customization options in your living space, such as bringing your own furniture or decorations?

7. How important is the quality of food and dietary options in the nursing home to you?

8. What are your thoughts on the importance of social interaction and community in a nursing home?

9. Do you have any specific concerns about safety and care in a nursing home?

10. What advice or recommendations would you give to people considering moving to a nursing home for the first time?

3.2. Interpretation and organization of customer needs

With the responses to these questions, a group session was addressed, having the goal to interpret the customer needs. After the raw data we obtained had been discussed, we came up with the customer needs shown in Figure 1, with their respective importance related to the frequency those were mentioned:

Figure 1: Hierarchical List of Customer Needs

Customer needs	Importance
The MB is customizable	
The MB is prepared to let residents bring personal stuff	***
The MB makes it easy to personalize the bedrooms	***
The MB is ventilated	
The MB has plenty of windows	**
The MB receives a lot of light	**
The MB has well-connected ventilation ducts	*
The MB is peaceful	
The MB is soundproofed	**
The MB is private	**
The MB is comfortable	***
The MB has different facilities	
The MB has common rooms	***
The MB has a infirmary	***
The MB has outdoor areas	***
The MB has smoking areas	*
The MB is clean	
The MB has dust proof walls	*
The MB has good accessibility	
The MB has ramps	***
The MB has railings	**
The MB is step-free	***
The MB has spacious	**
The MB is warm	
The MB has insulating walls	**

The MB has insulating windows	**
The MB is good looking	
The MB is decorated	**
The MB has a good facade	*
The MB is eco-friendly	**

3.4. Relative importance of customer needs

Having identified the project's customer needs, we created a survey where respondents rated each need on a scale of 1 to 5:

1. Feature is undesirable.
2. Feature is not important.
3. Feature would be nice to have.
4. Feature is highly desirable.
5. Feature is critical.

This survey helped us prioritize the importance of each customer need according to our target audience's perspective, enabling us to align our project more closely with their preferences and priorities. Upon aggregating responses from the surveys, we calculated an averaged rating, represented on Figure 2, reflecting the collective assessment of these needs by our respondents.

Figure 2: Customer needs importance

No.	Feature	Importance
	The MB is customizable	
1	The MB is prepared to let residents bring personal stuff	4
2	The MB makes it easy to personalize the bedrooms	4
	The MB is ventilated	
3	The MB has plenty of windows	4
4	The MB receives a lot of light	5
5	The MB has well-connected ventilation ducts	3

	The MB is peaceful	
6	The MB is soundproofed	5
7	The MB is private	4
8	The MB is comfortable	5
	The MB has different facilities	
9	The MB has common rooms	4
10	The MB has a infirmary	5
11	The MB has outdoor areas	4
12	The MB has smoking areas	3
	The MB is clean	
13	The MB has dust proof walls	3
	The MB has good accessibility	
14	The MB has ramps	3
15	The MB has railings	3
16	The MB is step-free	4
17	The MB is spacious	3
18	The MB has elevator	
	The MB is warm	
19	The MB has insulating walls	4
20	The MB has insulating windows	4
	The MB is good looking	
21	The MB is decorated	2
22	The MB has a good facade	3
23	The MB is eco-friendly	3

4. Target Specifications

The metrics for a modularized building along with their respective units of measurement are represented in Figure 3. In this way, future comparisons can be made according to these needs.

Figure 3: List of metrics

Metric No.	Need Nos.	Metric	Imp.	Units
1	1,2,8	Existence of Customizable Modules	3	yes/no
2	2	Types of furniture	2	nº of types
3	3,4,8	Number of Windows per Modular Unit	4	nº of windows
4	3,4	Natural Light Exposure Index	5	index
5	3,5	Air Quality Index (AQI) within Modular Units	4	index
6	3,5	Average Ventilation Rate within Modular Units	2	air changes /hour
7	5	Efficiency of Ventilation Ducts	3	m^3/min
8	6,7	Sound Transmission Class (STC)	4	rating
9	7	Resident Privacy Rating	4	scale 1-5
10	7,8	Existence of individual rooms	5	yes/no
11	8	Resident Comfort Rating	4	scale 1-5
12	8,9,11, 17	Average Surface per Resident	3	m^2
13	9,10,11 ,12,17	Space Utilization Efficiency	3	%
14	9	Amount of common areas	4	nº of common areas
15	10	Availability of Medical Facilities	5	yes/no
16	11	Surface of Outdoor Areas	4	m^2
17	11	Amount of Outdoor Areas	4	nº of outdoor areas

18	12	Existence of Smoking Area	2	yes/no
19	14	Amount of Accessible Ramps	3	nº of ramps
20	18	Amount of Elevators	3	nº of elevators
21	15	Presence of Railings in Common Areas	4	yes/no
22	19,20	Energy Efficiency Rating	3	rating
23	19,20	Insulation Effectiveness	4	scale 1-5
24	19,20	Average Indoor Temperature	5	ºC
25	21,22	Aesthetic Rating	2	scale 1-5
26	23	Sustainability Certifications	3	certification
27	23	Use of Eco-friendly Building Materials	3	yes/no

5. Concept Generation

First of all, a black bow was built. The black box symbolizes the central challenge we face in our project, as outlined in our mission statement. In our context, it represents the task of creating modular homes for elderly care that provide the utmost comfort and customization. It helps us enhance our modular home concept. Our black box can be seen in Figure 4.

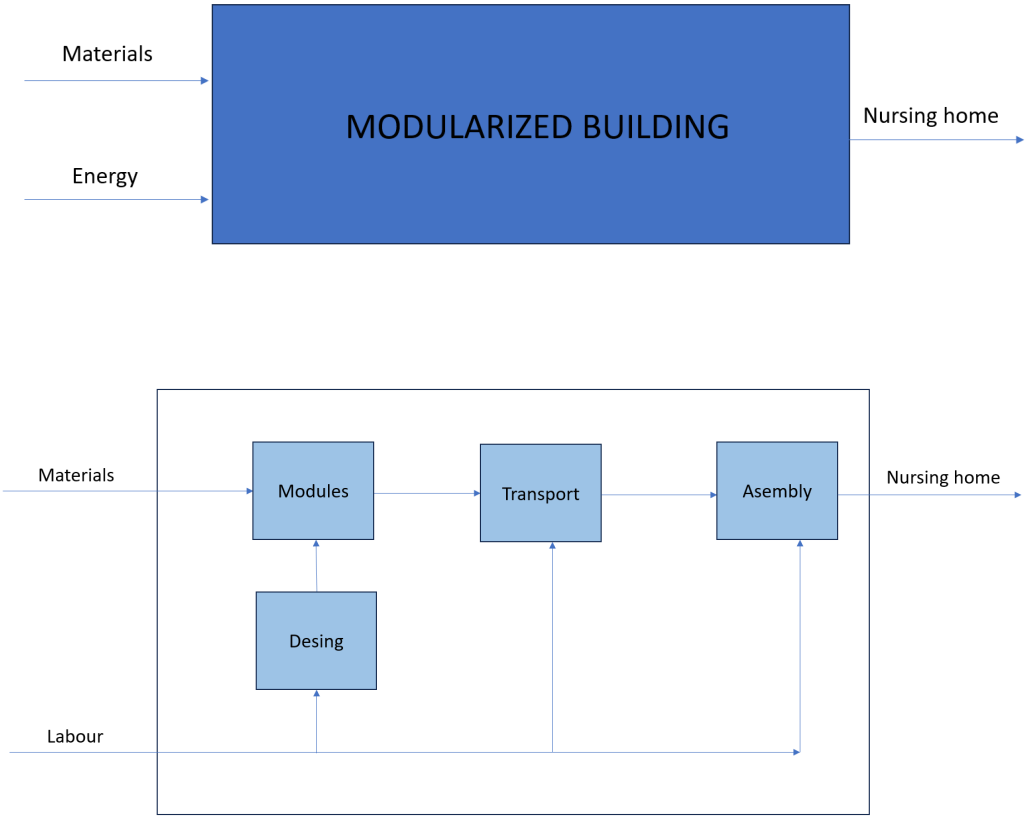


Figure 4: Black Box

In our effort to create homes tailored for elderly care, we used a teamwork approach that combined brainstorming with a customized method called the classification tree, using Mindmap. Our first step was a brainstorming session with the whole team to generate lots of ideas and insights for our elderly residents' needs.

Because our main goal is to provide comfortable and customizable living spaces, the traditional method of combining ideas did not quite fit. Instead, our brainstorming session gave us many new ideas that formed the basis of our plan, shown below in the tree organization. Some initial ideas that did not seem important at first turned out to be helpful later.

Next, we tried to look at similar products and services in the market. However, it was impossible to find companies that dedicate to this type of product.

In team sessions that followed, we combined and refined these ideas, making sure to address any problems we identified. This process helped us shape our approach to designing homes that prioritize the comfort and well-being of our elderly residents. We created the Mindmap that can be appreciated in Figure 5.

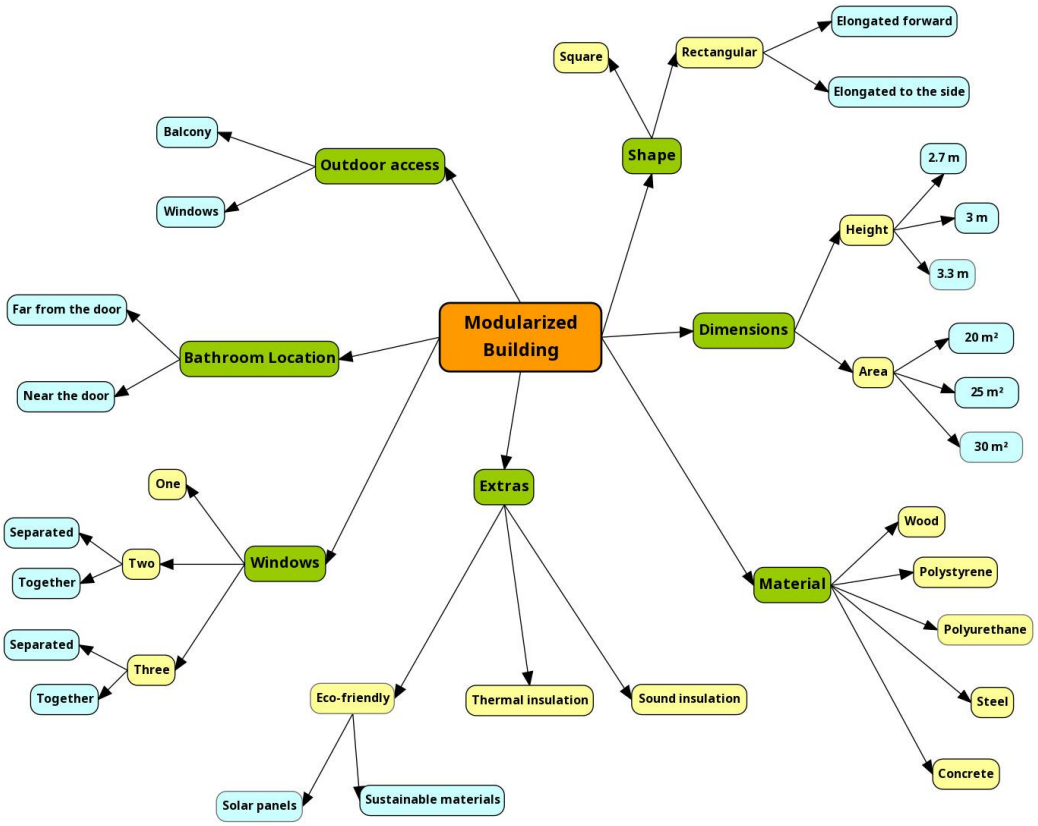


Figure 5: Classification Tree using Mindmap

We have also drawn different module possibilities while we brainstormed in order to visualize the reality of the project and help us decide our final concept. Most of them are about the bedroom modules, but we have included some for the common areas as well. These drawings can be seen in Figure 6, 7 and 8. (Windows are represented as small rectangles on the outline of the drawings)

Figure 6: Module drawings for bedrooms

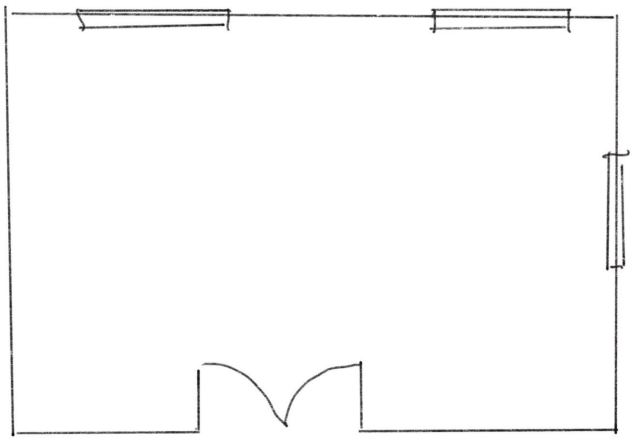


Figure 7: Module drawings for living rooms and dining rooms

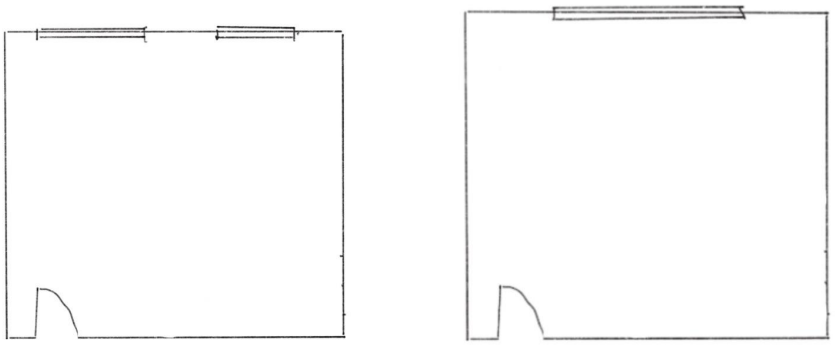


Figure 8: Module drawings for nursing and other little rooms

As it can be appreciated, the different rooms are combinations of different shapes and different distributions of bathrooms and windows, all mixed together, creating the concepts we have shown.

In order to have some more detailed concepts, we developed some 3D designs which can be seen in Figure 9. In them, the same concept as in Figure 6 can be seen, but in a better way.

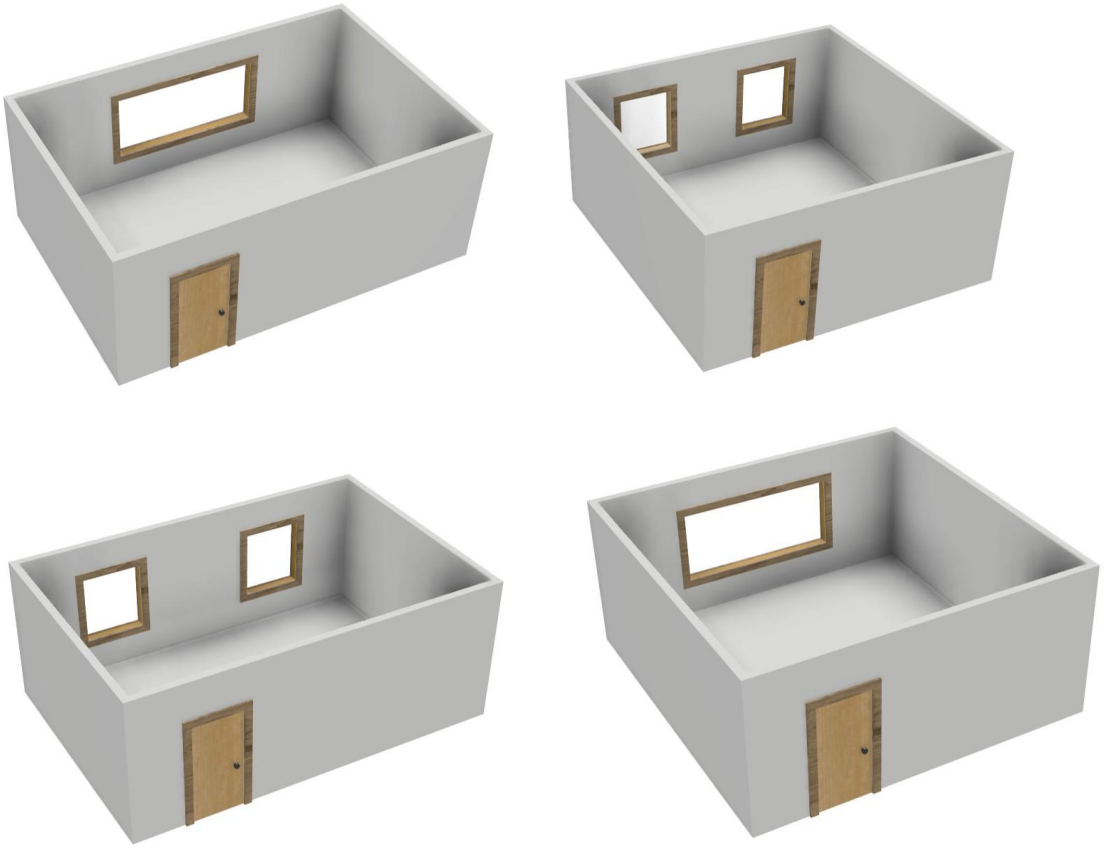


Figure 9: 3D designs of the concept

Until this point we had focused on designing one module for the residents rooms and another larger module for the common areas, such as living rooms. However, we later realized that it was better to have only one basic module and build different rooms combining between them to get the one that we needed. That's why we decided to have the three different types of walls that can be seen in Figure 9: one with a window, one with a door and one without anything (only the wall). In this way, we could combine the basic modules and the walls to get all types of rooms.

With this, we designed a removable wall system to combine them all together to form rooms with different sizes and shapes, so we came up with two pretty self-explanatory ideas for mobile walls:

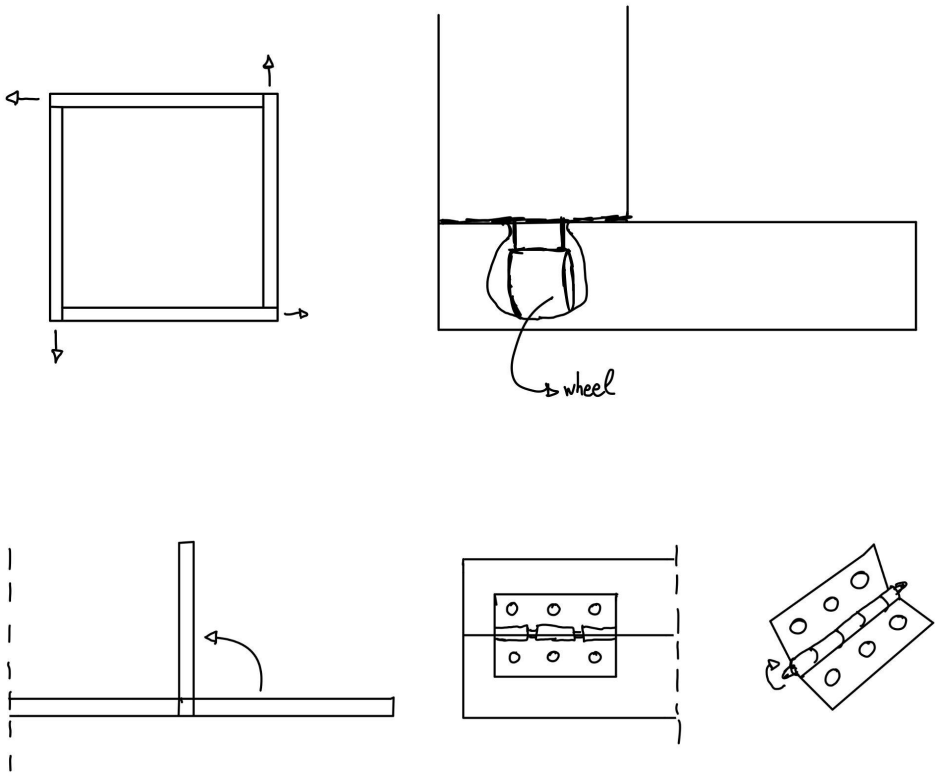


Figure 10: Removable wall systems

First of all, we can see a kind of rolling wall system, in which each wall is placed letting a free space for the other wall to be removed. The walls are moved with a wheel-rail system to allow the wall to slide. Some advantages of this system are that they are easy to transport and they do not require additional space. Some disadvantages are that they have an increased installation complexity (but they are easy to move once they are installed) and they require periodic maintenance.

Then, we designed a kind of folding wall system using a well-designed “hinge” mechanism to ensure stability and security. Some of the advantages are that they have an easier installation and they need less maintenance. The main disadvantage is that the walls need an extra space to remove the walls.

5.2. Material analysis

After conducting thorough research and browsing the internet for information on prefab housing materials, we decided to explore more sustainable alternatives to traditional options. During our investigation, artificial wood emerged as a promising choice. However, the challenge was to narrow down the specific type of artificial wood from the numerous options available. As we moved forward, we considered various factors, ensuring that the chosen material not only met sustainability criteria but also aligned with the specific needs of our modular modules for elderly care facilities.

In our project evaluation process, we utilized two essential tools to assess the most suitable material for constructing modular modules for elderly care facilities. These tools, the Advantages and Disadvantages Table and the Decision Matrix, allowed us to methodically evaluate various material options based on predefined criteria.

In the first step of our evaluation, we created an Advantages and Disadvantages Table to compare different material options. This table served as a preliminary assessment tool, providing an overview of the strengths and weaknesses of each material in the context of our project. We identified key criteria that are critical to our decision-making process, including sustainability, durability, cost, ease of customization, and availability.

This table allowed us to identify the relative advantages and disadvantages of each material. It offered valuable insights into which materials performed well in specific areas and which might have limitations. However, it was a qualitative assessment, and to make a more informed decision, we moved on to the Decision Matrix.

Figure 11: Advantages and Disadvantages table

Type of Sustainable Wood	Advantages	Disadvantages
Recycled Plastic Wood		
	-Highly sustainable, manufactured from recycled plastic and reclaimed wood	-May be more expensive than natural wood
	-Resistant to moisture and rot	-Some types may fade with prolonged exposure to sunlight

	-Requires no painting or sealing maintenance	
	-Long lifespan	
Composite Wood		
	-Highly sustainable, often made from recycled materials	-Can be more expensive than natural wood
	-Durable and weather-resistant	-Appearance may not be as authentic as real wood
	-Does not warp or crack easily	-May contain binding agents that are less sustainable
	-Variety of color and texture options	
	-Low maintenance	
Laminated Wood		
	-Sustainable, as it minimizes wood waste during manufacturing	-May be more costly than natural wood in come cases
	-Excellent structural strength	-Lacks the same aesthetic appearance as solid wood
	-Wide range of available sizes and shapes	-May use adhesives that are not environmentally friendly
	-Suitable for working with woodworking tools	
Medium-Density Fiberboard		
	-Sustainable due to efficient use of wood fibers	
MDF		
	-Smooth and uniform surface	-Not moisture-resistant
	-Suitable for working with woodworking tools	-Susceptible to swelling in humid environments
	-Widely used in furniture and cabinetry production	-Contains binding agents that may not be eco-friendly
Bamboo Wood		

	-Highly sustainable, known for rapid growth	-May be more expensive than softwoods
	-Comparable hardness and strength to some hardwoods	-Availability may vary by region
	-Versatile applications from flooring to furniture	-Potential habitat disruption due to large-scale bamboo farming
Wood-Plastic Composite (WPC)		
	-Sustainable, often includes recycled materials	-Some types made fade with prolonged sun exposure
	-Resistant to moisture and insects	-Price may be higher than natural wood in some cases
	-Appearance closely resembles natural wood	-Contains plastic materials that may not be fully sustainable
	-Available in a variety of colors and finishes	

5.2.1. Decision matrix

The Decision Matrix was the second crucial tool in our evaluation process. We assigned weights to each criterion based on their relative importance to our project. Sustainability, durability, cost, ease of customization, and availability were each given a specific weight percentage to reflect their significance.

We then assigned scores to each material for each criterion, considering real-world data and practical considerations. These scores were in the range of 1 to 5, where higher values indicated better performance. The Decision Matrix calculated weighted scores for each material, taking into account the assigned criteria weights.

The decision matrix is a decision matrix without datum, following the absolute method (Concept Scoring), evaluating each alternative based on its individual merits, without a specific reference point or datum. Each alternative is scored independently against a set of criteria.

Figure 12: Material Decision Matrix

Criteria	Weight (%)	Recycled Plastic Wood	Composite Wood	Laminated Wood	MDF	Bamboo Wood	Wood-Plastic Composite (WPC)
Sustainability	30	4	3	4	3	5	3
Durability	25	5	4	4	3	3	4
Cost	20	3	4	3	4	2	4
Ease of Customization	15	4	3	4	4	3	4
Availability	10	3	5	3	5	3	5
Weighted Score (out of 5)	-	3.7	3.7	3.7	3.6	3.3	4.2

Based on the weighted scores, Wood-Plastic Composite (WPC) has the highest overall score of 4.2, making it the most suitable material option for our modules according to the specified criteria and their assigned weights.

6. Concept Choice

For deciding the best design concept for our bedroom modules, we have compared the eight options we had, numbered from 1 to 8 in Figure 6.

We discussed what the selection criteria should be, and came to the agreement that the following have to be considered:

1. Affordability
2. Space
3. Distribution
4. Transportability
5. Mixability

These were taken into consideration because we concluded that they represent well the mix of the needs of the elderly people that are going to live in the nursing home and that they are easy to produce and assemble.

This decision matrix is a decision matrix with datum (Concept Screening), because here we are comparing several design concepts or alternatives to determine which one is the closest to meeting our criteria or the ideal design.

The ratings given mean, respectively:
1 → The concept fulfills the criteria
0 → The concept fulfills the criteria partially
-1 →The concept does not fulfill the criteria

Figure 13: Selection Matrix

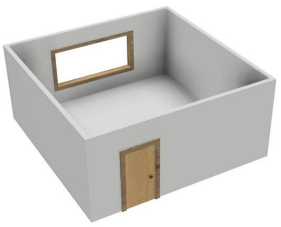
	Concepts								
Criteria	Weight	1	2	3	4	5	6	7	8
Affordability	35%	1	0	1	0	-1	–1	0	0
Space	25%	1	1	0	0	1	1	1	1
Distribution	10%	0	0	-1	-1	1	0	1	0
Transportability	10%	0	0	0	0	1	1	1	1
Mixability	20%	1	1	1	1	0	0	0	0
Σ+1		3	1	2	1	2	2	2	2
Σ0		2	2	2	3	1	2	2	2

	Concepts								
Criteria	Weight	1	2	3	4	5	6	7	8
Affordability	35%	1	0	1	0	-1	–1	0	0
Space	25%	1	1	0	0	1	1	1	1
Σ-1		0	0	1	1	1	1	0	0
Net value		80	45	45	10	10	0	45	35
Ranking		1	5	2	6	6	8	2	4
Continue?		Yes	No	No	No	No	No	No	No

After carefully considering the decision matrix, we have concluded that Concept 1 is the most suitable choice for our project. This decision was reached by thoroughly evaluating the various criteria and their relative importance, as outlined in the matrix.

Concept 1 not only aligns with our project's overarching goals and objectives but also exhibits a superior balance between affordability, space, distribution, transportability and mixability. Its potential for long-term scalability and adaptability, coupled with its strong alignment with industry trends and consumer needs, makes it a compelling choice. Its inherent flexibility also allows for a degree of customization to meet specific project requirements.

For the living rooms and other big rooms we concluded that using the rolling walls, as it seems a more viable option than folding walls for us, they can be assembled with the concept chosen.



7.DFM and DFE

In our quest to enhance the design of our modules, we are focusing on two critical aspects: Design for Manufacturing (DFM) and Design for Environment (DFE). These principles guide us to create modules that are not only visually appealing but also efficient to make, easy to put together and environmentally friendly. Our goal is to strike a balance between great design and practicality, ensuring our modules meet the specific requirements of our elderly care facilities while also being cost-effective and sustainable. We're determined to set a new standard in the industry, where quality, performance, and efficiency come together.

7.1 Design for Manufacturing (DFM)

In the process of design and manufacturing, the concept of Design for Manufacturing (DFM) holds a pivotal role. DFM focuses on optimizing product design with the aim of enhancing its manufacturability, reducing production costs, and ultimately, delivering a product that excels in both quality and efficiency. For achieving this, seven steps have been followed, developed just below. These steps serve as the guiding framework to ensure that our design seamlessly transforms into a tangible reality.

7.1.1. Consider Strategic Sourcing Decisions:

For the strategic sourcing decisions we need to consider where the materials and components will be sourced from for manufacturing the modules.
As previously explained, the main material for our modules will be Wood-Plastic Composite (WPC). Particularly in Sweden, we are fortunate to have access to well-established suppliers known for their commitment to sustainability and quality.

In Sweden, a reliable source for WPC is WOODPLASTIC (Woodplastic Scandinavia AB). They have garnered a strong reputation for providing high-quality sustainable materials tailored to the construction industry. Their dedication to eco-friendly practices aligns perfectly with our sustainability goals.

They are a very well-known company in the prefabricated-housing sector, which can be seen in Figure 14.

Figure 14: Woodplastic Scandinavia AB

In fact, they have a selection of different-looking types of this material, which accomplishes one of the goals of our modules: personalization. This is reflected in Figure 15.

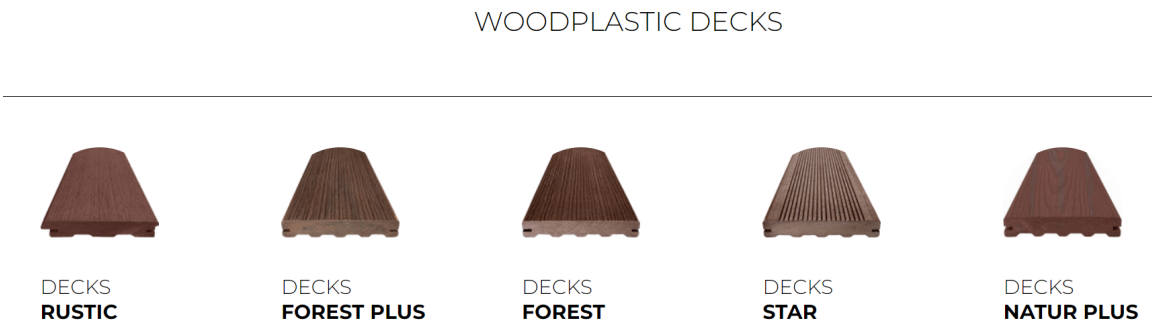


Figure 15: Different-looking types of WPC

Another reputable supplier in Sweden is Newstone Sweden, which specializes in WPC materials, offering an ideal solution for our module construction. Figure 16 shows their material offers.

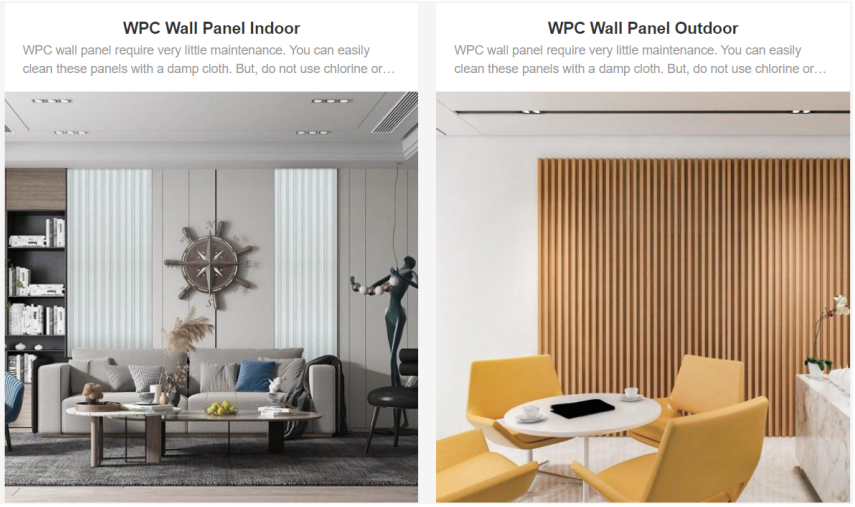


Figure 16: Newstone Sweden

Of course, there are a lot of other materials and components needed in one of these modules (insulation, windows, plumbing systems…) but, as they are common materials and many suppliers are available nearby, they will not be a topic to discuss in this project.

7.1.2. Estimate Manufacturing Costs:

It is essential to conduct a meticulous estimation of manufacturing costs. This involves a granular assessment of the expenses associated with the production of each module, considering multiple variables. Having an estimation of such a complex project requires much more information than what we can manage to get, however, we have been able to

investigate on how to reduce costs in the manufacturing phase. These include: labor costs material costs, machinery and processes, quality control and waste reduction.

7.1.3. Reduce Component Costs:

In our pursuit of reducing component cost, we have been diligent in our selection process, particularly in the choice of Wood-Plastic Composite (WPC) as the main material. This decision was not arbitrary; rather, it was a result of meticulous material analysis and the creation of a decision matrix, explained before in this report. Notably, one of our key criteria, carrying significant weight in our assessments, has been the cost factor associated with WPC. By prioritizing cost-efficiency as a fundamental criterion, we have aligned our design choices with the overarching goal of reducing component costs.

7.1.4. Reduce Assembly Costs:

In this phase we center on optimizing the design of our modules to facilitate seamless component integration. By minimizing the time and resources required for assembly, we aim to achieve a highly efficient assembly line. This entails carefully crafting module designs that not only meet our quality and functionality standards but also enable swift and straightforward assembly. Through design enhancements, innovative assembly techniques, and the use of standardized components, we aspire to significantly reduce assembly costs without compromising the integrity of our modules by: modular design, innovative assembly techniques and quality assurance.

By reducing assembly costs through design optimization and innovative techniques, we anticipate an overall reduction in assembly expenses, making our modules more cost-efficient and easy to assemble.

7.1.5. Reduce Supporting Production Costs:

In the production phase of our modular system, a comprehensive plan to effectively reduce supporting production costs is needed. This plan is multifaceted, encompassing several key strategies: Efficient Inventory Management, Precision Production Scheduling, Waste Minimization, Supplier Relationships and Energy-Efficient Practices

Through the implementation of these strategies, we aim to optimize the production processes, minimize waste, and streamline the supply chain. By doing so, we would be well-positioned to significantly reduce supporting production costs, ultimately contributing to the overall profitability of our modular system.

7.1.6. Reduce Logistics Costs:

In our quest to reduce logistics cost, we have placed significant emphasis on selecting Swedish suppliers for our project. This strategic choice means that customs-related expenses are eliminated, and its close proximity to our project site minimizes transportation costs. It is important to note that while we have tailored our approach to the specific circumstances of Sweden, should this project be situated in a different country, a thorough

investigation and assessment of potential local suppliers would be conducted, with a focus on their expertise in this sector and the available options to ensure cost-effective logistics.

7.1.7. Consider the Impact of DfM Decisions on Other Factors:

It is vital to consider the effects of our decisions on other critical factors within our project. This multi-dimensional approach ensures that our DfM decisions contribute positively to all essential aspects of our modular system.

- Sustainability: Our DfM decisions align with sustainability goals by minimizing waste, optimizing material usage, and prioritizing eco-friendly materials. This approach ensures that we meet sustainability objectives and reduce our environmental footprint.

- Quality: While cost-efficiency is a primary driver, we maintain commitment to quality throughout the DfM process. Our decisions are carefully evaluated to ensure that they do not compromise the quality standards we have set for our modules.

- Safety: Safety remains a paramount concern in our project. DfM decisions are scrutinized to guarantee that they do not introduce safety risks during manufacturing, assembly, or the product's end-use.

- Customer Satisfaction: The ultimate goal of our project is to deliver modules that satisfy our customers. DfM decisions are weighed against their potential impact on customer satisfaction. If a decision could enhance the user experience or meet specific customer preferences, it is integrated into the process.

7.2 Design for Environment (DFE)

In the pursuit of sustainability and environmental consciousness for our modularized elderly care facility, the Design for the Environment (DFE) approach assumes a pivotal role. DFE entails a methodology centered around designing products and processes to minimize their environmental impact across their entire lifecycle, from raw material extraction and manufacturing to operational use, and eventual disposal or reuse.

In this project, the application of DFE principles involves the deliberate selection of materials, the implementation of energy-efficient systems, and the adoption of practices that not only enhance the facility's ecological footprint but also cultivate a wholesome and comfortable environment for its residents.

With the objective of developing the DFE, the following aspects have been prioritized:

7.2.1. Selection of Sustainable Materials

In the pursuit of sustainability, our modularized elderly care facility prioritizes the use of environmentally-responsible materials. Timber sourced from certified sustainable forests forms the backbone of our construction, ensuring a renewable resource with minimal ecological impact. Additionally, recycled steel and concrete with low embodied energy are employed, further reducing our environmental footprint. These choices not only align with our commitment to responsible resource management but also contribute to a healthier, more sustainable living environment for our residents.

7.2.2. Energy Efficiency and Sustainable Technology

At the heart of our modularized senior care facility is an ongoing commitment to energy efficiency and sustainable technology. By incorporating good insulation systems, LED lighting systems and high-performance windows, we aim to reduce energy consumption. In addition, we take advantage of the energy from solar panels to generate clean and renewable energy, thus mitigating our carbon footprint. These measures not only ensure a comfortable and environmentally friendly living space for our residents, but also serve as a model for sustainable building practices in our broader community.

7.2.3. Water and Waste Management

In our modularized senior care facility, a comprehensive approach to water and waste management is of great importance. Water conservation measures, such as low-flow fixtures and rainwater harvesting, will be implemented to minimize consumption. Additionally, a robust recycling program will be established to ensure that waste is properly sorted and processed. Our commitment to responsible water and waste management not only reduces environmental impact but also sets a standard for sustainable practices within the senior care industry.

7.2.4. Resident Safety and Well-being

Ensuring the safety and well-being of our residents is also a very important point at our modularized senior care facility. We prioritize the use of non-toxic and hypoallergenic materials in construction to create a healthy indoor environment. Additionally, we implemented advanced safety features such as non-slip flooring, handrails, and well-lit common areas to prevent accidents and promote mobility. Our commitment to resident safety extends to prepared emergency protocols, ensuring quick and effective responses to any unforeseen circumstances. By integrating these measures, we aim to provide a safe and nurturing environment where residents can live comfortably.

7.2.5. Sustainable Transportation and Accessibility

At our modularized senior care facility, we prioritize sustainable transportation options and ensure accessibility for all residents. Convenient access to public transportation and the provision of charging stations for electric vehicles promote green travel, especially for visitors. Additionally, well-designed hallways, ramps and elevators ensure ease of movement for residents with varying levels of mobility. By emphasizing these aspects, we not only

reduce our environmental impact but also encourage inclusivity, allowing each resident to navigate our facilities comfortably and independently.

7.2.6. Maintenance and Durability

At our modularized senior care facility, we prioritize materials and design elements that promote longevity and require minimal maintenance. By selecting durable materials and finishes, we aim to minimize the need for frequent repairs or replacement. Additionally, we implement a proactive maintenance program to address any potential issues promptly, ensuring the facility remains in optimal condition for the well-being of our residents. This commitment to durability not only improves the overall quality of the living environment, but also contributes to a sustainable and economical approach to facility management.

7.2.7. End-of-Life Material Management

In the final phase of the life cycle of our modularized senior care center, special attention is paid to the responsible management of materials. We implement a structured approach to the disassembly, recovery and recycling of components and materials, ensuring they do not end up in landfill wherever possible. Additionally, hazardous materials are handled in accordance with relevant environmental regulations to prevent damage to the environment. This commitment to careful management of end-of-life materials underscores our dedication to sustainable practices throughout the facility's entire life cycle.

7.2.8. Life Cycle Evaluation

To ensure a comprehensive understanding of the environmental impact of our modularized senior care facility, we conducted a life cycle evaluation. This assessment evaluates the environmental effects of the facility from its inception, covering raw material extraction, manufacturing, construction, operational use and eventual decommissioning. By analyzing the entire life cycle, we can identify opportunities to continue improving and refining our sustainability efforts.

7. Discussion

Throughout the development of our modularized elderly care facility, we faced many challenges that sparked creative thinking within our team. Instead of stopping us, these challenges inspired us to come up with new and inventive ideas, testing our ability to solve problems. One significant challenge was figuring out the right measurements to guide the construction of the nursing home.

Our main goal was to make sure both elderly residents and caregiving staff felt comfortable. This meant finding ways to measure something personal, like the feeling of being "at home." We looked at different factors like the size of spaces and indoor temperature, but turning these into specific measurements was tough. The idea of "home" is different for everyone, making traditional measurements not very practical.

To add to the challenge, there were no set standards for measuring the success of modularized nursing homes. This led us to take a creative approach, drawing insights from regular nursing homes but realizing the need for a unique way to measure success in our innovative project. Our team's ability to adapt and think ahead not only showed our skill in navigating uncharted territory but also highlighted that new ideas need new ways of measuring success.

Looking back at our teamwork, it's clear that the journey was just as important as reaching our destination. Our teamwork and unwavering commitment not only helped us overcome challenges but also allowed us to present a concept that goes beyond what's expected in elderly care facilities.

In designing our modularized elderly care facility, we explored the details of creating spaces that truly feel like home. This went beyond physical attributes, including emotional and psychological elements to make a holistic and nurturing environment. While we grappled with the challenge of quantifying a feeling, this exploration deepened our understanding of the many factors that contribute to true comfort.

The lack of benchmarks for our unique model made us rethink and adjust our measurements to ensure a more accurate evaluation. Our focus on personalization and adaptability, without predefined standards, shows our commitment to not just meet but exceed the expectations of traditional nursing homes.

As we navigate new territories in the modularized nursing home market, our project stands as a guide for future innovations in elderly care. The teamwork, creative thinking, and resilience shown by our team position us as pioneers, ready to set new standards for compassionate and innovative care for the elderly. Our journey doesn't end with building a facility; it marks the beginning of a new era in elderly care solutions.

8. Conclusion

The challenges we faced, rather than hindering our progress, became opportunities for innovation, propelling us to devise a solution that goes beyond the conventional norms.

Our in-depth exploration into creating a comfortable nursing home evolved into a vibrant arena for refining our skills and expanding our shared knowledge. The quest to measure the intangible concept of "being at home" led us beyond traditional metrics, delving into the complex realm of emotions and the subtle aspects of psychology. Embracing a holistic approach, we acknowledged that true comfort extends far beyond the physical environment. While drawing insights from conventional nursing home metrics, our project demanded a unique methodology, leading to the development of a new set of metrics tailored to the distinct features of our groundbreaking model.

The success of our modularized elderly care facility is not merely a response to immediate needs; it marks a paradigm shift in the elderly care sector. It has revolutionized the traditional industry by offering numerous advantages. From an industrial perspective, our modular approach significantly reduces construction costs and time, providing a cost-effective and efficient solution to meet the growing demand for elderly care facilities. Simultaneously, it places flexibility and adaptability at the forefront for our elderly residents, fostering a sense of independence and comfort often lacking in conventional institutions.

Moreover, the absence of comparable offerings in the current market underscores the success of our project. This presents us with a unique and promising opportunity to capture an untapped segment of the market where the demand for innovative and adaptable elderly care solutions is on the rise. Our pioneering modularized elderly care facility not only addresses this demand but also sets a new standard for the industry.

In summary, our venture represents more than a project; it symbolizes a paradigm shift in the elderly care sector. By providing an efficient and adaptable solution in a market devoid of competition, we stand poised to meet the future with confidence and a commitment to improving the quality of life for our elderly population.

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10. Appendix

10.1. Gantt Scheme

PROJECT: Modularized Building

TMKT78 Product Development

Group 8

Project start date: 05/09/2023

Scrolling increment: 1

Milestone description	Category	Start	Days	Hours
Project development				
Mission statement	On Track	17/09/2023	1	1
GANTT Scheme	On Track	18/09/2023	2	2
Brainstorming	On Track	20/09/2023	3	3
First submission	Milestone	22/09/2023	1	
Identify customer needs	On Track	23/09/2023	5	5
Target product specifications	On Track	28/09/2023	5	5
Second submission	Milestone	03/10/2023	1	
Concept generation	On Track	04/10/2023	6	6
Third submission	Milestone	10/10/2023	1	
Evaluate and concept selection	On Track	11/10/2023	6	6
Fourth submission	Milestone	17/10/2023	1	
DFM and DFE consideration	On Track	18/10/2023	4	4
Prepare oral presentation	On Track	19/10/2023	4	4
Oral presentation	Milestone	12/10/2023	2	
Conclude report	On Track	12/10/2023	6	6
Report submission	Milestone	18/10/2023	1	

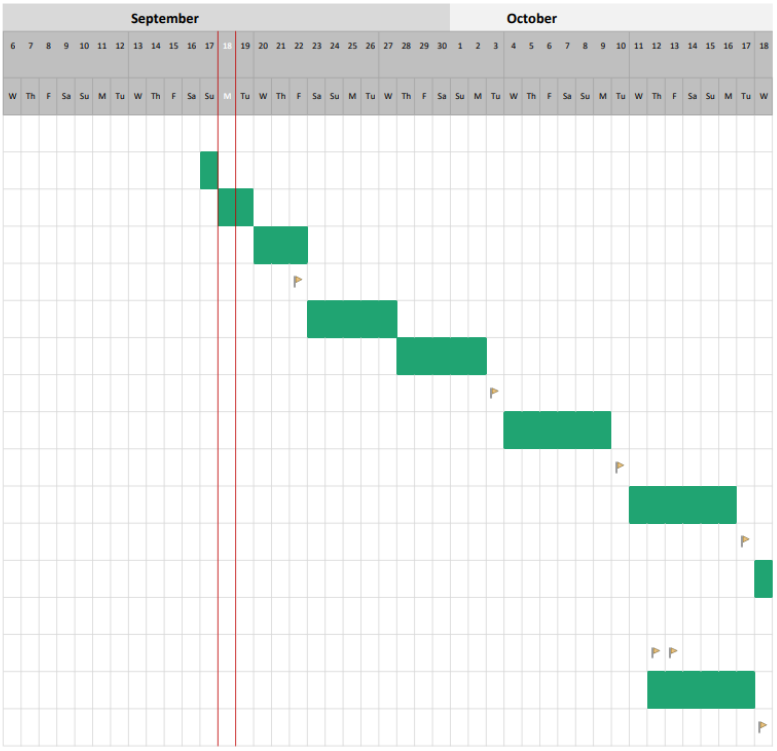

Figure 17: Gantt scheme

BRIC - Project

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Project Course Advanced TMPM05, TMPM03 and TMPP03

Fall 2023

Abstract

The world is currently addressing a climate crisis, requiring large organizations and industries to change their usual workflows. The construction sector, having contributed 21% to Sweden's carbon footprint in 2020 (*Utsläpp av växthusgaser från bygg- och fastighetssektorn*, 2023), is particularly crucial in this context. Moreover, the industry actors are currently facing issues in implementing innovations and sustainable practices, encompassing challenges related to both materials and processes.

This thesis is conducted with BRIC, a research project focusing on innovation in the construction industry. The goal of the project is to investigate what the most critical hindrances to innovation in the construction industry are, and how the attitude towards sustainability in the construction industry can change. Finally, the goal is to create a physical/ visual concept that creates awareness and raises discussion around sustainability and innovation in the construction industry.

A study consisting of literature studies and interviews generated information that was analyzed and divided into different categories of insights. Based on this information, the group conducted idea-generation sessions and developed several concepts. The members created low-fidelity prototypes of some different concepts and then used concept screening to choose the final concept that was produced as a high-fidelity prototype.

The final concept “EcoBuilding challenge” is a board game produced to be utilized in workshop settings. The game aims to create awareness and transparency in the construction industry by addressing hindrances, opportunities and raising discussions. The goal is for the players to build a house that has the lowest environmental impact, while facing common challenges and get perspectives that affect these choices.

1. Introduction

The world is currently addressing a climate crisis, requiring large organizations and industries to change their usual workflows. The construction sector, having contributed 21% to Sweden's carbon footprint in 2020 (*Utsläpp av växthusgaser från bygg- och fastighetssektorn*, 2023), is particularly crucial in this context.

Meanwhile, the actors in the construction industry are facing issues in implementing innovations and sustainable practices, encompassing challenges related to both materials and processes. This in turn impact factors such as pricing, resource requirements, and environmental effects associated with construction projects. Considering the scale and duration of these projects, it becomes essential to identify the reasons hindering innovations as well as explore opportunities and solutions that can enhance sustainable practices.

This thesis is conducted together with BRIC, a research project aiming to find new ways and tools that can lower the threshold for innovation and sustainability in the construction industry. Our project and contribution to the BRIC project constitutes a wide research study, investigating hindrances to innovation as well as future opportunities in the construction industry. Additionally, the group strives to produce a visual/ physical prototype that addresses the identified insights from the research.

1.1 Research questions

In this study, the aim is to answer the following research questions:

R1 What are the most critical hindrances for implementing innovation in the construction industry?

R2 How do the methods and processes in construction industry differ from design methodology?

R3 How can the attitude towards sustainability and innovation in the construction industry change?

1.2 Group Goal

To motivate and create a good environment for the project group to fulfill the project by determining the project goal, performance measure and how to fulfill the learning objectives together as a group.

1.3 Project goal

The project's goal is to investigate and identify hindrances and opportunities in the construction industry regarding innovation and sustainable practices. Based on the identified insights, the group aims to create a visual and physical representation that highlights the hindrances and opportunities in the construction industry.

1.3.1 The course goal

The course goal is for all the students in the group to fulfill the learning objectives and document their work with a written rapport including sub-reports as well as give half time and final presentation.

1.3.2 The goal for the BRIC project

The goal of the BRIC project is to create an understanding of the constructions industry's shortcomings and how changes can be introduced in a more efficient way. The goal is also to contribute with information and knowledge to highlight potential changes for the industry.

1.4 Performance measure

To contribute to the understanding of the construction industry's process and help the actors see possible ways to introduce innovative and sustainable changes for materials and processes made today.

1.5 Learning objectives

By using a well-planned and structured way to work in good contact with the project owner as well as the supervisors will the group *master the identification, selection and application of the theory and knowledge areas based on a situation-specific problem.*

By using critical thinking and reflecting on knowledge the group will *be able to plan and implement research and industry-related product development projects.*

With good collaboration and thoughtfulness, the group will *systematically integrate the knowledge acquired during the study period in order to solve a real design product development project.*

As a result of working on the topics above will the group *apply methodology and subject knowledge from the construction and product development area.*

By using the knowledge of engineering and previous courses the group will *create, analyze and evaluate technical solutions.*

By critical thinking and observation, the group will *assimilate the contents of the relevant literature and relate their work to it.*

By using communication among the group as well as discuss with supervisors along with relying on previous knowledge can the group *critically review, discuss and control a product development project.*

1.6 Boundaries

The given limitations currently include:

- The project will focus on the building industry in Sweden.
- Multistory housing for 2 families.

1.7 Deliverables

This project will more than this report deliver:

For the course:

- A project plan.
- Half time presentation.
- Final presentation.

For the BRIC project:

- Documented identified insights relevant for the BRIC project.
- A visual and physical representation of the construction's hindrances and opportunities.

2 Methodology

In the following section, the methods and the methodology of the project are explained. The research approach for the project is mainly based on literature studies and interviews, while the concept development phase includes more creative practices. The methods are interconnected and aim to complement each other to create a deep knowledge base for the project.

2.1 Pre-study

To create an understanding of the project, a pre-study is usually used. A prestudy can also be referred to as preclinical research. The prestudy is the preliminary stage of a study and is constructed before starting the actual study. The study involves collection and analysis of data to determine the plausibility of the study and foresee potential problems that may arise during the study. A prestudy is usually conducted to ensure of a well-designed study and that the data collected will be reliable and valid. Furthermore can it help researchers identify potential issues with the design of the study or methodology before the study begins. (Manaher, 2023)

2.2 Affinity diagram

According to Dam and Siang (2022), an affinity diagram is a large gathering of mixed information that is categorized into different themes. This method is beneficial when aiming to create an understanding of the insights and data gathered during research, as well as to organize ideas (Dam and Siang, 2022)

2.3 Literature study

To build the research on and related to existing knowledge is the building block of all academic research activities regardless of your discipline. Looking into other prior, relevant literature is a solid base for all research projects. It can also be seen as an excellent way of showing evidence or find areas that are lacking research or answers. This is seen as a critical component of creating theoretical framework and building conceptual models. (Snyder, 2019)

2.4 Interviews

In this study, a semi-structured interview format is used. According to *Delve* (2022), this is a data collection method where the interviewer asks the respondent a collection of open-ended questions, following them up with supplementary questions to further explore the respondent's interest. The method enables the interviewer to stay focused on the topic, while keeping the possibility to explore relevant ideas and questions that occur during the interview (*Delve*, 2022).

The interviews are used by the project members as a data collection method to gather qualitative information about the construction industry and subjects related to the project. The aim is to create an understanding of the industry as a whole and to identify issues regarding innovation and sustainability experienced by different actors. (Wikberg Nilsson, Ericson and Törlind, 2015)

2.5 Idea generation methods

In order create concepts and ideas are the custom to use generation methods depending on situation are different methods used below will the used methods for the report be described; The Six Thinking Hats, Brainstorming and Dark Horse.

2.5.1 Six thinking hats

The method Six Thinking Hats was developed by Edward de Bono to focus on different roles perspectives. Every role is represented by a different hat where each hat aims to lead to a focused perspective from a specific role. If the method is used correctly can the method lead to innovative solutions and ideas. The aim of the method is:

- Maximize the production of ideas and collaborate as well as minimize contra productive behaviors during the process of creativity.
- Closely focus on the problem and think through the issues, decisions and possibilities in an organized and systematic way.
- Use lateral thinking in order to generate more and better solutions and ideas.

- Reduce potential conflicts among the members since the focus is on the hat's perspective and nothing else.
- Imitate innovation.
- Create meetings that are creative and focused on results.
- Think beyond the obvious solutions and create possible alternative solutions.
- See possibilities where often hinders are found.
- Look at the problem from another perspective and gain an unexpected perspective.
- Achieve meaningful results during a shorter among of time.

The method aims to teach to structure the creative thinking and be able to use the different hats further along in the process than just during the idea generations. (Wikberg Nilsson, Ericson and Törlind, 2015)

2.5.2 Brainstorming

The Brainstorming method is an idea generation good to generate a great number of ideas The method aims to. Brainstorming was developed by Alex F. Osborn and is today used in many different shapes and forms. The execution can warry but have there are ground rules that needs to be followed:

- Don't criticize, not others or yourself. Do not think about the usability, feasibility or price. There is no need to be logic. The members of the workshop are not allowed to do negative comments about other participants ideas since all evaluation and criticism are saved for after the session
- Aim for crazy and wild ideas. Encourage that crazier idea can be better. The members can express them however they want, and everyone should feel saft in the creative environment.
- 1+1=3. Cobine and improve the different ideas as well as use the different ideas to improve and change other ideas in order to get a better result.
- Aim for quantity over quality. It is easier to get better ideas if there are more ideas to choose from.

Furthermore, is it important to have a theme of what the ideas should evolve around and have a question related to the chosen theme to start the session with. (Wikberg Nilsson, Ericson and Törlind, 2015)

2.5.3 Dark horse

The Dark Horse method aims to stimulate the brainstorming session and apply a clear-thinking model during the evaluation of solutions, where one or a couple wild ideas are moved further along in the voting process. A "dark horse" is:

- Aan idea that seems risky, radical and often crazy.
- An idea that is not completely aligned with the goal and the assignment, rather steers it into a new direction.
- An idea that requires great development as well as a great amount of testing in order for it to be successful.
- An idea that can be revolutionary in the branch if it is executed correctly.

The idea behind the dark horse is for the design team to develop solutions that are outside the box by developing something outside the regular frame of the area. It can also lead to seeing the potential for concepts and solutions that did not seem plausible from the beginning by looking at the problem and finding dark horse solutions. (Wikberg Nilsson, Ericson and Törlind, 2015)

2.6 Prototyping

Prototypes are physical models that are built in order to test different concepts. It is usually used as a test where different lessons and developments are gained from testing the prototype. It can also be used to test

different materials, models and methods to find the most useful for the design's purpose. (Wikberg Nilsson, Ericson and Törlind, 2015)

2.6.1 Low fidelity prototyping

Low fidelity prototype is a cheaper and simple prototype used to visualize the idea and ease the communication among the members. A low fidelity prototype can also increase the creativity for the group and create an environment that aims toward the same goal. The prototype is usually sketches or creations of paper since the most important part is to evaluate the concept and does not make it ready for production.

2.6.2 High fidelity prototyping

A high-fidelity prototype is as close to the finished product as possible both in the sense of design and the flow of the product. This type of prototype can therefore be tested as if it were the finished product. This will in its turn show potential problems in the interaction and usability of the product.

2.7 User testing

User testing is usually done with a high-fidelity prototype to gain an understanding of the products uses and potential problems. This is due to that the users can have a hard time to verbalize their experience or wanted experience. The user testing aims to gather valuable information of the development process. (Wikberg Nilsson, Ericson and Törlind, 2015)

3 Theory

This section presents the information gathered during pre-study, interviews, and literature studies. The section covers the different actors in the construction industry, the current process, sustainability, regulations and a comparison between different industries.

3.1 Different actors in the construction industry

This chapter describes the different actors involved in construction of housing.

3.1.1 The country board
The state establishes the framework for planning and construction through the Planning and Building Act, which is determined by the parliament and government. The County Administrative Board (Länsstyrelsen) primarily represents and oversees the state's interests in the various processes of the Planning and Building Act. The County Administrative Board has different roles in these processes, including an advisory role and a supervisory role through its ability to review certain decisions. The County Administrative Board is also the first instance for appeals concerning, among other things, preliminary opinions, permits, commencement notices, and completion notices. Lastly, the County Administrative Board is tasked with monitoring municipalities' compliance with the Planning and Building Act and providing municipalities with advice and support, including supervisory guidance. (Boverket, 2022).

3.1.2 The municipality
The municipality has several different roles in the Planning and Building Act. It serves both as an authority and property owner. The municipality is also responsible for certain services such as water and sewage, as well as waste management. It is the municipality that develops and adopts comprehensive plans, detailed plans, and area regulations. Decisions are made by the municipality's elected officials. (Boverket, 2022).

3.1.3 Building Committee
In every municipality, there should be a building committee. The building committee is an authority committee composed of elected representatives. The committee is supported by an administration with civil servants. The building committee makes decisions regarding permits and preliminary opinions and oversees the various stages of the construction process. Additionally, the building committee is responsible for supervising compliance with planning and building legislation. (Boverket, 2022).

Both politicians and civil servants in the municipality must adhere to rules regarding bribery, conflicts of interest, and misconduct. Under certain conditions, the municipality can be held liable for damages. (Boverket, 2022).

3.1.4 Other Stakeholders
Several stakeholders in society are affected by the provisions of planning and building legislation. Some are explicitly mentioned in the legislation, such as the property owner, and are therefore directly subject to the regulations, while others are indirectly affected. Those who are instrumental in planning and construction processes are often not the state or the municipality but rather other stakeholders, such as developers, builders, and property owners. (Boverket, 2022).

3.2 Actors and Responsibilities
In construction, there are simplistically two main actors:

- The builder who wishes to construct and is responsible for ensuring compliance with both public law regulations and private law regulations and contracts (Boverket, 2021).
- The municipal building committee, which oversees the builder's fulfillment of obligations according to the Planning and Building Act (2010:900), PBL, and its regulations, also makes certain decisions during the construction process. The building committee's duties are based on public law. (Boverket, 2021).

The process of construction can be described in various ways, depending on whether one views it from the builder's perspective or from a public law perspective, which is represented by the building committee. (Boverket, 2021).

3.2.1 The Construction Process from a Public Law Perspective

The construction process from a public law perspective begins after a building permit has been granted or after a notification has been submitted. Several steps need to be completed, and several decisions need to be made during the construction process. For instance, a commencement notice from the building committee is required to initiate actions subject to a permit or notification. For most actions, a control plan must also be developed, and the building committee must conduct at least one site visit. All actions subject to the requirement for a commencement notice must also receive a completion notice from the building committee before the building structure can be put into use. (Boverket, 2021).

3.2.2 Construction from the Builder's Perspective

The builder must, of course, adhere to and meet the public law requirements for construction. However, there are also many civil law issues involved in the process of building. For example, land, expertise, materials, and contractors may need to be procured through civil law contracts. Intertwined with the public law construction process are other aspects that the builder needs to manage. One way to describe the various stages of construction from the builder's perspective is illustrated in the figure below. (Boverket, 2021).

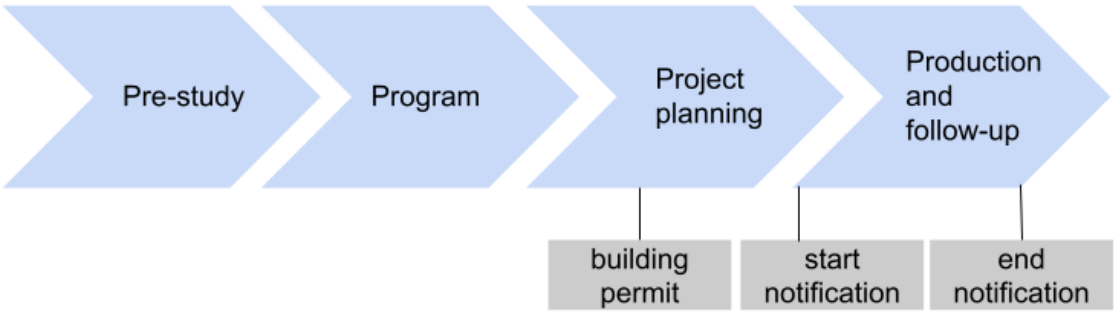

Figure 1: Visualization of construction process

The top row with arrows illustrates the stages of construction from the builder's perspective. The lower boxes depict some aspects of the public law process regulated by the Planning and Building Act (PBL) and the municipality's decisions regarding building permits, commencement notices, and completion notices. (Boverket, 2021).

3.2.2.1 Step 1: Preliminary Study

The preliminary study phase begins when the builder wishes to construct or establish something. Key questions include:

- What is to be built?
- Where is it to be built?
- What are the needs?

Frameworks for finances, functionality, technical specifications, legal prerequisites, and environmental considerations need to be described in a preliminary manner. Goals and visions for the construction project should be formulated in the preliminary study. (Boverket, 2021).

If the intended construction project requires the development, modification, or revocation of a detailed plan, a planning decision can be sought from the municipality. (Boverket, 2021).

The preliminary study concludes with the builder deciding whether to proceed with the construction project or not. (Boverket, 2021).

3.2.2.2 Step 2: Program

During the program phase, the objectives and requirements for the building and the site or area are specified, based on societal demands and the builder's own requirements. These objectives and requirements are documented in program documents. In the program phase, the builder also decides on the type of contract to be used for the project. If a design and build contract is chosen, a request for proposal (RFP) is prepared for the procurement of such a contract. (Boverket, 2021).

3.2.2.3 Step 3: Project planning

During the planning phase, the work involves design, layout, and investigation. Various alternative sketches and solutions are developed and compared. The client selects which option to proceed with. In this phase, there is also a system design process where different documents, such as building drawings, structural drawings, and installation drawings, are coordinated to meet both planning and building regulations as well as the client's requirements. If the client has chosen to use a construction contract (either separate or general), a request for proposal (RFP) is prepared for the procurement of the subsequent construction project. Typically, it is during the planning phase that building permits are sought. In preparation for the commencement permit, several technical documents may need to be generated, and detailed planning is carried out. (Boverket, 2021).

3.2.2.4 Step 4: Production and follow-up

Once the municipality has granted building permits and issued a commencement permit, the actual construction production can commence. The construction process must adhere to the drawings and instructions provided in the building permits and planning phase. Upon completion of the construction, it is typically followed by an inspection and a final consultation with the municipality. The municipality will then issue a final approval, allowing the building to be put into use. Once the municipality has issued a final approval, the construction phase is concluded, and the management and maintenance phase take over. (Boverket, 2021).

3.3 Regulatory Aspects

Regulations can frequently be intricate and inflexible, presenting challenges for the integration of innovative solutions while adhering to existing standards. Our investigation will delve into the regulations associated with building codes, environmental criteria, and safety prerequisites that might impede the adoption of sustainable construction practices.

3.3.1 Defining the Regulatory Framework in the Construction Sector:

In the Swedish construction industry, several regulatory bodies hold significant responsibilities in ensuring compliance, safety, and sustainability. The National Board of Housing, Building and Planning (Boverket), as an administrative authority under the Swedish Ministry of Finance, plays a central role.(Regulatory hierarchy – from law to general recommendation - Boverket, no date). Boverket holds

the responsibility of publishing essential regulations governing construction processes, encompassing acts, ordinances, and mandatory provisions relating to building rules, safety in case of fire, hygiene, and noise protection (Boverket, 2020).

Additionally, the Swedish Environmental Protection Agency (EPA) stands at the forefront of environmental sustainability in construction practices. While Boverket primarily focuses on construction regulations, the Swedish EPA oversees environmental concerns via the Swedish Environmental Code. This comprehensive legislation shapes actions affecting environmental objectives, including those pertinent to construction activities, and aims to foster sustainable development and a healthy environment for Swedish inhabitants (Swedish Environmental Protection Agency, 2020).

Moreover, legislative bodies such as the Swedish Parliament and Government substantially contribute to shaping construction-related legislation. Acts and ordinances, notably the Planning and Building Act (PBL) and Planning and Building Ordinance (PBF), are adopted by these entities, guiding land planning, societal progress, and construction processes (Swedish Parliament, 2010). The introduction of new regulations by governmental decisions can spur changes in construction procedures, creating an environment conducive to the adoption of innovative practices within the construction sector (Marija Jefimora and Tafertshofer, 2021).

3.3.2 Administrative and Legislative Instruments:

Local authorities have access to a range of administrative and legal instruments, including the Planning and Building Act, the Swedish Environmental Code, the Public Procurement Act, and Boverket's Building Regulations. These resources are complemented by the Swedish Local Government Act and the Act of Contracts, which introduce further conditions and instructions. Closing the knowledge gap, whether through in-house advancement or external partnerships, is essential to establish an atmosphere where various building solutions can vie fairly.

3.4 Sustainability in construction

The construction industry plays a significant role in the overall environmental impact on our planet. In recent decades, there has been an increasing push for sustainable practices in the construction sector due to its contribution to global carbon emissions and consumption of energy (Zhuan, 2023). The selection of building materials in construction is crucial for achieving sustainable development (Raut and Gomez, 2017). According to research, the construction industry consumes approximately 24% of the global raw material resource. This highlights the importance of utilizing sustainable materials in construction. Sustainable construction materials are those that have a minimal negative impact on the environment throughout their life cycle, from extraction to disposal.

3.4.1 Overview of Existing Sustainable Practices

In recent year, sustainable development and environmentally friendly practices have gained increasing attention in the construction industry worldwide. The various sustainable practices that are currently being implemented in the construction industry. This could include the use of eco-friendly materials, sustainable construction methods, waste reduction techniques, and sustainable design principles. (Reddy, B 2004) Here we can mention about some of the eco materials which used in construction sector:

1. **Recycled Steel**: The main motivation for engineers and clients who consider steel reuse is the environmental benefits the energy, carbon and other environmental impacts that are saved. (Densley Tingley, 2014)

2. **Recycled concrete**: In the construction industry, concrete is one of the main composite materials, hence the identification of techniques pointed toward decreasing the environmental impact is critical for achieving the green building goals and sustainable development goals (Merli, 2020)

3. **Smart windows**: enable varying the amount of heat and light that penetrate through the glass surfaces as needed, while maintaining outwards vision. These new dynamic windows, the electrochromic ones in particular, are proving to be more effective than traditional static systems - low-e selective glazing and automatic shading devices - at reducing energy consumption for lighting and air conditioning and providing greater comfort to users. (Casini, 2015)

3.4.2 Waste reduction techniques

The increasing awareness regarding environmental impacts from construction wastes has led to the development of waste management as an important approach for construction project management. Managing construction wastes is vital in order to cope with future sustainable development. We need to reduce or reuse waste and having a recycle strategy The term of waste reduction is related with the practices to reduce waste generation at it source. In construction project, it could be achieved through reducing or avoiding any activities and process that caused waste generation. (Hasmori et al, 2020)

3.4.3 Examples

Here are some locations constructed using sustainable methods.

- **One Central Park** is a city building with apartments and shops that is known for its innovative green design. It has sky gardens with more than 250 kinds of native Australian plants that make it a haven of peace in the middle of the city. The building also has advanced building control systems, solar power panels, and systems that collect rainwater. All of these features help the building be more energy efficient and environmentally friendly.(*One Central Park*, 2014)
- **Bosco Verticale** is a pair of living towers that are covered in trees and plants to take in CO2, make oxygen, and give birds and bugs a place to live. The towers use efficient insulation and renewable energy sources, which makes them much less harmful to the earth. This idea shows how vertical architecture can bring nature and sustainability into cities.('Vertical Forest | Milan', 2014)
- **The Edge** (Amsterdam) is often cited as one of the greenest and most sustainable office buildings in the world. It uses many cutting edge technologies, like solar panels on the roof, rainwater collection, and smart lighting systems that change based on the amount of natural light and the number of people inside. The form of the building makes the most of natural light, which means less need for artificial lighting. Green roofs add insulation and biodiversity to the building.(*EDGE | The Edge*,2014)
- The international building and development company **Skanska** is known for its dedication to environment. They have done many eco-friendly things, like using recycled and locally sourced materials, focusing on energy-efficient building designs, and reducing trash through efficient construction methods. Skanska actively supports green building methods and has worked on many environmentally friendly projects around the world.(*Skanska global corporate website*, 2020)

3.5 Willingness to pay

Environmental awareness was the subject of four questions. In the first question, people were asked if they thought they were environmentally conscious. There were two possible answers: yes or no. About 80 percent of the buyers say they care about the environment. On average, families that care about the environment make more money each month, have more educated adults, and are bigger. These changes

are small, though, and don't mean much. Also, environmentally conscious families don't seem to be buying different types of houses based on size or quality inside, but they do seem to be buying homes with more environmentally friendly features. (Mandell and Wilhelmsson, 2011)

A survey of 477 people who lived in green and non-green buildings was used to look at their stated WTP (willingness to pay) for apartments in low-energy and environmentally labeled buildings. People who live in green buildings are usually more willing to pay more for them. However, respondents had different opinions about how much they would be willing to pay for 24 low-energy buildings and buildings with environmental approval. People may not be ready to pay as much for buildings with an environmental certificate because they are not sure that the certificate means the building is more valuable. The results send a strong message to the industry that certifying private buildings may not be worth it if environmental performance is not considered in the valuation process. Customers are ready to pay more for features that they understand and can see how they could help them, like features that use less energy. (Zalejska-Jonsson, 2014)

971 homeowners in Sweden's Kronoberg Region filled out an online survey form that we used for this study. About 76% of those who answered plan to renovate soon. About 71% would rather renovate separate parts of their home, while only 5% would like to renovate their whole house in stages. People who own homes and have more education and a higher income are more likely to make changes to their homes that make them more energy efficient. The people who live in those houses are also younger and care about the environment. Their concern for the environment was a strong factor in their choice to make things more energy efficient. This suggests that their actions are part of a larger effort to protect the environment. (Pardalis *et al.*, 2019)

A new Novus research from Sodra shows that Swedes want to see more environmentally friendly wood buildings. A lot of Swedes (64%) think that their city or town should build climate-smart buildings like schools and health centers. Even in an economic downturn, more than seven out of ten (71%) believe that Sweden should keep investing in building products that are better for the environment. (*Sodra* , 2023)

3.5.1 Factors Impacting the Apartment Purchasing or Renting Decision

The results of this study show that information accessibility should be taken into account when talking about how energy and environmental issues affect a customer's choice to buy. When the energy or environmental effect of a building sends a positive signal and could raise its selling price, developers are more likely to tell potential buyers about it. But the lack of knowledge in the market has effects. First, people who might buy a building are told how great green buildings are, but they don't know what to expect from regular buildings. Second, the helpful information sets clear standards, which could affect how satisfied the residents are overall. (Zalejska-Jonsson, 2013)

Finally, the customer may not trust environmentally profiled buildings because they can't see the environmental benefits directly and some study has even called them into question. Customers who are cautious may think there is a higher chance of investing and be less willing to pay .(Zalejska-Jonsson, 2013)

3.6 Comparison between innovation adoption in car industry and construction industry

According to Knez, M. and Obrecht, M. (2018), consumers might be more accustomed to innovation in cars due to frequent upgrades and tangible technological advancements. There are precise statistics, for example, in terms of fuel saving, that help customers to compare and understand the benefits of EV cars. In contrast, construction projects might be seen as more traditional, making it harder for customers to perceive the benefits of sustainability initiatives immediately. (Zalejska-Jonsson, 2014)

The automotive industry currently faces strict regulations and emissions standards, which can drive innovation and incentivize the adoption of new technologies like electric cars (Knez and Obrecht, 2018). While Beerepoot and Beerepoot (2007) said that construction might not face clear and strict level of regulatory pressure for sustainability, impacting the urgency for innovation.

In the automotive sector, there's tight global competition among companies, particularly in the US, Europe, and China, driving innovation, especially in technologies like electric vehicles. (Tesla Is No Longer Alone in the Electric Vehicle Race, 2022). Conversely, the construction industry is predominantly local, lacking the intense global competition seen in automotive, which slows down rapid innovation in sustainable construction practices.

The construction industry involves multiple stakeholders with varying interests, making it challenging to align everyone towards adopting new sustainability practices. (Marija Jefimora and Tafertshofer, 2021). Meanwhile, the automotive industry might have more centralized decision-making processes, facilitating quicker innovation adoption.

3.6.1 Comparison between incentives in the construction industry and car industry:

In Sweden, banks are providing opportunities for green building credit, allowing financing for both residential and commercial real estate projects, regardless of their scale. This financing option is for companies and housing associations aiming to prioritize environmental concerns during the construction of new properties (‘Climate roadmap to zero emissions’, no date). Additionally, green mortgages are being offered at reduced interest rates for individuals residing in environmentally conscious homes. These loans are available to those whose housing meets specific criteria, such as A/B ratings as per the Swedish National Board of Housing Building and Planning's energy classification, Nordic Ecolabel certification, passive house certification, or gold/silver certifications from the Sweden Green Building Council.(‘Climate roadmap to zero emissions’, no date). The criteria required to access these incentives are somewhat unclear, leading housing companies to ask for clarification on what qualifies as 'green' projects. This lack of clarity poses challenges for banks and green bond programs alike.(Mangold and Mjörnell, 2023; ‘Climate roadmap to zero emissions’, no date)

In comparison, incentives in car industry seems like to be more effective. In the automotive industry, several incentives drive innovation and make it more attractive for customers: Incentives like tax credits, subsidies, or rebates for purchasing electric or fuel-efficient vehicles reduce the overall cost of ownership. This makes innovative cars more financially appealing to consumers. (Ali and Kondal, 2022)

Investment in infrastructure and services like investment in charging stations for electric vehicles enhances convenience and addresses the concern of range anxiety, encouraging consumers to adopt electric cars. (Ruan and Lv, 2022). Stringent emission standards or regulations that incentivize the production and sale of eco-friendly vehicles encourage automakers to invest in innovative technologies, ultimately benefiting consumers with cleaner and more efficient vehicles. (Ruan and Lv, 2022). According to Habich-Sobiegalla, Kostka, and Anzinger (2018), public education initiatives and awareness campaigns highlighting the advantages of innovative cars, such as reduced emissions, lower fuel costs, and government incentives, effectively increase consumer interest and acceptance.

4. Findings

This chapter describes the findings from the research, including both literature study and interviews. The chapter is divided into several sections, beginning with hindrances to innovation and drivers for innovation.

4.1 Hindrances to innovation in construction industry

In this section, identified hindrances to the implementation of innovation in the construction industry are clarified. Information is gathered from both interviews and literature studies and organized into different categories.

4.1.1 The nature of the industry

To begin with, the construction industry is highly complex because of several factors. Characteristics in the construction industry depend on the characteristics of buildings, as described by Slaughter (1998) as "Buildings are large, complex, intended to last for an extended period, created and constructed through a temporary collaboration among various organizations, within a project, within a specific social and political context". It's a combination of various conditions that influence the creation of a building, making it challenging for innovations to emerge and spread because the next building produced is influenced by a different combination of conditions. (Ahlqvist, 2014)

According to Er (2020), innovation is uncommon in the construction industry. In general, trying out new things seems to be unconventional, which results in a culture that doesn't foster innovation. Furthermore, (Er, 2020) believes that the reason the industry lacks innovation is that companies are stuck in their old ways and just not used to that kind of approach. Accordingly, Jansson (2023) stresses that the construction industry is lazy and prefers their usual way of working. As most actors stick to this mindset, they don't force each other to innovate as in other industries (Jansson, 2023).

Furthermore, Goksøyr (2023) underscores that the industry tends to be highly conservative, with many stakeholders sticking to familiar workflows they have used for years. She believes that this conservatism is linked to the length of the project cycles and the financial investments. Actors in the industry often perceive the adoption of new methods and innovations as a risk (Goksøyr, 2023).

4.1.2 Seen as a potential failure and financial risk

According to Er (2020), the construction industry has a well-used method to achieve their goals. Thus, bringing innovation into the method or process is rather viewed as a potential failure than success (Er ,2020). Furthermore, Jansson (2023) mentions that there is a fear of using new products and materials because the consequences if failing can be heavy. There are several known examples where a new innovation was implemented and failed, which induced fear in implementing new innovations and products in the industry (Jansson, 2023). Additionally, there is a lot of money involved in a project and the result of an innovation that fails can be extremely financially costly. Accordingly, Warell (2023) mentions that failure in the construction industry costs around 1 billion SEK every year and argues that this creates a strong incentive to not introduce another possible failure.

Furthermore, the fact that buildings are supposed to endure over an extended period of time puts a greater pressure on the physical composition of the buildings (Er, 2020). This makes it riskier, for instance, to use a new material whose long-term durability is unknown, resulting in project managers waiting to implement new innovations until the long-term negative effects are identified (Er, 2020). Moreover, (Goksøyr, 2023) highlights that once reference projects become available for review, stakeholders

become more open to experimenting with new innovations. However, she emphasizes that the willingness to be early adopters of innovation is largely a matter of personal preference, which varies depending on the specific client or project contractor (Goksøyr, 2023).

Moreover, Warell (2023) mentions that actors don't want to be responsible for taking risks alone. If you instead split the risk among several actors and create a common insurance, the risk would be moved from a single actor to the whole chain, which would lower the threshold to take risks.

4.1.3 Actors don't realize the benefits with operating sustainable

According to Jansson (2023), actors in the construction industry lacks awareness of the advantages of innovations and sustainability. Often, the sustainability part is included in the end of the project to fulfil sustainability goals, rather than in the early stages of a process (Jansson, 2023). Jansson (2023) highlights that his frequently leads to increased expenses and a failure to realize the genuine benefits of operating sustainably. According to (Er, 2020), the clients of a project often have minimal enthusiasm for the final product, prioritizing only meeting the basic requirements. They view buildings as short-term assets and fail to recognize the connection between the buildings and the success of their primary business. As a result, they are unwilling to initiate innovation (Er, 2020). Furthermore, Goksøyr (2023) emphasizes the importance of providing clients with evidence that demonstrates the value of innovations and a clear estimate of their associated costs. Without such information, clients may not perceive any benefits in pursuing innovation, as it often demands additional time compared to their usual workflow and requires new knowledge (Goksøyr, 2023). Additionally, Goksøyr (2023) mentions that clarifications of financial benefits are essential to make clients change their approach.

4.1.4 Lack of collaboration and knowledge transferring

Jansson (2023) highlights that there is a lack of well-defined methods for collaboration among project stakeholders, leading to information loss during collaboration. In certain cases, the implementation of lean processes has proven the capacity to enhance both the process and collaboration among these stakeholders (Jansson, 2023).

Accordingly, Warell (2023) argues that the issue is the high number of actors, and not a specific one. He compares the construction industry with the methodology of integrated product development and recognizes the big difference between the industries. He stresses that the actors in the construction industry often do their part and use their processes, and then throw it to the next one, which creates a non-integrated workflow. Additionally, Warell (2023) highlights the need for a function or person that creates coordination.

Moreover, the temporary organizational composition of actors operating under social and political conditions also affects construction projects (Ahlqvist, 2014). Thus, construction projects involve an interaction between social and technical dependencies that develop simultaneously in different parts of the project, involving various actors and technologies (Ahlqvist, 2014) The author argues that this dynamic creates opportunities for new solutions to emerge within construction projects, while complicating the spread of these solutions to other projects, as they become so unique due to the temporary and project-specific technical and social conditions. Accordingly, Goksøyr (2023) highlights that actors need to be aware of new innovations to be able to suggest them in the first place, and that this is not always the case. She further underscores the importance of knowledge sharing between actors as well as projects.

4.1.5 Lack of demand for sustainability

According to Jansson (2023), customers of the construction industry do not demand sustainability and innovation in the same way as in other industries. Goksøyr (2023) emphasizes that the reason could be

that costumers lack the knowledge of sustainability in this area, as buildings are complex and include multiple building blocks. Consequently, customers may face challenges in determining the sustainability of a building and may be uncertain about what expectations to set for a company (Goksøyr , 2023). Additionally, she stresses that there are several factors present when investing in a residence, such as price, location and aesthetics. Especially the heavy financial investments might lead to customers caring less about the environmental impact (Goksøyr , 2023). Moreover, Jansson (2023) mentions that one of the most important factors to change the approach within the construction industry is that customers start asking questions and demands sustainable buildings. Accordingly, Goksøyr (2023) argues that if customers start requiring this from companies, the clients will automatically be forced to prioritize sustainability.

4.1.6 Regulations hindering innovation

According to Karlsson, A. and Edeland, F. (2018), stricter environmental regulations often impose additional costs on firms. These costs can include compliance costs, such as implementing new processes or technologies, obtaining permits, and conducting environmental assessments. Hence, these added expenses can discourage firms from investing in innovative sustainable technologies (Karlsson, A. and Edeland, F, 2018). Moreover, the authors highlight that if regulations do not provide sufficient incentives for firms to adopt sustainable technologies, they may be less motivated to invest in innovation. Without clear benefits or rewards for adopting sustainable practices, firms may choose to stick with traditional methods and technologies (Vogel, 2020).

Moreover, Beerepoot, M. and Beerepoot, N., (2007) stresses that regulations can create uncertainty and risk for firms, particularly when it comes to adopting new technologies. Actors may be hesitant to invest in innovative solutions if they are unsure about the regulatory requirements or if they fear that regulations may change in the future. This uncertainty can stifle innovation and discourage firms from taking risks (Beerepoot, M. and Beerepoot, N., 2007). Accordingly, Pelkmans and Renda (no date) highlight that strict regulations can create a compliance burden for firms, diverting their resources and attention away from innovation. Firms may need to allocate significant time and resources to ensure they are meeting regulatory requirements, leaving less capacity for exploring and implementing innovative solutions. (Pelkmans and Renda, no date)

Additionally, regulatory approval processes can be lengthy and complex, causing delays in the adoption of new technologies. This can be particularly challenging for small and medium-sized firms with limited resources. The lengthy approval processes can hinder the timely implementation of innovative sustainable technologies. (Dewick and Miozzo, 2002)

4.1.7 Behind in IT solutions

Hofman (2023) stresses that the construction sector is behind in terms of digitalization and information technology (IT) adoption. While digital tools are frequently used in the planning phase of projects, the construction phase is characterized by a more manual, hands-on approach, lacking the level of digital integration seen in planning. Hofman (2023) highlights that IT solutions are seen as challenges as they are not user-friendly enough for involved stakeholders, and the number of actors in the construction process makes it difficult to implement a unified system.

4.2 Positive drivers for innovation in the construction industry

In this section, identified drivers for innovation in the construction industry are described. Information is gathered from both interviews and literature studies and organized into different categories.

4.2.1 EU Taxonomy

According to Hofman (2023), several regulations that will affect the sustainability in the construction industry are upcoming. For example, she mentions the EU taxonomy for sustainable activities. The EU Taxonomy is a key component of the EU Renewed Sustainable Finance Strategy, designed to encourage financial and industrial sectors to prioritize investments that contribute to climate neutrality in the European Union (EU). Its primary objective is to establish a classification framework for sustainable investments, focusing on six environmental objectives. For investors, this serves as a basis to identify and market investments as sustainable, and thereby enhance transparency.

The implications for the buildings sector include the development of technical screening criteria for economic activities within this sector. This encompasses activities such as the installation, maintenance, and repair of renewable energy technologies, as well as instruments and devices for measuring, regulating, and controlling the energy performance of buildings. Furthermore, manufacturing and mining criteria for other economic activities and environmental objectives under the EU Taxonomy will have broader impacts on supply chains within the building sector.

According to Warell (2023), regulations are an efficient way to push actors toward making sustainable choices. On the other hand, he mentions that other incentives are important as well. Accordingly, Hofman (2023) argues that actors will make more conscious choices just knowing the industry is about to change.

4.2.2 Green mortgages

Several banks offer what are called "green mortgages," with discounts on home loan interest rates but with certain requirements. One common requirement is that the building must achieve a specific energy class. According to Hofman (2023), this serves as a strong incentive for customers to buy more energy-efficient buildings and contribute to the environment.

4.2.3 Innovation programs

According to Hofman (2023), there have been several examples where owners and the construction industry have worked together for innovation programs. For instance, she mentioned an example where a company built their own head quarter in wood, as they could take the risk of implementing innovations. Moreover, Hofman highlights other more experimental projects that are not aimed to last for 20-150 years as common buildings. She stresses that lowering the risk is essential for actors to be willing to try new ideas, both regarding actors and responsibility.

4.2.4 Long-term clients

According to Casselbrandt (2023), the most important actor to pinpoint regarding sustainability is the client as they have the largest possibility to make a change. Furthermore, he stresses that there is large difference between companies depending on for how long they will keep the buildings. Clients who are going to sell the buildings quickly seems to put a low emphasis on sustainability and choose the alternatives that are “sustainable enough”. On the other hand, companies who will keep their buildings during a long time put a greater focus on sustainability.

4.2.5 Transparency can increase market demands

According to Guttorp (2023), market demands vary across different types of buildings. For smaller houses, like Attefallshus, end customers show a greater willingness to experiment with new and sustainable materials, even if they come at a higher cost. There's a sense of closeness to the people and a feeling that individual choices can make a positive impact (Guttorp, 2023).

On the other hand, the scenario is different for larger-scale buildings according to Guttorp (2023). These projects are more influenced by the requirements set by municipalities or real estate companies. If these

projects have specific sustainability metrics, they tend to perform well. However, there's a notable lack of concern from end customers. Apartments, in particular, don't show the same level of interest unless they are explicitly marketed as sustainable. In these cases, there's often a disconnect between the building and the concept of sustainability that is not apparent to the end customers (Guttorp, 2023).

According to Guttorp (2023), this implies that closeness and transparency into the buildings is essential to raise interest and awareness among end customers. Hence, if implementing these factors in an efficient way, the market demand on sustainable builds could increase. Consequently, the construction industry would be required to adapt to the new demands which would serve as a driving force for innovation and sustainable practices.

4.3 Analysis of findings

The study of innovation in the construction industry reveals some significant challenges. The industry's large projects and temporary collaborations make it difficult to consistently use new and improved methods. Also, there's a resistance to trying new things and taking financial risks for innovative practices.

A key issue is that many actors in the industry aren't aware of the benefits of new approaches and sustainability. Often, considering sustainability comes too late in a project, missing chances to utilize cost-effective and eco-friendly methods. Moreover, problems with working together and sharing knowledge among different groups and projects also slow things down. The industry doesn't have a standardized way of doing things, making it difficult to spread good ideas.

On a positive note, there are things pushing for change. Expected rules, like the EU Taxonomy, could help guide the industry to more sustainable practices. Financial rewards, like green mortgages, give customers a practical reason to choose eco-friendly options. Working together on innovation, especially in projects with fewer risks, gives a good place to try out new ideas. The influence of long-term clients, who want to keep buildings for a long time, is also helping positive change.

Even if there are opportunities and solutions on the horizon, the construction industry needs to change significantly to be able to innovate and use sustainable practices in a systematic way. To begin with, the actors need to be aware of the issues and hinders that are present today, in order to be able to discuss solutions and opportunities.

5. Implementation of methodology

This chapter describes how the methods described in chapter 2 was implemented by the group.

5.1 Information gathering

This section describes the information gathering conducted by the group.

5.1.1 Pre-study

To create an understanding of the project, the group conducted a pre-study. This was an essential preliminary step in the research process, as the members had no prior experience with the subject. The study focused on understanding the construction industry today, including experienced hindrances for operating innovative and sustainable. The gathered information served as a foundation for the project, including problem identification, initial exploration, and planning. The method used was primarily literature studies, but without defined research questions.

5.1.2 Affinity diagram

The group used affinity diagram twice during the process. To begin with, the method was utilized to decide on the overall goal of the project together with research questions. The group members conducted several brainstorming sessions with different themes, including research questions, goals, and expected outcomes of the project. The ideas were written down on post-it notes and then placed on a whiteboard. Lastly, the members organized the ideas into different categories and decided on an overall goal and research questions.

Additionally, the method was used to analyze the information gathered during the research phase. The group wrote down information from interviews as well as the literature study on post-it notes and then created several categories of insights. The session was conducted in a similar way as the first one.

Figure 2: Picture of affinity diagram conducted by the group.

5.1.3 Literature study

To collect qualitative data, a literature study is conducted. To operate efficiently, every group member explores one subject related to the project. The different areas are hinder for innovation, sustainability, regulations and processes and actors in the construction industry. After dividing these among the members, relevant data bases such a Google Scholar and Unisearch is used to find relevant articles. To quickly identify suiting articles, the group begin with reading the abstract. If the information seems to be relevant, the conclusion is also read. Lastly, a determination whether to include the information or not is

made. When gathered relevant articles, a conclusion of the information is presented to the other group members and submitted in text.

5.1.4 Interviews

The interview study was conducted together with actors that the group considered as relevant for the project. In total, six people were interviewed during the project. The interviews were held online due to the respondents living in several different locations. Furthermore, not all group members were present on the interviews to create an environment where the respondent felt safe. One of the group members asked questions, while one or two others were taking notes. The interviews lasted for about 45 – 60 minutes.

To create an easy-going environment, the group members began the interview by introducing themselves and the BRIC- project. Furthermore, questions about the respondent and their relation to the project were asked, as well as simple questions regarding the construction industry. Lastly, questions about experienced issues and hindrances were asked. The list of interviews can be viewed in table 1 below.

Table 1: List of interviews

Respondent	Title	Date
Ulla Jansson	*Professor*	20-09-2023
Emily-Claire Goksøyr	*Architect*	06-10-2023
Johan Casselbrandt	*Architect*	31-10-2023
Anders Warell	*Professor*	06-11-2023
Lars Guttorp	*CEO*	07-11-2023
Anna Hofman	*Chemist*	12-11-2023

‘

5.2 Concept development

For the concept development phase, the group used the methods described in chapters 2.4 and 2.5. In the following chapter the implementation of these methods will be described further. Below is a visualization of the process made for developing the concept.

Figure 3: Visual representation of the concept development phase.

5.2.1 Idea generation

Based on the gathered and defined insights from the prestudy, the group conducted several idea generation sessions.

To begin with, the members began with a six-thinking- hat session based on the most important insights. The group came up with six different perspectives, including children, superheroes and elderly. The members started brainstorming.

Furthermore, the group conducted a simple brainstorming session. The rules of the brainstorming were a part of the whole project such as not criticizing ideas and encouraging more ideas. For the part of idea generation that focused on brainstorming, the members wrote down ideas on post it-notes for a set amount of time. The ideas then were talked through and discussed further.

After gaining more simple ideas and logical ideas the members perform the dark horse method where the aim was to create more creative and groundbreaking ideas. After collecting the different ideas discussions started to see if a variation of them could be possible as a final concept.

5.2.2 First ideas

From the idea generation did the group get three concepts to consider. The first concept was a computer program for the meeting between the client and the builder where different combinations of materials and components would be evaluated together. The program would also show the price and potential long-term savings for the chosen materials in order to encourage the buyer to see the benefits of more ecofriendly materials.

The second idea was a simplification of showing the constructions timeline and combining it with a computer program. The board was meant to be a conversation topic and showing where choices are made into the timeline. At each choice would be a QR-code to the website where the different options would be shown as well as their benefits. The combination would lead to more understanding about the process of building a house as well as clearly showing options for components and the positive effect changes can have. This would solve the issue described in the interviews that the buyers rarely understand the process and changes that can be made.

The last concept discussed was a game to be used in workshops. The players get different material cards where they are presented with the material's sustainability, cost, durability, and environmental impact. Along with the material cards would hinderance cards be presented to provide players with a more comprehensive understanding of challenges faced in construction. Such as restriction of a specific material or resistance to change.

The aim of the game would be for players to construct the most sustainable and cost-efficient house by selecting the right materials. This is leading for the players to gain an understanding of the materials cost and sustainability when building a house.

5.2.3 Concept screening

To land in the best concept to develop were a concept screening preformed. At this point other perspectives were taken into consideration such as when the prototypes should be used and what it would contribute to the construction industry. The screening led the group to move along with the game and create a better prototype.

5.2.4 Low fidelity prototypes

After landing in a few different concepts low fidelity prototypes were produced to gain a better understanding about the concepts and ideas around it. The discussions that followed were small changes to the concept and how it could further be developed. For example, was a game board added as dice in order to create more of a game instead of just a quiz. Another example of changes where the different scoring of the materials was chosen to be visualized in a simpler way of a scale instead of numbers along with the discussion cards.

Figure 4: Low fidelity prototype of the game

5.2.5 High fidelity prototypes

After choosing the concept, a high-fidelity prototype was created to get a better understanding of the game and show where further developments can be made concept. The prototype helped highlight the problems and analyze how the game would be best used in a scenario.

5.2.6 User testing

When a high-fidelity prototype was made were also user test preformed. This was in order to get an understanding of how the game would be played and areas that did not function as planned as well as how the game can create discussions and ideas about the construction industry.

5.2.7 Iterations

After the user testing the group find some iterations that had to be made for the game to fulfill its meaning and work best in a workshop setting.

6. Construction

In the building phase of our project, we put our thoughts into actual structures. By testing and fixing things, we ensured our game was effective in workshops.

6.1 Autodesk Fusion 360

During the building phase of the project, we used two important software tools to make the planning and prototyping processes faster and better. Autodesk Fusion 360 was first used to make a detailed virtual a prototype. As you can see in figures 5,6,7 this program helped us carefully plan and see how our eco-friendly building model would look in terms of its shape and dimensions. By digitally creating the prototype, we got a good idea of how to build the real structure in the workshop. This made sure that the creation process was highly accurate and precise.

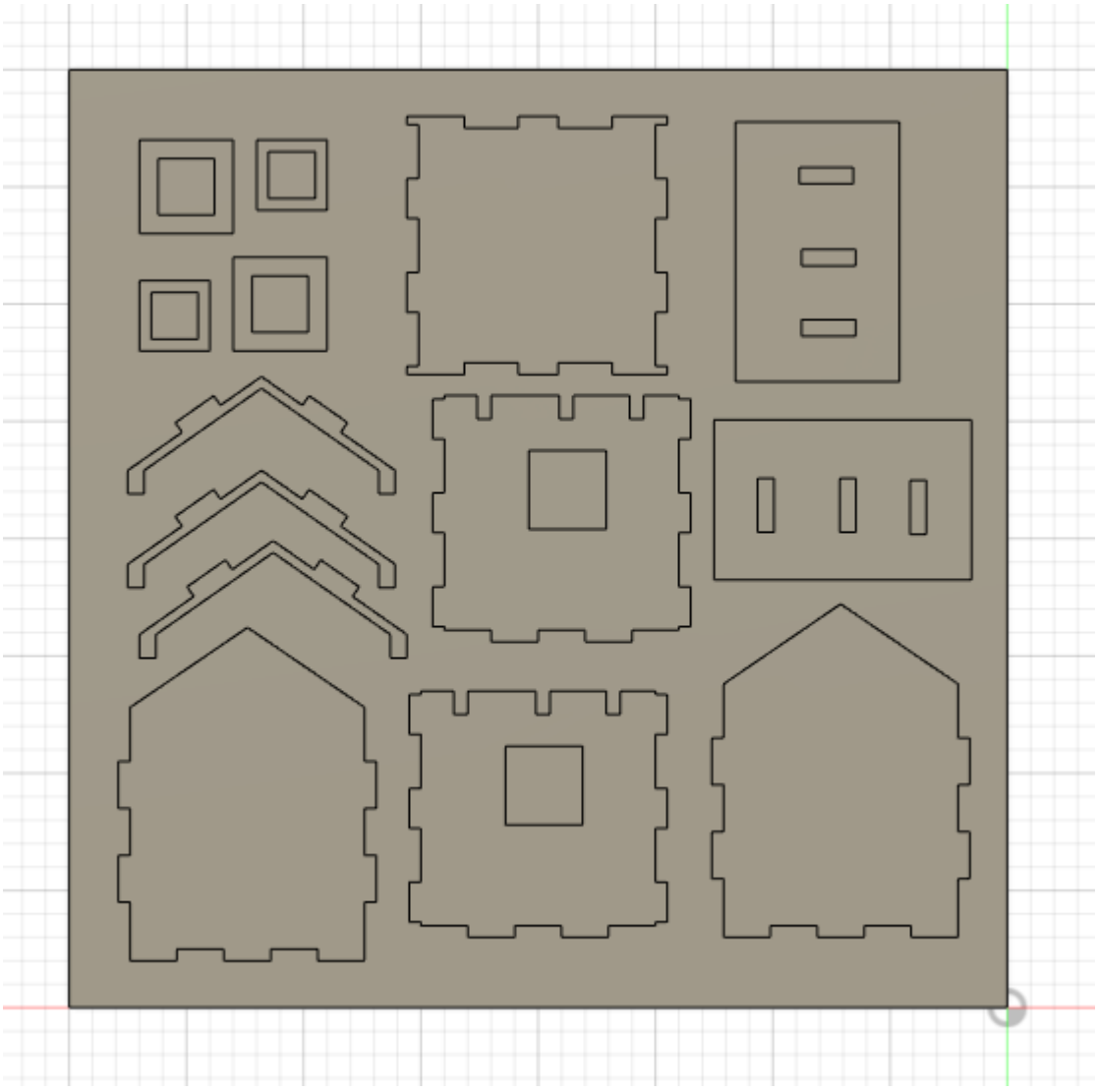

Figure 5: 2D model in Autodesk Fusion 360

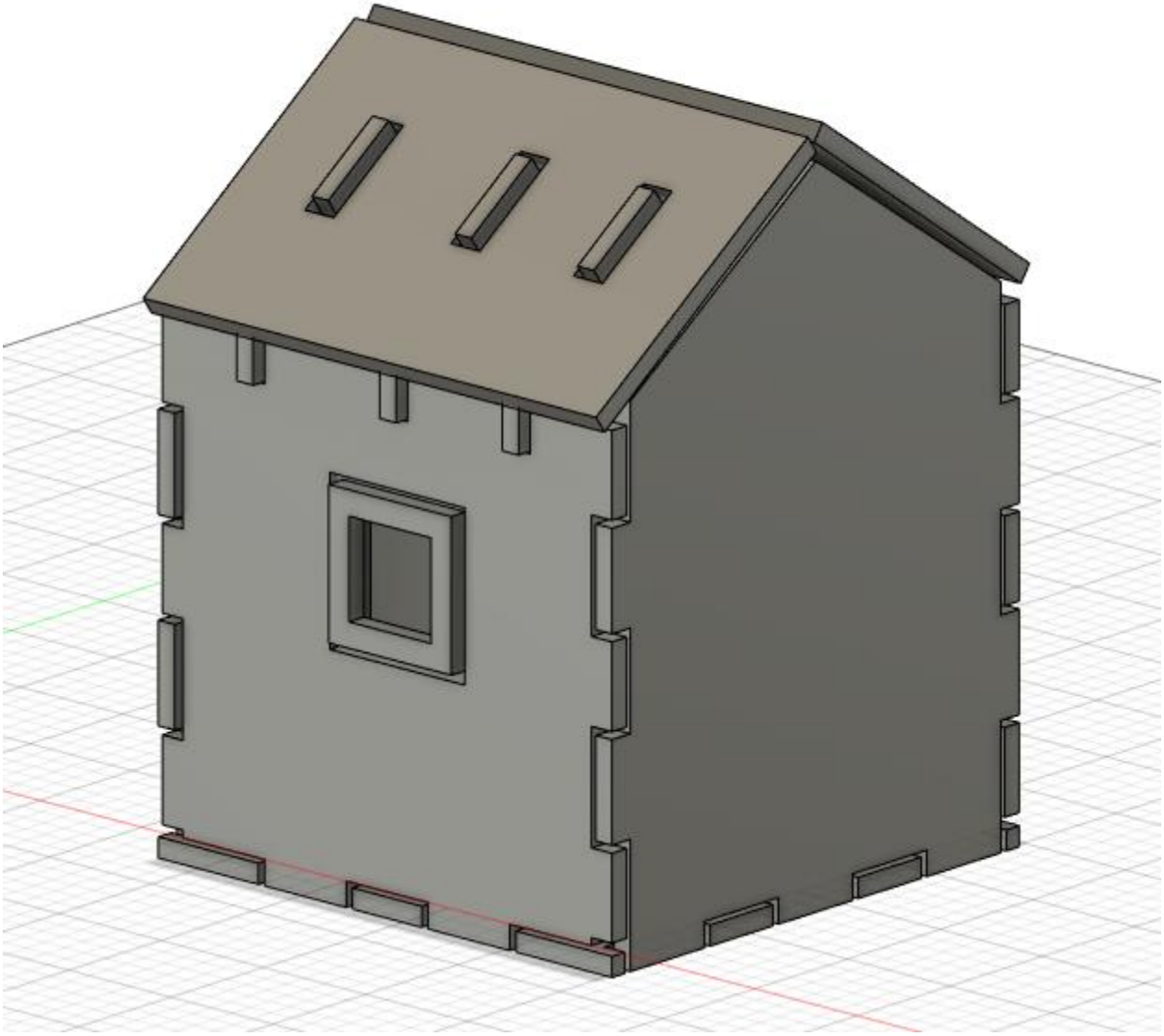

Figure 6: 3D model in Autodesk Fusion 360

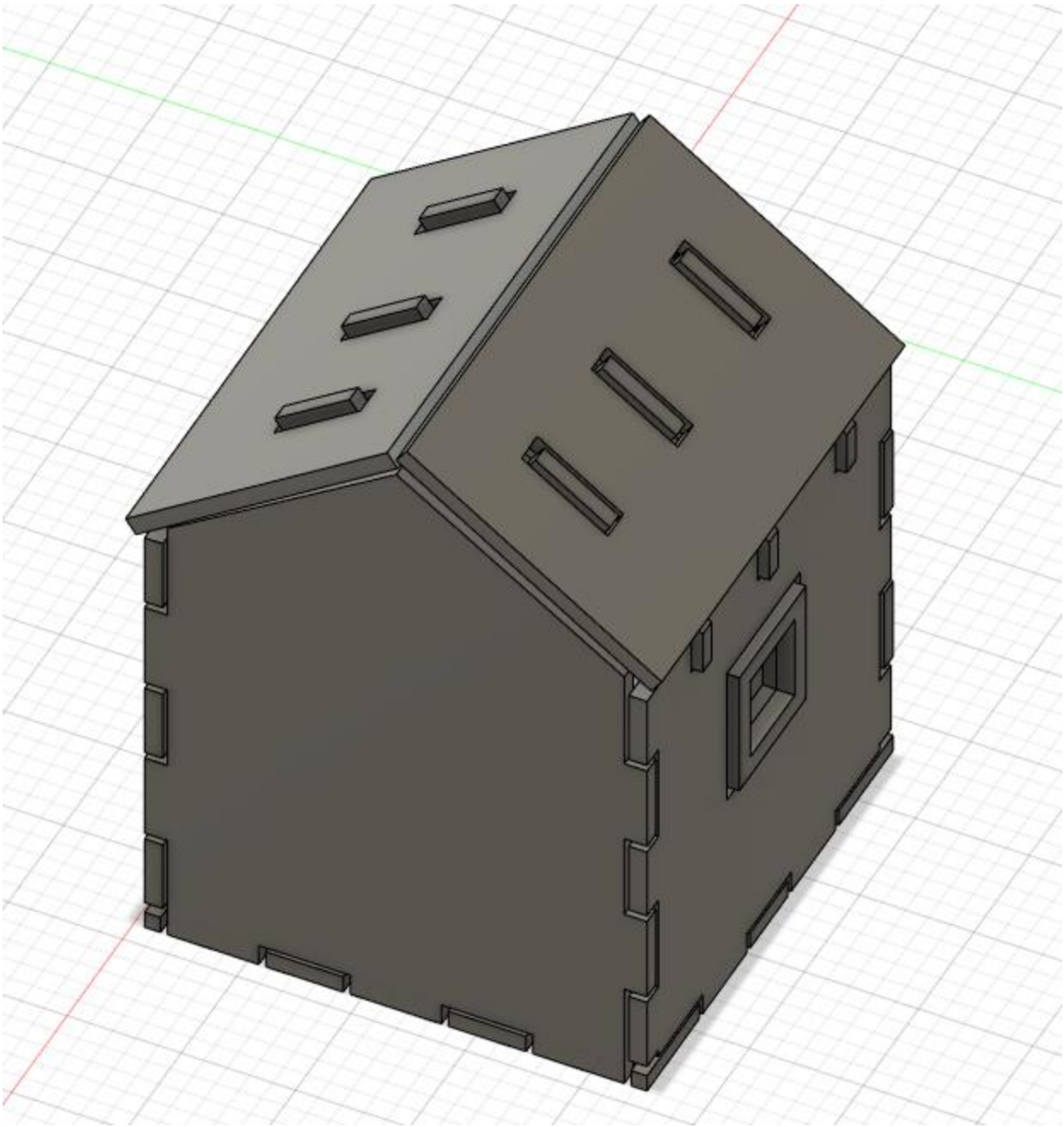

Figure 7: 3D model in Autodesk Fusion 360

6.2 Inkscape

After the design part, as you can see in Figure 8 we used the Inkscape software to better understand the prototype by rendering it in 3D. Inkscape brought the virtual model to reality, making it possible to see the planned building in a way that felt real. This visualization was very helpful in figuring out what problems might come up and how the plan could be made better. The results that Inkscape gave us were used as a visual guide to help us make decisions and improve the prototype even more before we started building it.

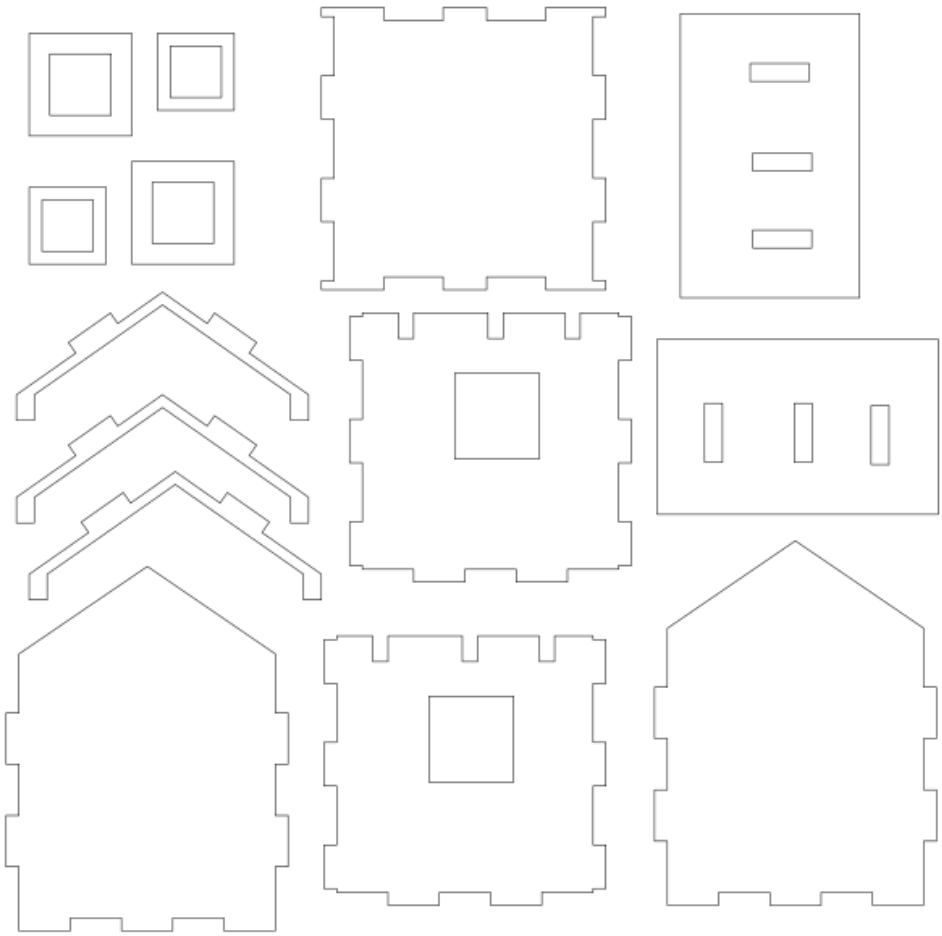

Figure 8: Vector graphic model in Inkscape

6.3 Laser cutting

Laser cutting technology became an important part of our workshop activities as we worked on making our prototype real. The output from the Inkscape software was used in laser cutting to make exact copies of the pattern on real materials. Our prototype's parts; walls, windows, roofs, floors and beams were produced quickly and accurately by laser cutting, converting digital concepts into real workshop products. It ensured accuracy in the creation of actual components, which was important in fulfilling our ideas

6.4 Information on the card

Plenty of research and information gathering are required to develop the information for the Material and Component cards. We research details on various building materials, emphasizing costs, environmental effects, and sustainable aspects. Three kinds of cards are used by us: Material cards show the various materials used for each component of our prototype. Opportunity cards give players different ways to construct a more environmentally friendly home. The aim of hindrance cards is to provide players with a complete understanding of the challenges encountered in sustainable construction. The goal of this comprehensive method is to produce informative cards that provide an extensive summary of the different building materials and components. Our objective is to create a helpful instrument which, by deep research and data gathering, offers smart choices for sustainable building techniques.

6.5 Figma

We used Figma to make the concept for our board game. We worked together to make and improve the plan, look, and parts of the game, like the board and cards, using Figma which is a flexible design tool. This platform was easy for everyone on the team to use, so we could work together without any problems. we could make changes in real time, and the final design was both visually appealing and in line with our goals. Figma was one important component of making the board game interactive and educational.

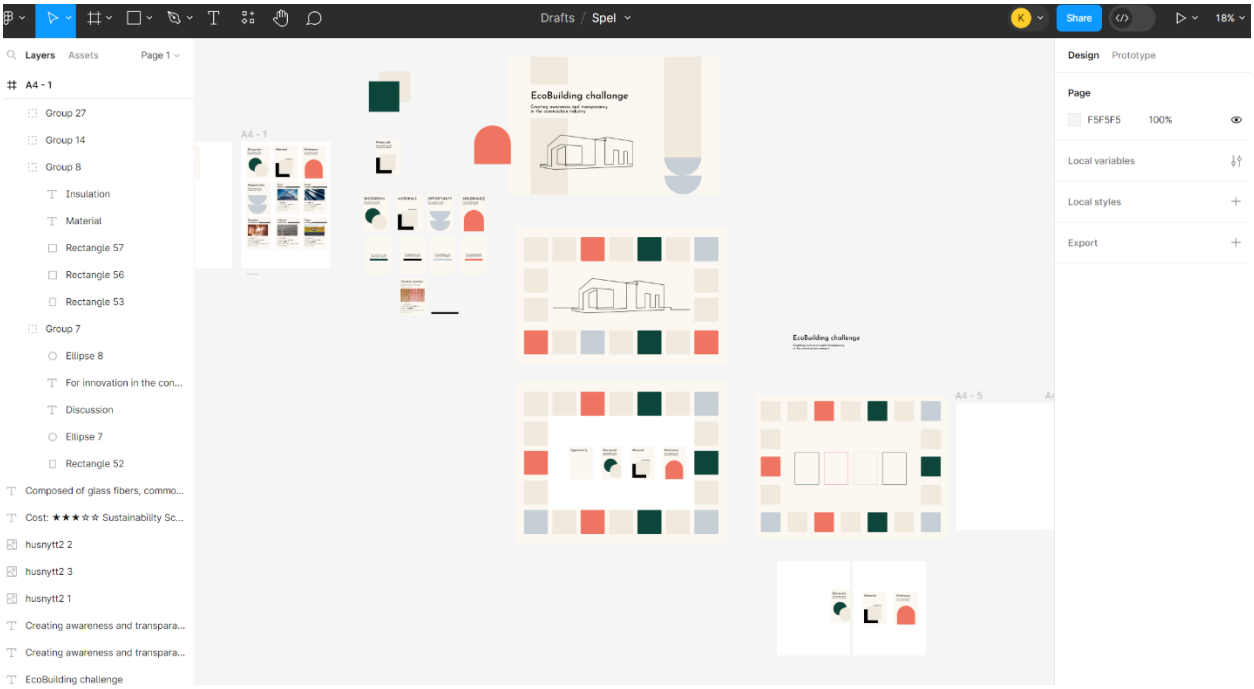

Figure 9: Printscreen from Figma.

7. Final concept

The final concept “EcoBuilding challenge” is a board game produced to be utilized in workshop settings. The game aims to create awareness and transparency in the construction industry by addressing hindrances, opportunities and raising discussions. The goal is for the players to build a house that has the lowest environmental impact, while facing common challenges and get perspectives that affect these choices.

The development process landed in the game mentioned above. The game is focused around four players that take turns throwing the dice. The dice both shows the number of squares the player moves as well as indicates the number of one component the player should pick. The following numbers are corresponding to the six different components for the house:

1. Walls
2. Windows
3. Floors
4. Beams
5. Roof
6. Insulation

The component the player gets is randomized, however the materials can be chosen if they are still available to collect. Leading the players to carefully consider their choices.

As the players move around the board are their possibilities to end up on squares in colors red, green and white. The white is considered square where the players get to collect a component for the house. The red indicates a hinderance card and the green an opportunity card. Furthermore, are there also discussion cards that aim to ask questions and get the players to start talking about different questions related to the area of house construction.

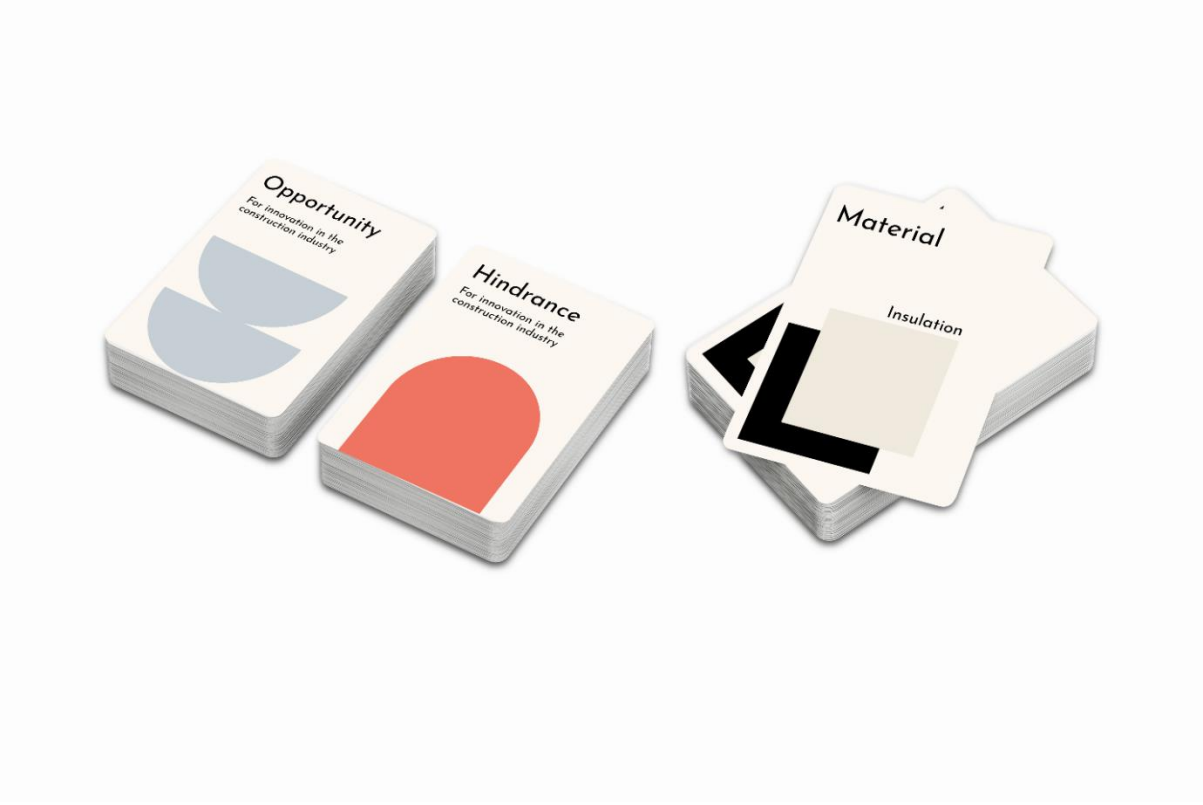

Figure 10: Different cards included in the EcoBuilding challenge.

Figure 11:Material cards

Figure 12: Game board.

Figure 13: The 3D house.

7.1 Further developments

Further development involves a more comprehensive approach in various areas after this study. Exploring different actors' attitudes, considering psychological and social factors that may cause resistance to sustainable approaches in construction. Regulatory Framework Analysis requires an expanded exploration, delving deeper into construction industry regulations. It's imperative to suggest potential regulatory enhancements fostering innovation while maintaining safety and quality standards. Sustainability Initiatives warrant exploration into ongoing industry projects promoting sustainability. Analyzing successful sustainable projects and discerning key success factors serve to inform future endeavors. Moreover, enhancing the Comparison with Other Industries necessitates a broader exploration encompassing diverse innovative sectors beyond automotive, extrapolating insights to revolutionize innovation adoption within the construction domain. Detailed Game Design necessitates a thorough explanation of card game mechanics, elucidating player interactions, the scoring system, and the direct correlation between choices made and the overall sustainability of the constructed houses. Creating visually engaging cards with clear and concise information.

8. Final debate

Then papers describe the lack of understanding the purchaser has over the situation when building a house and the lack of long-term thinking. The laws are lacking and understanding from the different actors' perspectives is a rarity along with an industry that is very set in its ways. To gain the understanding of the process from different angles and starting discussion do the project hope to raise awareness of the problems today as well as suitable alternatives for the construction of a house.

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LUNDS UNIVERSITET

Sustainable Building Sector

How to reduce waste generation in the Swedish building sector

INTN01 Project group 1: Michaela Alsterberg, Vilhelm Brattström Mathiesen, Victor Gunnarsson, Mabel Klein, Alva Olsson

Word count: 4182 incl. abstract.

Table of contents

1. Abstract

This is a project report for the Innovation Engineering course INTN01 at LTH. The course centers around innovation and the design thinking framework. In this report, we have been asked to provide a solution to how the construction industry can change to create a sustainable and circular building sector. Through employing the design thinking framework to our project work, needs were identified, solutions brainstormed, prototypes developed and evaluated. The scope of the project was narrowed down to identify why the sector is generating waste. The final prototype in this project was an app, *UseNoWaste*, that acted as a platform for construction companies and suppliers to buy and resell materials that were not used and would otherwise become waste.

This solution got positive feedback from our handler and from the course coaches. It can increase awareness of materials purchasing within the sector and is also needed now that material costs are increasing. From a more holistic perspective, it also reduces waste generated by the building sector and thus makes it more sustainable and circular.

2. Introduction to Innovation and Design thinking

What is an innovation? An innovation is an invention that is used in the market, and not only by the inventor. An invention is some novel idea transformed into reality, and innovation is the successful implementation of that invention. An innovation includes a broader perspective of understanding the customer's need or desire, understanding how you can work with partners to deliver a solution, and what the financial flow from the solution is over time (Keeley et al, 2013). In this course, we have explored and learned the process of innovation based on the design thinking framework.

The innovation process is hard to describe. Perhaps because it is cyclic, interactive, and nonlinear, and includes moving back and forth between design process stages to make sure that the solutions that are invented meet a real need (Warell, 2022). The design thinking process can be compared to the art of cooking an advanced-top-class meal. Just as chefs blend diverse flavors for unique dishes and draw inspiration from various culinary sources to create a unique dish, innovators gather insights from a multitude of different sources to craft innovative solutions. The design is also dependent on the approach and mindset of the innovators rather than any specific process step. Innovation benefits from a growth mindset, rather than a fixed mindset.

Design thinking in this report will be illustrated by the two models, *Design thinking 101* and *Double diamond*. *Figure 1* illustrates the process of design thinking while *Figure 2*, the double diamond, gives the reader a better visual understanding of how the process steps in design thinking are iterative.

Figure 1: Design Thinking 101 (NN Group, 2016)

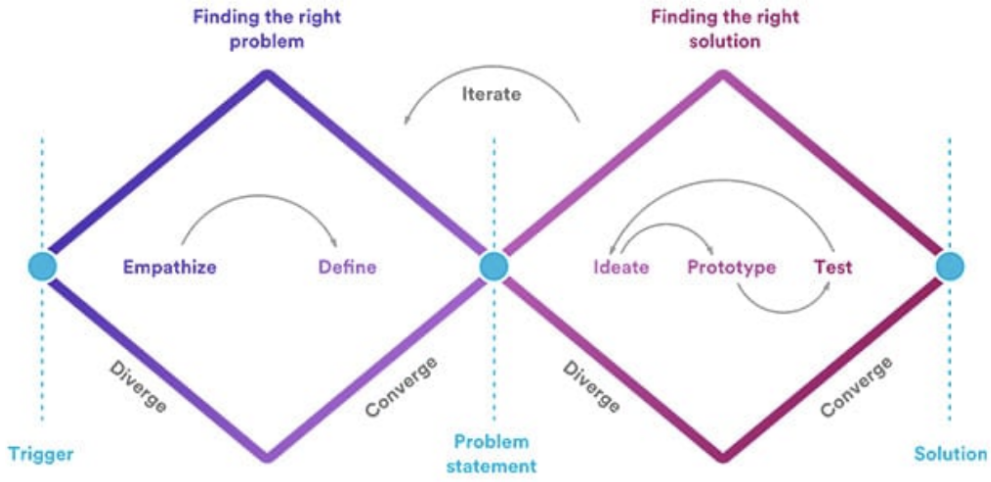

Figure 2: Design thinking as a five step "Double diamond" process (witekio.com)

2.1 The project

This project aims to find a solution to how the building sector can become more sustainable. The process towards a solution is underpinned by the objectives to find a solution that is feasible, viable, desirable and in line with United Nations Sustainable Development Goals.

Our given issue was formulated as follows; *How can the constructions industry change to create a sustainable and circular building sector?*

The innovation process was, as described before, guided by the three spaces of innovation used in design thinking; *Understand, Explore, Materialize*. This report describes how different exercises helped the team pinpoint a specific problem and propose a solution. Interviews with Ulla Jansson, who lectures within the LTH Profile Area Circular Building Sector, were used as guidance through the process.

3. Understand

The *Understand* phase of the project centers around understanding context, users, needs, behavior, trends, technologies etc. This phase is divided into *Empathize* and *Define*. *Empathize* focuses on needfinding and precedes the *Define* step. However, the steps might go back and forth since the information found in the *Empathize* step must be analyzed to form a *Challenge in one sentence* in the *Define* phase. For example, the *Empathize* and *Define* steps were performed multiple times in our team since there was a need to conduct further research into the users needs after having defined a specific issue. The journey is nowhere near linear and can start over again during any stage of the innovation process. For example, we had to reiterate after getting feedback on our first prototype.

3.1 Empathize

The global building sector is a critical component of our modern society and employs a lot of people globally. Unfortunately, it also plays a substantial role in the consumption of energy and the emission of greenhouse gasses. According to the UN environment programme status report 2022 the building and construction sector accounted for 34 percent of energy use globally (UN environment programme, 2022).

It is urgent to address the environmental impact of the building sector. Therefore, a starting point in the innovative process was to understand the given issue. In the given project definition it was stated that efforts to reduce the environmental impact of construction are ongoing and have been for quite some time, with the clear consensus that the industry must move towards lower energy consumption, reduced climate impact, and minimal waste. However, it is stated that the existing solutions are not used to any significant degree. To understand why this is, you need to analyze the environment and the trends that exist.

To do this, the group conducted a DEFT analysis, see *figure 3,* and based on that analysis, climate change, CSR, and population growth were seen as the main *drivers* towards a sustainable sector. Furthermore, the *enablers* that were identified as the most important were the building companies. The building companies were by the group identified as the group with the most influence in this industry, if they are not willing to adapt change is difficult. However, all *enablers* listed below were seen as important. It was the group's perception that the building sector is traditional and slow moving, therefore profit and behavior were identified as the main *friction* factors. This means that the attitude towards new technology and solutions may be negative. Furthermore, cost and finance profit could be identified as *blockers*, often, more

sustainable solutions come with higher cost - this at least is the perception. Therefore, one fear is that companies are not willing to invest in these solutions.

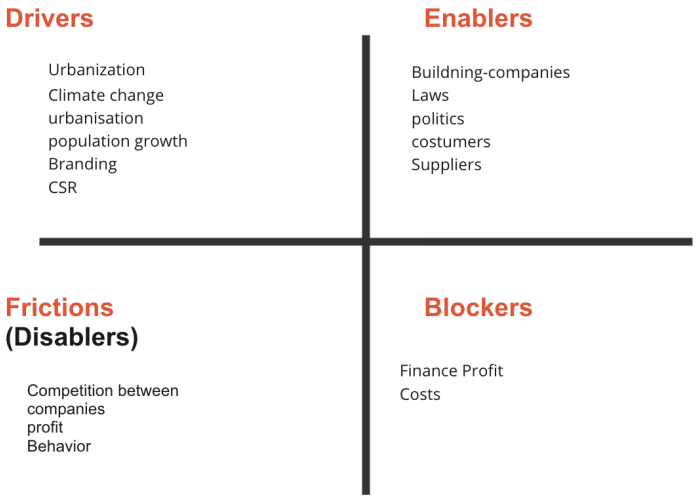

Figure 3: DEFT analysis of the building sector

A stakeholder map was constructed with the aim to identify and understand the different stakeholders in the building industry. Since buildings involve a lot of stakeholders such as architects, engineers, suppliers, and end customers it is important to be aware of their importance, their power and what their expectations are. In *figure 4* below, stakeholders and their needs have been visualized, to see Appendix B for a definition of the different stakeholders.

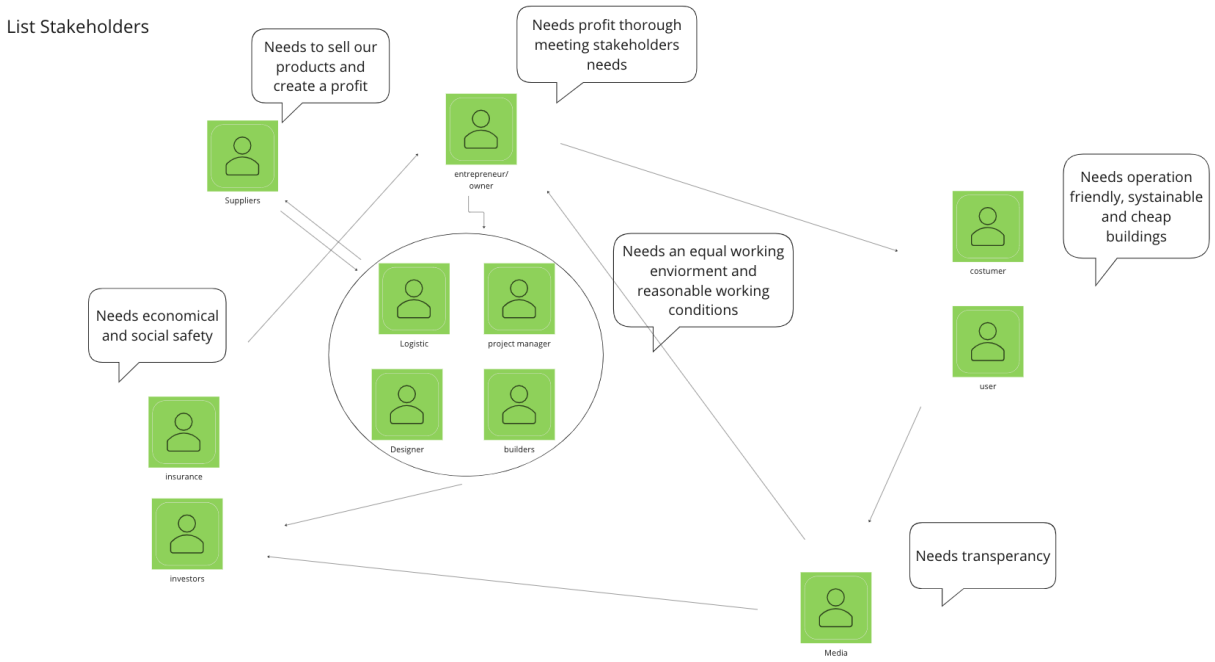

Figure 4: stakeholder map

3.1.1 Further Analysis of Needs

Following the principles of design thinking, a crucial component of the inspiration phase involves the observation of people's or businesses' needs. This phase can be visualized with a POEMs (People, Objects, Environments, and Messages) map along with an Empathy map. These analyses were conducted after our first coaching session, and we had therefore narrowed down the scope to concern the needs associated with waste reduction.

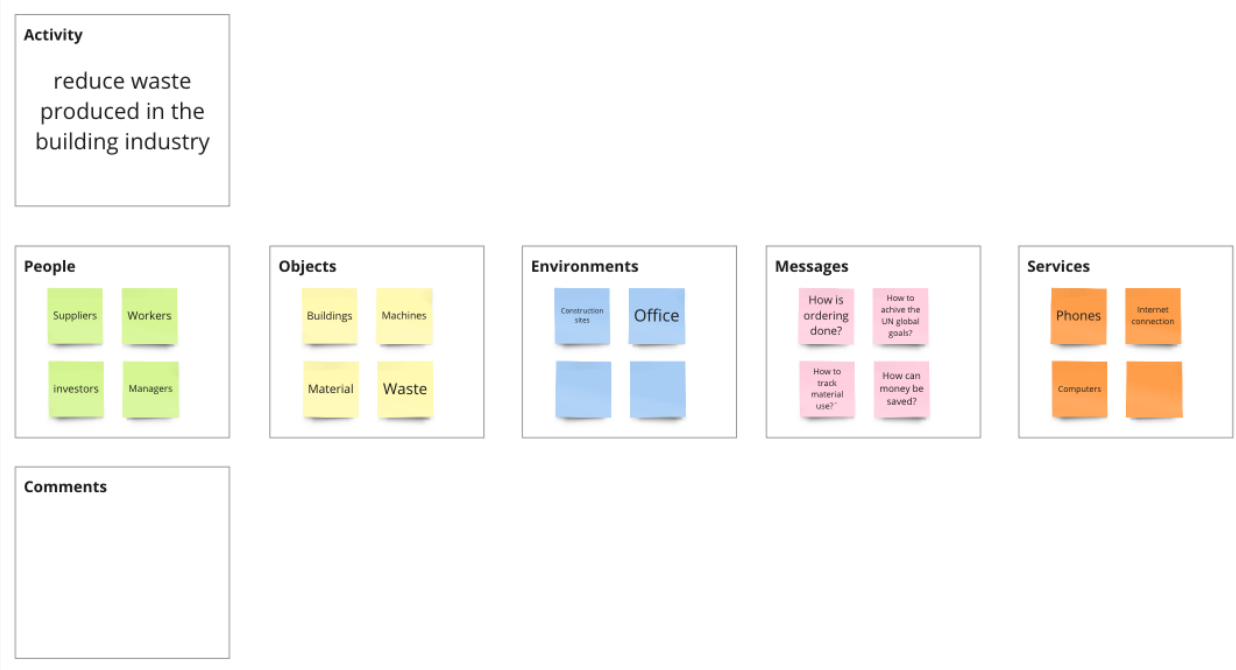

Figure 5: POEMS map

In the POEMS map, *figure 5,* we encountered several key challenges. We had limited knowledge about the construction business. Nevertheless, we had access to our contact person Ulla Jansson whom we used as an expert resource throughout this entire project. Moreover, we got valuable insights from our project coach and online resources. From these various sources, we were able to gather valuable information and perspectives.

We used the POEM map to segment and categorize different needs. We segmented the people involved into four distinct groups: *construction workers*, *project managers*, *suppliers*, and *investors*. This division allowed us to understand the diverse roles and perspectives within a construction site. The myriad of objects and tools employed within these construction environments was categorized into four separate categories. Following that, we looked into where these groups operated to better understand the environment our innovation was supposed to be used in. We differentiated between office settings, where planning, coordination, and administrative work took place, and the construction sites themselves, where the actual construction work takes place.

This comprehensive mapping exercise gave us valuable insights and a foundation upon which to continue working on using an Empathy map.

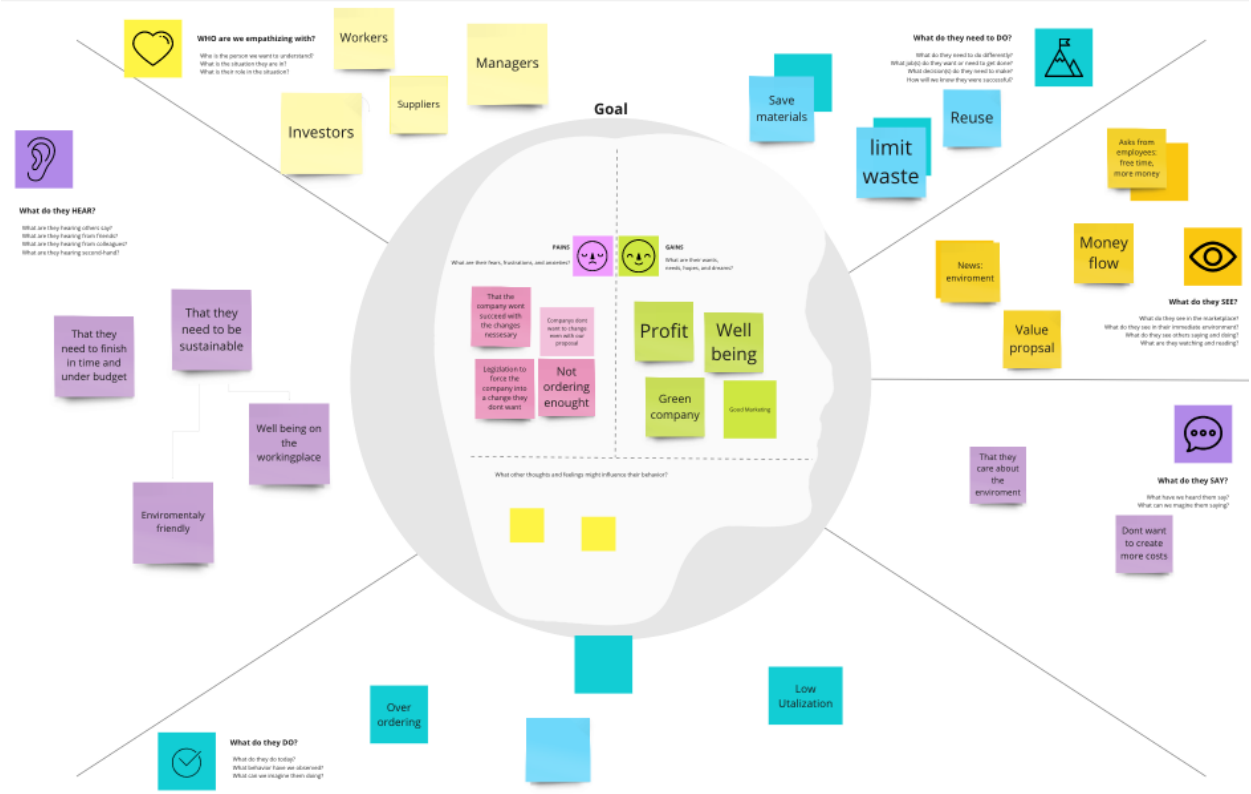

Figure 6. Empathy map

The Empathy Map, *figure 6,* became the canvas on which we continued the portrait of the construction sites' different personas and their experiences regarding our subject. To gain a thorough understanding, we then focused on ‘What do they hear?’ by trying to imagine ourselves as a fly on the wall in observing their conversations, instructions, and the challenges that are their daily experiences. We explored 'What do they do?' to understand the actions they undertook within their roles and 'What do they need to do?' to summarize the objectives and tasks they aimed to accomplish. Understanding their 'goal' was important too, to get an overview of why we do this. To comprehend 'What do they see?' meant seeing the physical environments, tools, and surroundings central to their work. Lastly, we delved into 'What do they say?' to capture the words and expressions that might surface in diverse situations.

As we collaboratively filled every section of the Empathy Map, our discussions became increasingly insightful and rewarding. It was all about understanding and allowing us to see the world through the eyes of those we aimed to help. This empathetic perspective became one of the cornerstones of our project, showing the path towards solutions that were aligned with the needs, emotions, and aspirations of the individuals within the construction industry. In retrospect, our empathetic approach fueled our project's success and drove the creation of solutions that truly resonated with the construction sector.

3.1.2 Research related to identified needs

According to the World green building council there is a great demand for new buildings and they predict that within the next 40 years, 230 billion square meters of buildings will be needed.

At the same time more than half of the waste produced around the world originates from the material used in the building sector and a lot of waste ends up in landfill sites. Additionally, 32 percent of the waste that ends up in landfills descents from construction sites. A lot of materials are ordered for construction. However, without ever being utilized, 13 percent are sent to landfills (Brady et al, 2021)

The excessive waste from construction sites is also affecting water, air and land negatively and the waste can be linked to the use of natural resources. If a life cycle approach were applied to the usage of material this could result in methods for waste reduction, reuse and recycling (Ismaeel & Kassim, 2022).

By adapting a circular economy perspective to the building sector, investments will generate value over the longer run since they will be seen as reusable. Furthermore, 25 percent of the material cost can be reduced by reusing materials such as asphalt and concrete. (Brady et al, 2021)

3.2 Define

Based on the research process during the *Empathize* phase, a number of problems were identified. However, after discussing our initial research and group ideas during the first coaching session, we chose to concentrate our efforts on addressing the issue of excessive waste from building companies' tendency to over-purchase materials. This narrowed down the scope of the project.

This scope definition resulted in our mission statement, *figure 7*. We want to create a solution that connects the construction companies with each other and the suppliers of materials. They lack awareness of their procurement process and this leads to increased cost. As we have seen, there is also increased pressure to become more circular and sustainable within the sector. Thus, the building sector needs help with improving the procurement process. More specifically, they need help incorporating circular flows, and identifying alternative ways of conducting the procurement process.

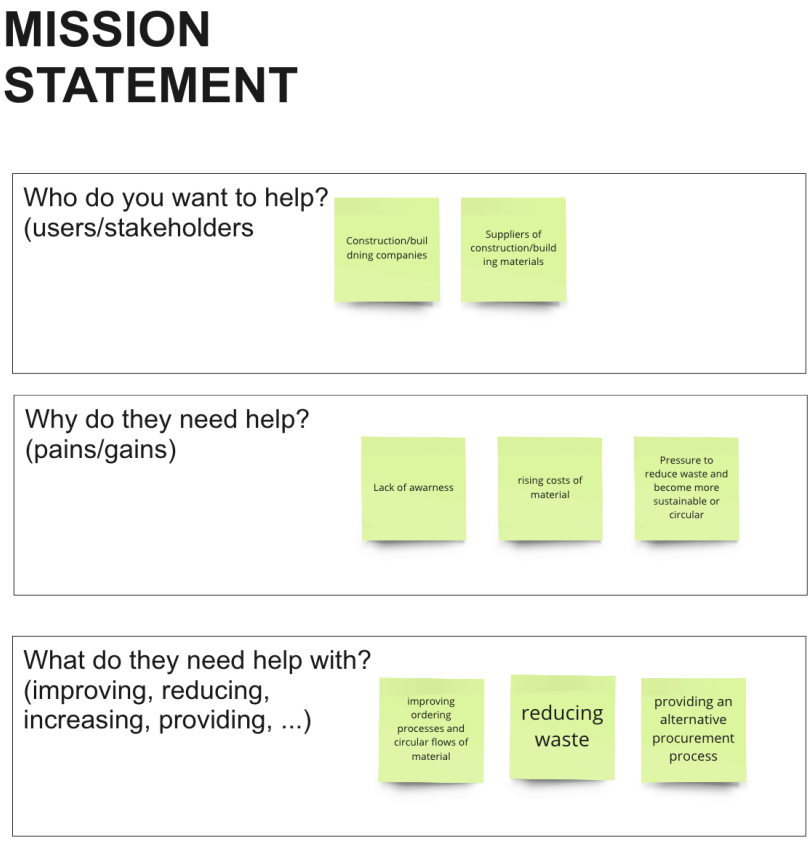

Figure 7: The mission statement linked to reducing waste generation within the building sector

3.2.1 Challenge in one sentence

The research and problem finding, combined with the analysis of needs within the building sector, has led us to formulate our challenge in one sentence as follows:

Find a sustainable solution that stops waste generation early in the construction process.

4. Explore

The *Explore* phase of the Design Thinking framework consists of *Ideate* and *Prototype*. The *Ideation* process serves as the creative engine for a successful innovation journey. In this phase, insights and inspiration from our research was translated into ideas that further could be developed, prototyped and tested.

Generating a variety of different ideas is all about divergent thinking among team members. All individuals must be encouraged to think beyond conventional boundaries and possibilities and to generate as many different ideas as possible (openideo, n.d). Different perspectives spark more ideas and unlock additional potential for innovation.

Once we had a substantial collection of ideas we shifted to evaluating and selecting the most promising ideas. This was based on criterias such as feasibility and alignment with project goals.

These ideas were then developed into prototypes. Our team's *Ideation* and *Prototype* processes will be explained below.

4.1 Ideation

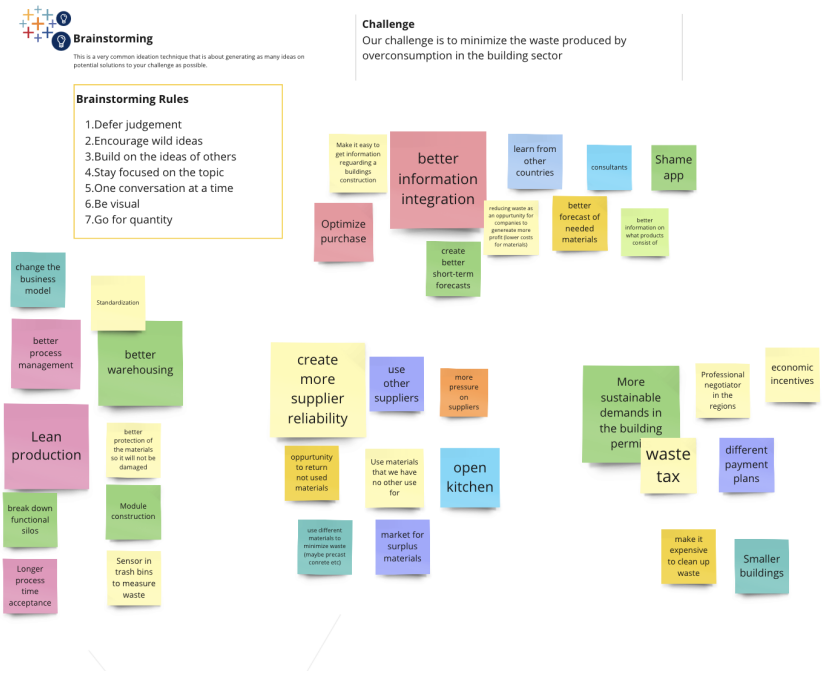

Figure 8: Brainstorming map with ideas that we particularly liked being written on larger post-its

During one of the workshops a brainstorming map was created to follow up on all ideas, *see figure 8.* The ideas were grouped into different themes. Everyone was then allowed to make their favorite idea bigger as a non-symmetrical voting system instead of direct voting. It became clear that the most liked ideas were ideas connected to:

- Better information integration
- Lean production
- More supplier reliability

4.1.1 Define solution

After the brainstorming workshop, the team had various ideas of solutions. Based on these ideas our first solution was defined; A channel where construction companies tell suppliers what raw materials they are using through the process. However, our definition was re-evaluated and re-defined as; *An app where construction companies can report material utilization and material surplus, and other building companies and suppliers can buy the excess material*. This creates a platform for actors within the building sector to re-sell unused materials instead of them going to waste. This will generate extra income for the selling party and cheaper material for the buying party, simultaneously they will help reduce the environmental impact.

4.2 Prototyping

Prototyping can be used in various stages of the design process. In this particular project, we employed prototyping to further develop the innovation concept and clarify how our innovation works. Initiating the prototyping phase we choose to use low-tech methods, like drawing on paper. Low-tech prototyping promotes the attitude that the tools and techniques used are less important than the design question itself (Buchenau et al, 2000).

4.2.1 First Prototype

To make our first prototype, we created flowcharts for the user interface for the app. Initially, we wanted to dive straight into designing the user interfaces. However, after we got some advice about our approach we decided to start with the essential elements rather than the design and made some sketches on paper, see *figure 10*. This use of tools in a structured manner allowed us to prioritize the structural aspects of the prototype and facilitated easier modifications before delving into the visual aesthetics.

At this point we had discussed two different ideas and therefore we made two prototypes that had different concepts. However we did prefer the solution stated in paragraph 4.1.1 and the first prototype was based on that solution. The second one differed since it was an app where companies could optimize their material utilization. The customer journey for the first prototype can be seen in *figure 9*. With this prototype we aim to reduce the waste in the building sector by creating a platform where suppliers and building companies can buy and resell materials.

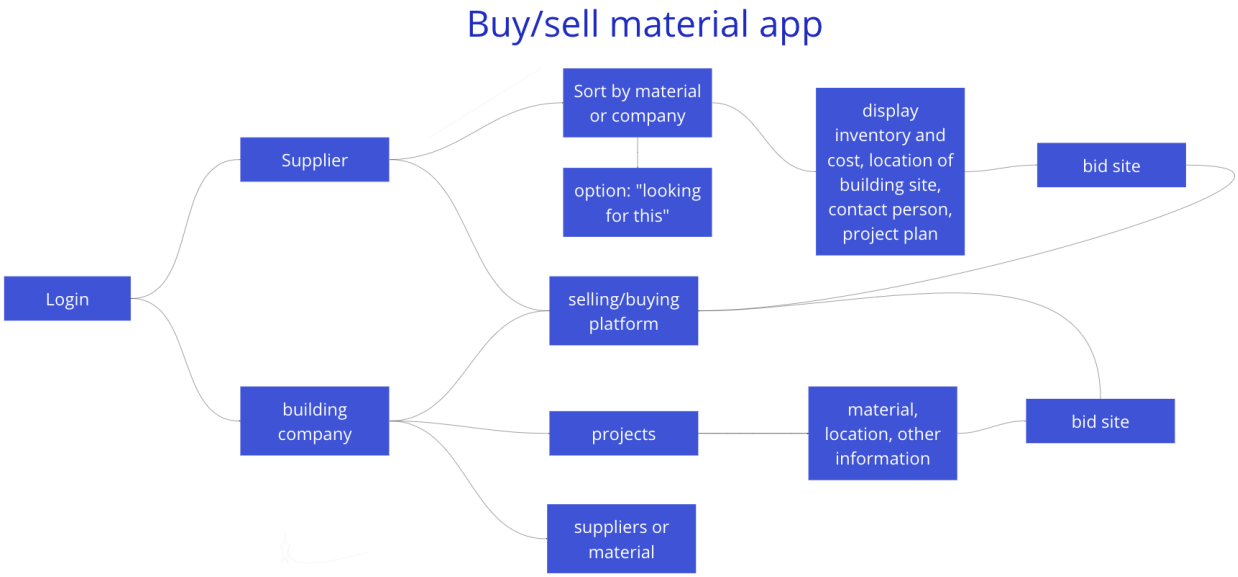

Figure 9. Flowchart of Prototype one

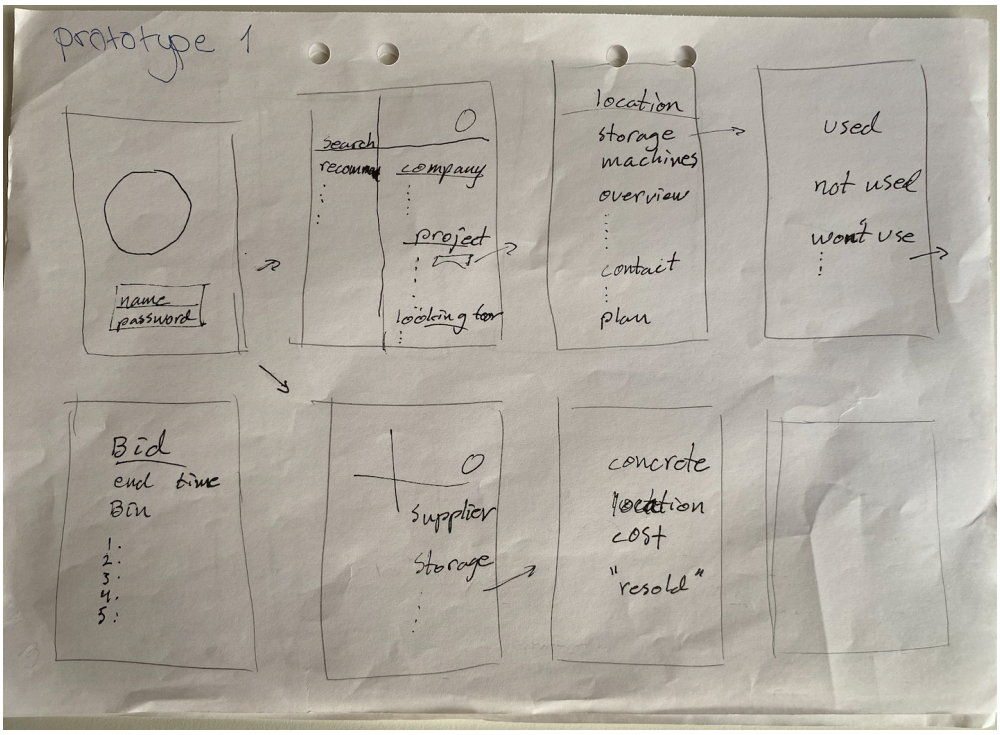

Figure 10. Prototype one -sketch

The second prototype, *figure 11*, is an app that reduces waste by helping the building companies optimize the material use for each construction project. The idea behind this prototype was that we would create an app where building companies could design their next project. This app would then help the construction company plan and optimize the use of materials. By having a data collection from former projects, the app would be able to optimize the next project.

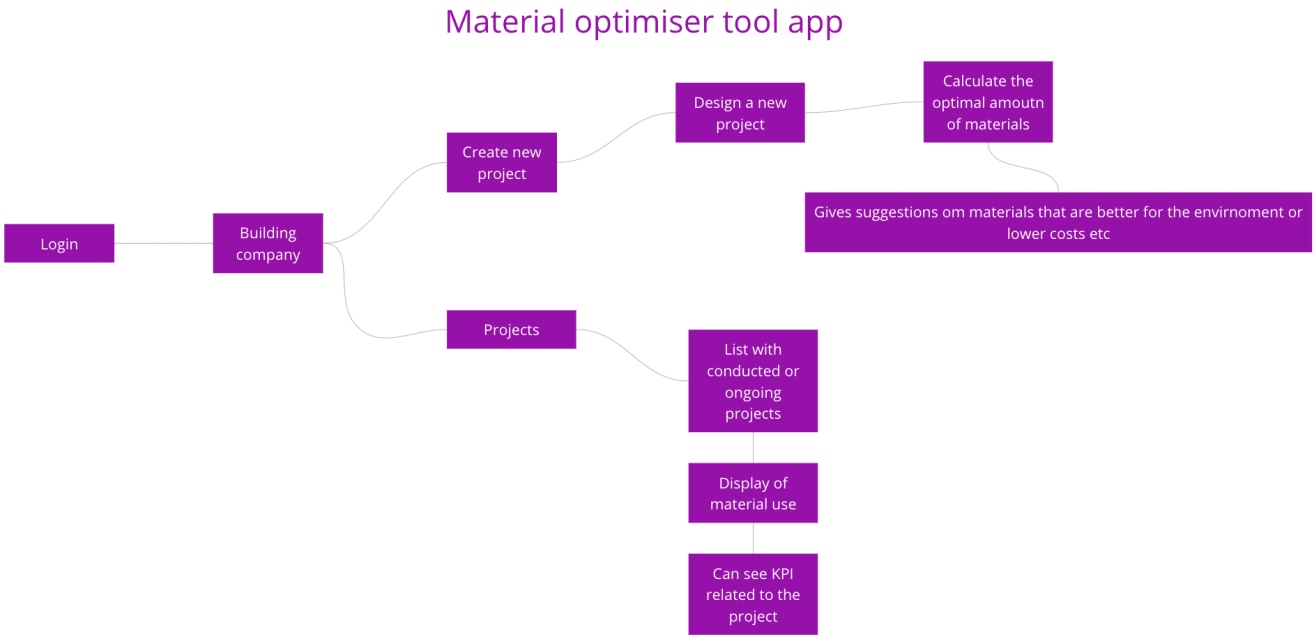

Figure 11. Flowchart of prototype two, an app that would optimize the material utilization

4.2.2 Coaching session 2

Before the second coaching session we had a meeting with Ulla Jansson. Jansson expressed great enthusiasm for prototype one, *figure 9*, as she believes it is the right time to introduce such an innovation to the market. This is mainly because of the increase in material costs, making it appealing for companies to find a solution that reduces their expenses. For this, among other reasons, Jansson advised us to focus on prototype one.

During the second coaching session we presented the two prototypes, however we mainly focused on the first prototype. The coaches gave us great feedback and seemed to appreciate the idea. However, they had concerns regarding the transportation between the different parties. They also had some concerns about insurance. Who will take responsibility for damaged material? Who is responsible for the quality of the materials when they are sold a second time? Lastly, our coach said that we should do a more detailed customer journey of the prototype for both the suppliers and building companies journey.

4.2.3 Final prototype

The final prototype is an app that acts as a platform where suppliers and building companies can buy and sell materials that are not used from construction sites. The app is called *UseNoWaste* and the app design can be seen in *figure 12* below. In this prototype, actors in the building industry get an account after being verified by *UseNoWaste* as a legitimate company. They can then search for materials that they need or want to sell. If the material is available they can view quantity, quality, shipping information and get contact information to the seller. The material can then be purchased in the app.

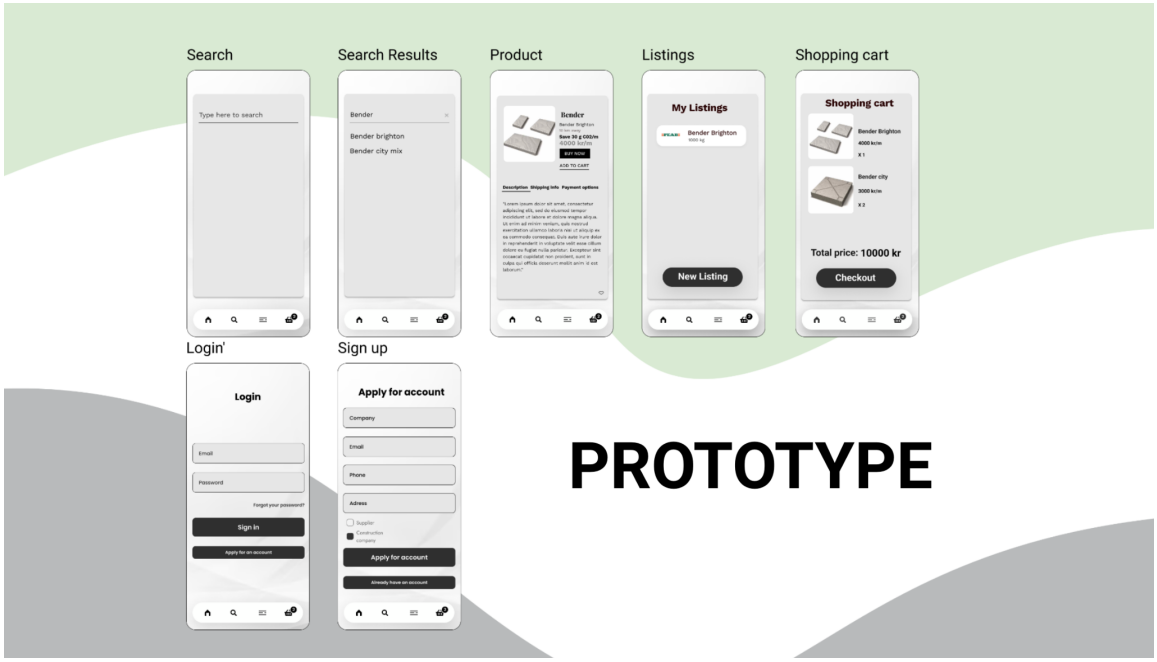

Figure 12: Final prototype

4.2.2.1 Insurance and Transportation

The quality of the material is essential for the buyers if they are to place a bid. In our prototype, the seller will be responsible for transparency regarding the quality of the materials. *UseNoWaste* would be responsible for investigating contradictory information and complaints. Since the material would go to waste if not sold, the building company's budget for waste management could instead be used for quality assurance. In this case it would still need to be researched whether they make a profit on the sale.

The shipping terms are decided by the seller and clearly stated in the shipment information in the app. Since Ulla Jansson argues that many construction sites are located close to each other, we expect that the transportation distances will be short. The supplier ships material to construction sites throughout a project, in some cases the same trucks that deliver new materials could pick up resellable surplus material that the suppliers have bought.

5. Materialization

The final phase of the innovation process is to materialize the solutions and need fulfillment from the *Understand* and *Explore* phase of design thinking, see *figure 1*. This is done through *Evaluation* and *Implementation*.

5.1 Evaluation

There are limited resources to evaluate our idea within the course of the project, due to time constraints and conflicting schedules. The evaluation will therefore be based on the information gathered during the previous steps in the innovation process and visualized in our business model canvas and value hypothesis.

At the moment, our understanding is that the building sector is not explicitly looking for a method to resell materials. However, there is an increasing interest in becoming more sustainable and reducing material costs. Our solution serves as a means to minimize construction waste, and creates a more circular procurement process. When considering the broader perspective, achieving climate goals is needed for society. While the app alone cannot complete this task, it can definitely make a meaningful contribution. For the reasons stated above, this innovation can be considered desirable.

It is of great importance that it is attractive for companies in the building sector to make use of this app in order for the concept to work. The app, *UseNoWaste*, will bring both environmental as well as economic benefits for building companies and suppliers. By reselling the unused materials, companies are able to recover part of the material costs. Suppliers will also be able to make more profit by buying back surplus material and then reselling it to a different customer company.

Using the app can also be useful for construction companies to show stakeholders that they are making an effort in becoming more sustainable. This can strengthen the company brand and image. Our business model canvas is demonstrated in *figure 13* and illustrates the importance of building partnerships with customers, in this case suppliers and building companies, to gain competitive advantage. Our key proposition to them is that we make them more aware of what

materials they are purchasing and in what quantities. *UseNotWaste* saves money by preventing these materials from going to waste.

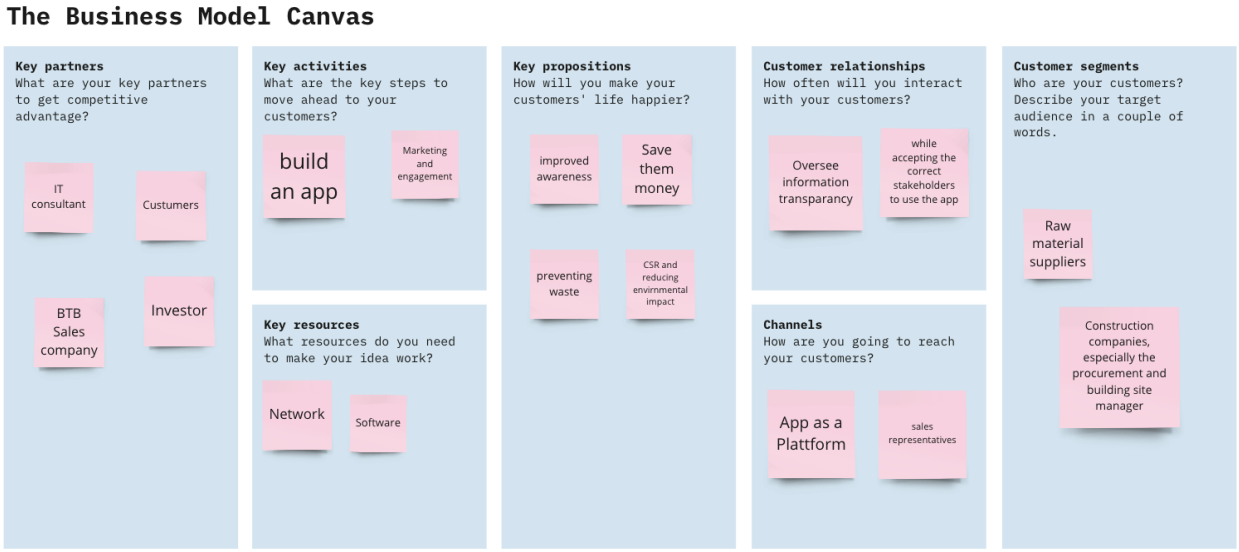

Figure 13: Business model canvas for the final prototype

The main competitors to our innovation are the current procurement processes. As can be seen in our value hypothesis, *figure 14,* our solution offers some core benefits over the current system. The main benefit and offerings are improved material sourcing that can be more cost efficient than the current system and more environmentally friendly.

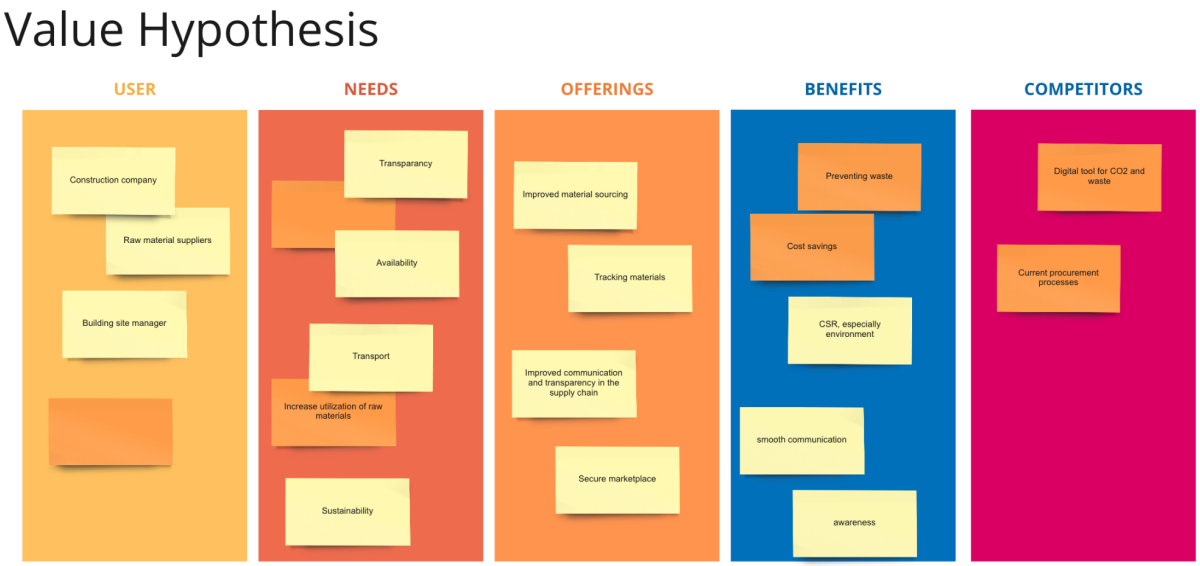

Figure 14: value hypothesis of the proposed solution

5.2 Implementation

The app can be implemented in a few different ways. The first and most promising approach is to introduce the app to a major supplier. This way, the supplier can repurchase and resell the surplus materials from all the companies they serve. This approach has the advantage that building companies do not have to disclose their private information regarding material costs and the discounts they get. Moreover, the supplier is already familiar with the regulations governing the seals and modes of transportation.

The second implementation method involves introducing the app to one, or more, major building companies. This could be beneficial as they could view this innovation as a competitive advantage and incorporate it into their business model canvas. Lastly, the app could be introduced to a network of smaller interconnected companies, like LMF30 (Jansson, 2023). The strength of such a group lies in its commitment to sustainability and the practice of complete transparency.

We deem the payment to us as a company should be a markup fee on every transaction on the app. This is since it will be easier for companies to start using the system when it is free to sign up which is vital for an innovation to commercialize. Furthermore it will seem cheaper to the company using the app since the payment to us will be from a net positive cash flow. However, this is something that needs to be further evaluated in a new innovation iteration.

5.2.1 Next steps and future perspective

The next steps of the innovation process is to get feedback from the intended users, as well as continuing to develop the prototype. This is important to make sure that the innovation is based on users needs and to also identify potential improvements in the prototype. A discussion with intended end users could also provide valuable information on how to conduct quality testing, how to tailor the app interface to the customers needs, and how to transport material between buyers and sellers.

A next step is also to gain a better understanding of pricing and costs for the development of the app. Right now, the pricing is still unclear and therefore a future investigation is to develop a pricing strategy. We see a possibility to cooperate with our customers, which would also help build the customer relationship.

6. Conclusion

The design thinking framework has helped us to develop a solution and later on a prototype that solves the almost impossible problem of making the building industry more sustainable. Through team discussions, external input and research, the team has iterated over the different design thinking phases to invent an innovation. Having a multidisciplinary team can come with benefits and challenges, during our coursework we experienced benefits mainly in the ideation phase. Most of the issues arose regarding ambition level.

Our innovation *UseNotWaste* is viable, feasible and desirable. This innovation supports the United Nations Sustainable Development Goals to help companies in the building industry become more sustainable. This innovation is in line with goal number 12; *Ensure sustainable*

consumption and production pattern. This project is just the beginning of an innovation, to make the innovation profitable in the market it still needs a lot of development.

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Appendix

Appendix A: Interview protocol from interview with Ulla Jansson 2023-09-25

- **What are the key causes of over ordering in the sector?**

When you do an estimation, you always overestimate to not stop the work in process. Sometimes the material is not available (Suez canal). Also discounts, buy 8 boxes - get 2 for free.

- **Explain that we are looking for solutions that minimize the waste produced by the building sector. Introduce our idea. Do you see any issues with our prototype?**

Likes the idea since it makes it easier to scan the market, and makes it easier to buy it "second-hand". It's a great idea for tracking material. She thinks it's even more useful if you approach it from the supplier's perspective. If materials are scarce, you can make a profit from selling materials.

Great for awareness. Many buildings in Sweden are quite similar because of legislation and cost. For our tool it is important to learn more about seals. No legislation on reused materials right now. *Byggproduktförordningen, boverket.se - is a website she recommends.*

Does not think we need to look into the hindrances. She does not think that the solution will be misused since storage price is expensive and also difficulties in public buying. If we want it close to reality - we should tie it to companies. What you are buying and at which price, is how you can compete with other companies. Look into Skanska, they would be ready to do this within different building sites.

LFM30 - organization focused on sustainability

She also mentioned another startup that used containers. Research.

- **Are there other tools out there that track material and waste?**

Digital tools for CO2 and for waste, but only from the trucks going out of the building site. This tracks material, but it is already waste so it cannot be reused. Our tool is close to the building site so it's preventing waste, meaning that it is sold before it becomes waste. Also good here in Sweden since the building sites are close - not long transportations.

- **Are building companies reluctant to share information? What systems exist and could we integrate our solution with any of them?**

Yes they do not want to share costs. Cannot share costs because of competition.

Rabattsatser: how well you know the producer / how big of a company you are gives you discounts. Up to 70% discount.

- **How would we get the companies to use our solution?**

Material prices are increasing so much - now is the time to implement a solution like this. This is the key reason for success with our invention. Scarcity of materials and sustainability are also factors, but prices are the driving factor.

Gives initiative to develop in the company, they can see how they can decrease cost. Can be a tool for gaining knowledge on purchasing and WIP.

- **Do you know anything about taxation?**

No, only that moms is the same for virgin and reused materials.

Appendix B: Stakeholders

A description of the different stakeholders identified in the stakeholder map.

Suppliers: The suppliers have an interest in their business and profit and for them it is important to sell their products. They want to sell their products to the company that offers the highest payment or to the company that they have the best collaboration with.

Customers: Customers could be both real estate owners and end customers such as private persons. It is important to know our customers because they are putting pressure on the building companies.

Media: Media is always interested in different businesses and it is important to be transparent against the media since they have the power to influence a lot of people.

Projectmanagers: the needs of the project manager along with builders, designers and logistics is important to prioritize. The workers will need equal opportunities, a safe working environment and fair working conditions. If we can not fulfill the needs of our workers the business will fail.

Shareholders: The shareholder is interested in profit.