GLASS CONTAINERS AS PRE-FABRICATED DOUBLE-SKIN FAÇADE ELEMENTS: REDUCING WASTE, SAVING ENERGY AND IMPROVING INDOOR CLIMATE IN BRICK BUILDINGS

by

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Architecture is a physical representation of social evolution.

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Abstract

Buildings are responsible for 40% of Greenhouse Gas (GHG) emissions and the current building stock will need retrofitting to help ensure that the Danish national climate goals are reached. There are many ways to save energy on heating and cooling and all recommendations should be followed to help make a building as sustainable as possible depending on its context, style, situation and more. Creating a `super-structure´ in recycled – upcycled – glass, in strategic places, around the exterior façade, increases the cavity temperatures, making for a more comfortable indoor climate by ensuring the thermal balance of the exterior structure – and protecting it from wind and rain – thus saving energy (and the structure) and reducing the chance of black toxic mold (BTM) on the inside of the exterior wall. Retrofitting buildings and increasing livability through an improvement of the indoor climate are inherently interconnected and interdependent – especially since humans currently use most of time indoors. Glass recycling systems in Europe and Denmark are connected: there is a flow of full bottles imported into Denmark and glass shards and whole bottles exported out of Denmark, and a smaller amount stay in Denmark and can be found as waste in nature. In this system, the transport factor of moving millions of tons of glass, makes this recycling system less than ideal. Instead, used empty bottles could be incorporated into a new upcycled glass double-skin façade (DSF) system, creating new spaces for building occupants while reducing the transport factor by a reduction of export – yet, this reduction of export of glass, back to production, also increasing the need for virgin materials, since less recycled glass returns, potentially causing more harm to environment through extraction activities to replace the lack of cullet – such a drawback is minor and when transport does not pollute, then perhaps all glass needs to be recycled into new glass. But, until then, making use of the glass bottles creates an opportunity for the a building owner(s) to do some low-tech glass walls which creates a `buffer´ zone between the outdoor and the indoor spaces; such an enclosed space stabilizes the temperature of the exterior skin making it less prone to moisture from rain or condensation from temperature differentiation, but also has social consequences in relation to the urban fabric and the image of the structure, its new layer, chapter and identity with its surrounding environment, such a factor perhaps cannot be measured. Because glass will be a valuable resource in the future also, it is crucial that the ventilated glass-bottle DSF system can be easily reintroduced into the system, ensuring its circularity in the 21st century resource-dependent circular national, regional (and global) economy by designing for dissambly (DfD), meaning that the parts of the building components can be taken apart, and each part traced back to its source, to clarity what materials are embodied. The barriers to creating an upcycled DSF system of used container glass are many and range from technical issues, EU laws for buildings materials as well as SAVE category restriction, which restrict visual façade altercations due to the historical heritage of a given building.

Keywords: A2020 Architecture, BIPV, BTM, CE, Earthship Biotecture, DfD, DSF, glass bottle wall, green transition, LCA, LCC, resource flows, SAVE categories, SBS, ZEB

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Abbreviations

BIM	Building information management (or modeling)
BIPV	Building-integrated photovoltaics
BTM	Black Toxic Mold
CE	Circular economy
CFD	Computational fluid dynamics
CPD	Byggevaredirektivet
CPR	Byggevareforordningen
DfD	Design for disassembly
DIY	Do-it-yourself
DIW	Do-it-with
DoP	Declaration of performance
DSF	Double-skin façade
ETA	European technical assessment
GHG	Greenhouse gases
IRT	Infrared thermography
LCA	Lifecycle analysis
LCC	Lifecycle cost
PM	Particulate matter
PV	Photovoltaic
RIBA	Royal institute of British architects
SDG	Sustainable development goals
SHGC	Solar heat gain coefficient
US	United States
ZEB	Zero-energy building

List of Formulas

$SHGC = Q_{room} / Q_{incident}$	Solar Heat Gain Cooefficient
$U = W/m^2K$	U-Value
$\lambda = W/mK$	Linear Thermal Transmittance / Thermal conductivity
Yearly savings * lifetime /investment > 1,33	Rentability formula

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Introduction

Saving energy, the Planet, and improving indoor climate may be possible if wearing your own trash can becomes a trend to define a sustainable epoch – much like Rob Greenfield wore his household trash on his person for 30 days, back in 2016, to help contextualize and realize the waste stream that modern society automatically produces as part of a consumeristic society which needs a sustainable transition. Such a transition in the building industry is part of a larger whole and it is clear that since most energy is used in existing built mass, retrofitting existing structures to higher energy standards, is key if Denmark is to reach climate goals such as goals set forth in 2020, 2030 and 2050.

Utilizing trash from consumer behavior is kind of old news for the green pioneers of the 20th century and is embodied by Earthship Biotecture, created by architect Michael Reynolds, who has been using different types of trash and recycled materials to erect off-grid buildings since the 1970s, in multiple ways; one of the ways trash is upcycled into a building component in Earthships, is the creation of bottle-walls with concrete as in-fill, which is the inspiration for the modified glass bottle-wall system that this thesis prototypes and analysis. It is argued that creating a DSF system with recycled glass will create a two-part sustainable solution, since it protects the exterior side of the architectural skin from the elements while ensuring the thermal balance while creating a ventilated cavity which creates an opportunity for pre-heated fresh air.

Yet, such new systems which naturally heats ventilated air are not yet part of energy frame analysis BE18 do not consider the solar heat gain coefficient (SHGC) from such a system. But despite lack of input possibilities, creation of DSF systems appear many places regardless. It is the hope of this thesis that consumers can become producers of their own DSF system to thereby lower their living cost and increase their standard of living through improved indoor climate.

The layout of the paper is as follows:

INTRODUCTION→PROBLEM DEFINITION→RESEARCH QUESTION→PROTOTYPING→ANALYSIS→CONCLUSION

Newspaper articles, 1st hand accounts (personal interviews and lectures) and videos are cited but are not included in *References*.

This thesis contains information gathered from prior years such as public lectures, and an essay from previous semester. This thesis is accompanied by tables and figures, which represent relevant information about the prefabricated glass-bottle walls to support the argument that prototyping can create a culturally-relevant and thermally informed design-solution, to accommodate the demand for energy retro-fitting existing building typology.

Chapter 1: Framing the project

"*Integration of passive strategies into a building is fundamental in the design of sustainable buildings.*"[1]

Architectural design and its practices have been slowly changing from a strictly aesthetic focus to a more resource-dependent design program focus, where the current reality, or situation, and Earth´s finite resources are the starting point of a design idea, though the visual properties (aesthetics) of a structure still communicate its purpose and identity to its surrounding environment. From global issues to local issues, a new type of designers can shift this focus, which is needed to mitigate climate change. This chapter creates the background for the research questions as it presents a brief history of architectural theory into the modern epoch from the ´Sustainability Paradigms´, from Steward Brand Brand´s 6 S´ of Architecture, Michael Reynolds Earthship Biotecture, Bioclimatic by Frank Lloyd Wright to the most recent one: regenerative (resilience, recovery paradigms) architecture which arose in the mid 1990s[2] – with elements and overlaps of biomimicry to create positive impact design that regenerates and ultimate becomes nature, see Figure 1.1.[3] Historically, a building´ façade is first impression to the observer; the ´power´ of the façade and its visual link to a buildings´ identity (and its inhabitants) and well-being, is the authors focus and research aim. Specifically, by reusing existing glass and assembling in unique prefabricated ways into a DSF system, presents multiple dilemmas which reach beyond the superficial ´look´ of a façade; the benefits and tradeoffs of not reusing glass containers back into the system are unknown, but using them as an additional ´Skin´, thus saving heating and cooling costs, improving the indoor climate and extending the lifetime of the exterior brick structure, since "*The wind driven rain on the constructions (solid brickwork) has a major negative influence on moisture related pathologies as mold growth, frost damage, indoor relative humidity and heat losses.*"[4]

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[1] Alemu, Alemu T, Wasim Saman, and Martin Belusko, "Airflow and Temperature Modelling of Sustainable Buildings at the Design Stage Can Prevent Unintended Consequences of Passive Features" (*Procedia Engineering*, 2017), 602.

[2] Shady Attia, Towards Regenerative and Positive Impact Architecture: A Comparison of Two Net Zero Energy Buildings, (*Sustainable Cities and Society, 2016*), 395.

[3] Zari, Maibritt Pedersen. 2018. "*Regenerative Urban Design and Ecosystem Biomimicry.*" Routledge, 4.

[4] Klaas Calle and N Van Den Bossche, Towards Understanding Rain Infiltration in Historic Brickwork Assessing the Feasibility of Using the Heat Temperature Function for a Long-Term District Heat Demand Forecast, (*Energy Procedia, 2017),* 677.

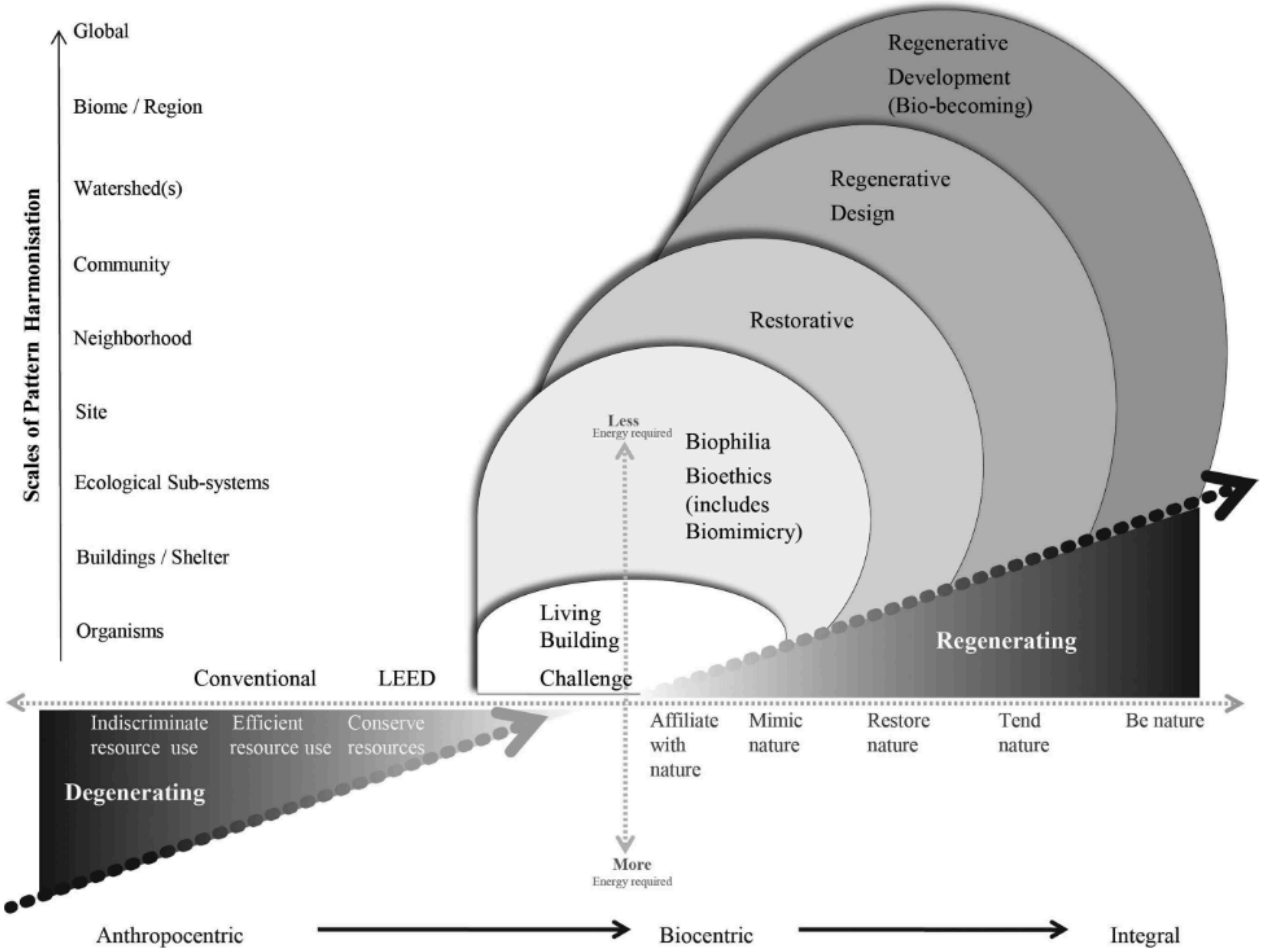

Figure 1.1: Trajectory of regenerative design, by Zari adapted from Regenesis 2000-2018.

And, especially in the edges of the wall[5]. DSF and its use and benefits in (retro-fit) architecture today are well-known, but such systems rely on manufactured float glass, which is a best practice high-tech solution. This thesis argues that a low-tech solution with collected bottles (glass containers), can help frame the potential in using this method and defining its typology as a retro-fit energy-saving design solution, can perhaps help facilitate the broader circular transition and boost low-tech bottom-up business opportunities, thus creating local opportunities (jobs) while creating a method where the client can save labor costs, since high costs of construction is also a factor that can hinder sustainable building design. Additionally, a DSF creates the opportunity to create pre-heated fresh air that is naturally ventilated in the air cavity between the existing exterior wall and the glass-bottle wall, which, if properly

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5 Abuku, Masaru, Hans Janssen, and Staf Roels, "Impact of Wind-Driven Rain on Historic Brick Wall Buildings in a Moderately Cold and Humid Climate: Numerical Analyses of Mould Growth Risk, Indoor Climate and Energy Consumption". (*Energy & Buildings*, 2009) 3.

managed, is a sustainable practice, but lack of knowledge about building physics and energy and material performance is a barrier[6] along with designer lack of skills in doing Life cycle Analysis (LCA) on façade elements since,

"*it is perceived as a hindrance to design creation, as too convoluted, and time-consuming…not practical.*"[7]

Instead of using LCA as a valid design tool, it has more often been used as a sustainability argument, as a post rationalization argument. Understandably, creating a sustainable transition is a learning curve and LCA (along with LCC) are still in their early phases and may take a whole generation of designers before becoming an inherent part of a designerly thinking approach – not surprisingly, albeit a steep learning curve for all designers, working with the difficulty of measuring sustainability, across different data sets, with different parameters that affect the analysis:

"*Inconsistent system boundaries explicitly and adopted in studies of buildings´ LCCa contributed to the discrepancies between the resultant buildings´ LCCa.*"[8]

Regardless of the use and confusion about parametric modeling of generic computer models, these new tools are part of the toolbox of the sustainable designer and also can act to argue and support the sustainable partí of solution. It can even be easier to design when certain things have been determined already from a technical standpoint. Architects (and designers) need to be 're-schooled'[9] so society can move towards a new sustainable aesthetic that is grounded in the reality of global finite resources and local conditions, instead of mere nostalgic sentimentalism that is stuck in the past, manifested in numerical SAVE categories – often made at random – and with a focus on visual aesthetics instead being valued from their actual sustainable values, from the quality of the indoor climate to the mitigation of climate change.

Ultimately, all works strive to achieve value and by analyzing the material streams that are involved with daily consumer activity, it is possible to gather a BIM-library of potential building elements and their life cycle costs. Thus, seeing an overview of glass containers potentially reveals where additional value can be created while creating additional value, without influencing the existing locked-in system.

System thinking is an inherent part of understanding resource flows and their inter-connectedness; how can co-creation and participatory design facilitate processes and/or change, modify and perhaps turn it all up-side down, in a long-term sustainable transition with a complex web of

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[6] Alemu, Alemu T, Wasim Saman, and Martin Belusko, "Airflow and Temperature Modelling of Sustainable Buildings at the Design Stage Can Prevent Unintended Consequences of Passive Features" (*Procedia Engineering*, 2017), 602.

[7] Naboni, Emanuele, The Use of Facade Mockups in LCA Based Architectural Design (*Procedia Engineering, 2017*), 760.

[8] Pan, Wei, Kaijian Li, and Yue Teng. 2018. "Rethinking System Boundaries of the Life Cycle Carbon Emissions of Buildings." *Renewable and Sustainable Energy Reviews* 90 (June 2017), 389.

[9] Jakob Brandtberg Knudsen., Syn på de 17 – Dialogmøde om FNs Verdensmål for bæredygtig udvikling lecture presented to Schmidt Hammer Lassen architects, June 2018.

materials, systems and actors. Figure 1.2[10] is such an overview with glass recycling processes displayed and different factors placed in boxes where in between box ´X_5´ and ´X_6´, there is an opportunity to reuse the used glass containers differently as DSF system instead of discarding into a glass container, for the glass to be transported further along the recycling system.

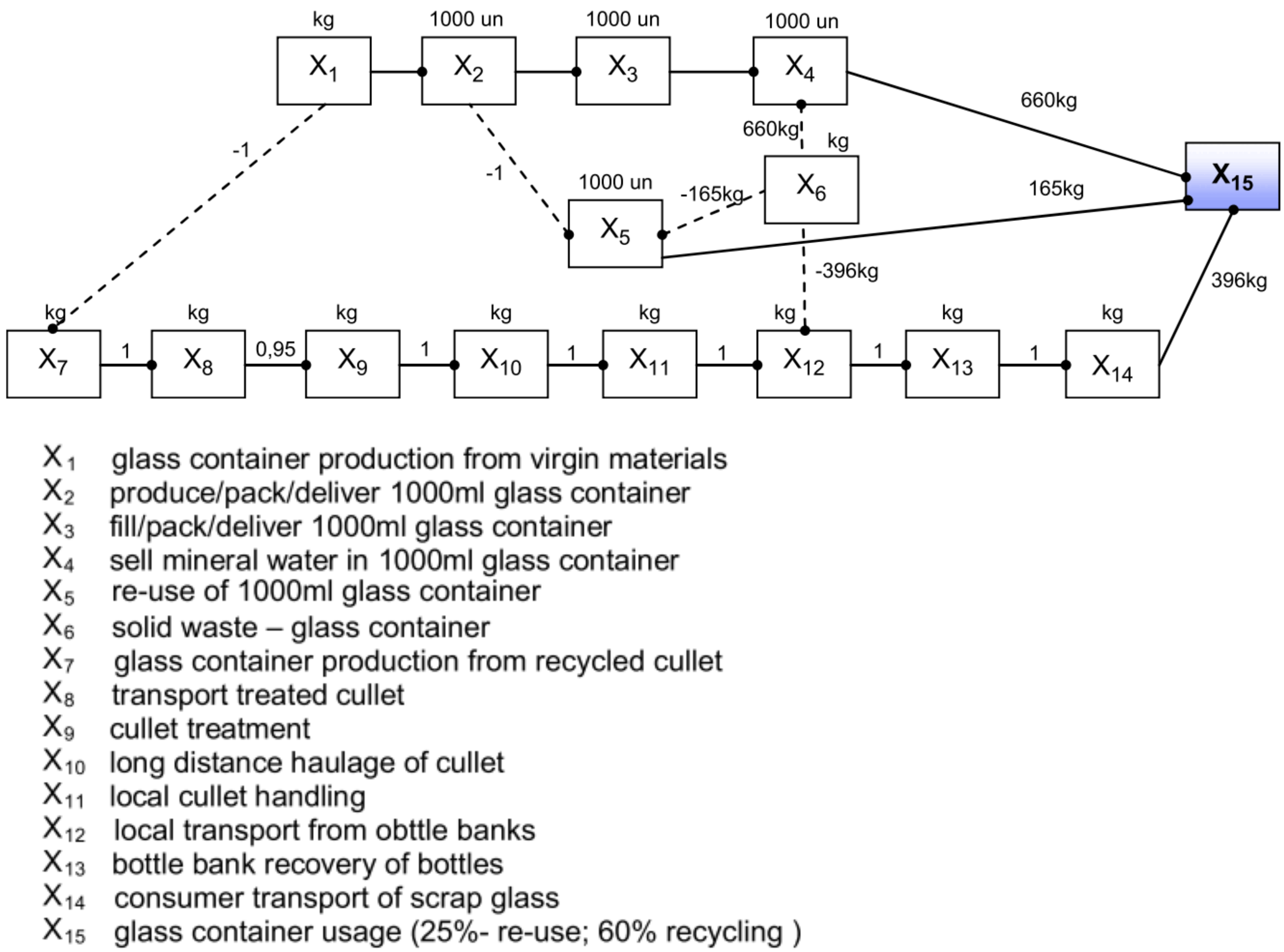

Figure 1.2: Glass containers consumption, reuse and recycling scheme, by Vellinini and Savioli.

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[10] Vellini, Michela, and Michela Savioli. 2009. "Energy and Environmental Analysis of Glass Container Production and Recycling." *Energy* 34 (12), 2141.

Additionally, Figure 1.3[11] shows two different waste out-puts with raw material as in-put and illustrates that the recycling system of glass is efficient, though there still is waste, meaning that there is a potential for more circular economic practices and future efforts.

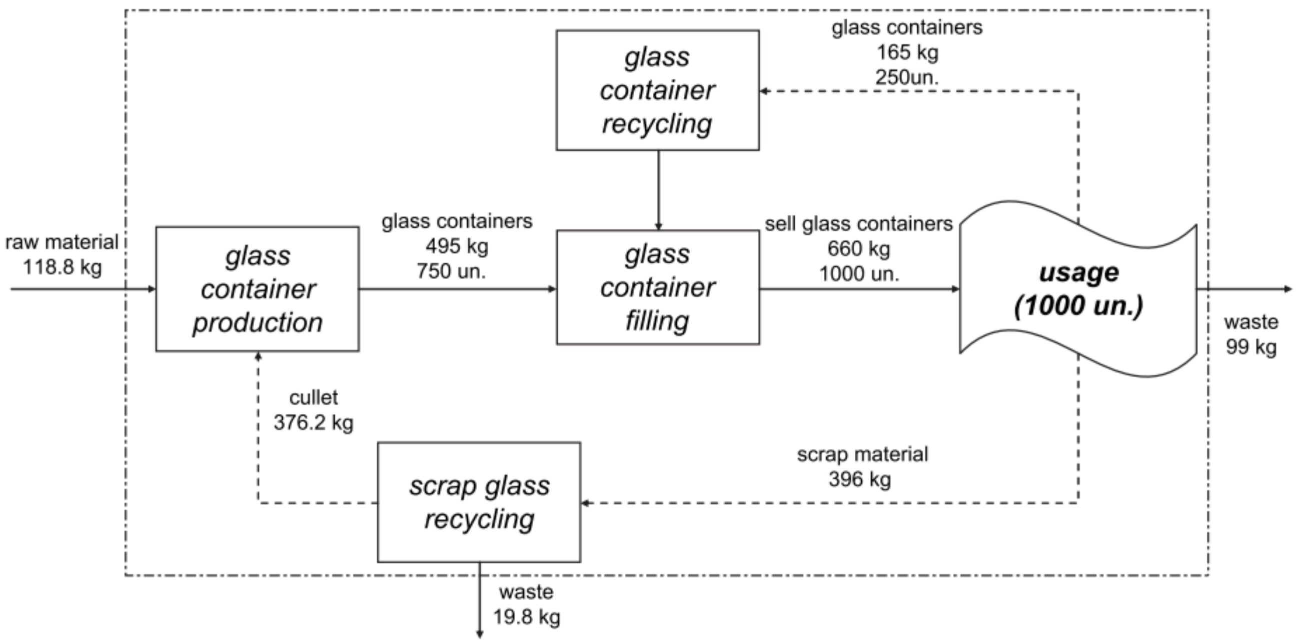

Figure 1.3: Material flux for glass containers consumption, reuse and recycling, by Vellinini and Savioli. Note how the scrap material is more than twice the amount of glass container recycling – meaning it is a fair share of glass bottle that is only used once in a use-cycle before being broken into shards (cullet) and put back into the system.

1.1 Background leading to scope of thesis: retro-fitting existing building stock into ZEB

Facing climate change and the potential of global economic woes and chaos, the focus on local efforts, such as improving the performance of the building stock become apparent. Many efforts run parallel to mitigate the many unknown changes of climate change, the quadruple squeeze which according to the IPCC, efforts need to be intensified with a new goal: to reach for 1,5 °C, instead of 2 °C, stating "we are very close to *tipping points*."[12] Though since according to Energistyrelsen, sectors such as transport and farming emit 10,5 mio. tons (31,7 %) and 13,3 mio. tons (40,2 %) tons CO_2, respectively – energy use in buildings is 7,1 mio. tons (21,5 %)[13] and 2/3 of Europe's residential building stock is more

[11] Vellini, Michela, and Michela Savioli. 2009. "Energy and Environmental Analysis of Glass Container Production and Recycling." *Energy* 34 (12), 2142.

[12] Ramskov, Jens. "Fire veje til halvanden grad." *Ingeniøren*, October 12th, 2018.

[13] Wittrup, Sanne. "Klimaplanen er en hård nød." *Ingeniøren*, October 5th, 2018.

than 40 years old.[14] Similar situation exists in the US where "*a large number of existing buildings have underperforming facades, and they are targets for considering improvements in their facades.*"[15]

Due to global patterns of urbanization, it is fair to assume similar conditions in building stock, in other parts of the World as well, making it relevant to understand how, when retro-fitting existing buildings into ZEB buildings, how can a DSF system be an integral part of the climate protection and indoor optimization since "*in 20 years 90% of buildings in Denmark will have already been built*."[16] And heating homes is a big contributor of greenhouse gases (GHG) and represents one of the largest potentials to mitigate climate change while saving energy and create better indoor climate since warm and dry homes are healthy homes although "tangible benefits of retrofitting the façade in existing buildings are not broadly known."[17]

1.1.1 Energy saving potentials in building stock, in general

The energy saving potential in renovating existing buildings tops the list of sustainable plans of actions for helping Denmark meet climate goals, see Figure 1.4.[18] The inter-connectedness of the architectural parts of a building ranges from site, to structure to overall systems and are too plentiful to cover in this thesis paper; yet they are relevant to weigh, since their combined efforts can facilitate the creation of a ZEB from multiple action improvements in an existing building; which also demands great care and competencies for the building owner.

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[14] Ecofys. 2018. "Healthy Homes Barometer 2018." Vol. 2018.

[15] Arias, Andrea Soledad Martinez. 2013. "Facade Retrofit: Enhancing Energy Performance in Existing Buildings." University of Southern California, 61.

[16] Jan Hyldgaard Christensen, Nøgletal for Bygninger, (Materialeplatform, 2016), 2.

[17] Arias, Andrea Soledad Martinez. 2013. "Facade Retrofit: Enhancing Energy Performance in Existing Buildings." University of Southern California, 139.

[18] Sørensen, Peter Birch, Jørgen Elmeskov, Pia Frederiksen, Jette Bredahl Jacobsen, Niels Buus Kristensen, Poul Erik Morthorst, and Katherine Richardson. 2017. "*Omstilling Frem Mod 2030. Byggeklodser Til et Samfund Med Lavere Drivhusgasudledninger*." Copenhagen: Klimarådet, 6 in appendix.

Omstillingselement	Potentiale	Samfundsøkonomisk omkostning	Letter omstillingen mod 2050
Energirenovering af bygninger	1,4 mio. ton CO_2e	Meget billigt	I høj grad
Individuelle varmepumper	3,3 mio. ton CO_2e	Meget billigt	I nogen grad
Energieffektivisering i produktionserhvervene	2,6 mio. ton CO_2e	Meget billigt	I nogen grad
Gas i tung transport	0,2 mio. ton CO_2e	Meget billigt	I nogen grad
Store varmepumper	0,9 mio. ton CO_2e	Billigt	I høj grad
Solvarme	0,8 mio. ton CO_2e	Billigt	I høj grad
Forsuring af gylle	1,0 mio. ton CO_2e	Billigt	I nogen grad
Elbiler	2,2 mio. ton CO_2e	Medium	I høj grad
*Energipil**	*0,6 mio. ton CO_2e*	*Meget billigt*	*I ringe grad*
*Træpillefyr**	*1,8 mio. ton CO_2e*	*Meget billigt*	*I ringe grad*
Overlap	-0,3 mio. ton CO_2e		
I alt	**14,3 mio. ton CO_2e**		
*Biogas i naturgasnettet**	*2,1 mio. ton CO_2e*	*Dyrt*	*I høj grad*
I alt	**16,4 mio. ton CO_2e**		

Figure 1.4: Selected switching elements (omstillingselementer), by Klimarådet.

Of all energy-saving potentials, this thesis attempts to synthesize multiple elements into one building solution: a pre-fabricated DSF wall with upgradable options such as BIPV and automated heat-recovery ventilation. Thus, improving the thermal balance in the exterior Skin and Structure (façade) which saves energy and can improve indoor climate: Additionally, this air-cavity of pre-heated air creates the opportunity to create natural ventilation which improves comfort inside – perhaps even with a filter, so NOx and CO does not come inside building to harm human health.

Recognizing the biggest energy-saving potentials and ranking them by largest savings is standard in the energy fanking of buildings in Denmark today, but may soon be changing due to its relative subjectivity, unclarities and grey areas and more. The deeper dimension is that often the experienced savings are less than the calculated savings, known as the performance gap, also perhaps to the changed behavior of the user(s).

A DSF system is a synthesis of insulating the Skin and Structure, from the outside, which is thermally superior, and improve the quality of the ´incoming´ air, so that the temperature and the purity of incoming air can be measured and controlled, per automatization perhaps.

According to Ecofys, published by VELUX: the housing type and ownership also plays a key role in determining the realization of a potential renovation project, "*single-family homes are the key to addressing health, since they are owned and the affects decision-making.*"[19] Thus, because of the independency and power (resilience) of the single-family homeowners, it is more realistic than cooperative buildings, where there are more users involved to interfere in a potential renovation project.

1.1.2 Indoor climate

We spend most of our time indoors; poor indoor climate can lead to sick building syndrome (SBS) which can cause allergies, in children and elders especially. Poor indoor climate, often caused by poorly insulated structures, is a silent crisis in our contemporary society since, according to VELUX: "*1 out of 6 Europeans reports living in an unhealthy building.*"[20] Measuring good vs. poor indoor climate is difficult to measure precisely; according to Lyng, indoor climate is one of the most complex matters in construction case,

"*the indoor climate is a combination of the outdoor climate, the building envelope, the technical solutions and the people who use the building. Therefore, it is not particularly easy to predict the indoor climate if, for example, one has to renovate or build new.*"[21]

A report by REBUS (Renovating Buildings Sustainably) defined four overall central parameters that affect our comfort and/or health in relation to indoor climate: Thermal, Atmospheric, Visual and Acoustic. And, have been developing a software tool (IV20) to access and classify the indoor climate, before and after renovations.[22]

1.1.3 Historical heritage (identity): SAVE categories and their value in the environment

Because of the SAVE category system that defines the socio-technical building landscape, the houses that need proper insulation the most, are the most difficult to achieve, due to aesthetic restrictions. Thus, a later architectural period is more realistic but is also, generally, better insulated. Because home-owners have more decision power than cooperative housing, most realistic is single-family homes from 1960s to present day since "more than 40% of single-family homes are built from ca. 1960 to 1970 measured in m^2."[23]

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[19] Ecofys. 2018. "Healthy Homes Barometer 2018." Vol. 2018, 7.

[20] Ibid, 9.

[21] GRØNT Byggeri. Et InnoBYG Magasin. 2018. "Bygningsejer - Kend Dit Indeklima." Taastrup: InnoBYG v/ Teknologisk Institut, 24.

[22] Larsen, Tine Steen, Geo Clausen, Gabriel Bekö, Anna Heebøll, Thomas Witterseh, Eva Hellgreen, Henrik N. Knudsen, and Lone H. Mortensen. 2017. "Centrale Parametre Til Karakterisering Af Bygningers Indeklima." 11.

[23] Ibid, 48.

1.1.4 Earthship Biotecture; recycling trash into building components

From Architecture to Biotecture – Earthship Biotecture, by architect Michael Reynolds, is the most sustainable structural system this author has encountered throughout decades of studying Architecture, and its related sustainability (and social) issues. The entire idea of, instead of just reusing building materials, they utilize available materials as building materials, is a neo-revolutionary idea, which should not just be labeled and thus defined as mere ´hippie stuff´ from the 1970s, since:

"*Building energy efficiency and urban waste management are two focal issues for improving environmental status and reducing greenhouse gas emissions*"[24] and there is meaning in re-thinking our systems to achieve a sustainable transition from our current regimes and landscapes, see **Chapter 2: Theory and method** architect Michael Reynolds has been building Earthship with bottles and other local materials and has created sustainable architecture for everyone (SAFE).

Besides using bottles as a climate-foil or super-structure, these bottles could also create a larger livable space which also would harvest the benefits of the DSF system, keeping exterior side of Skin dry and protected from wind cooling loads, increasing its thermal balance – thus improving indoor climate, and the benefit of creating an indoors space with is on the former outside of the house saves money:

"*When a greenhouse is attached...There are energy savings for all exterior wall types.*"[25]

Rob Greenfield project *Trash Me* created a buzz about waste in NYC when he wore his waste on his person for 30 days. Such public activism is topic background as much as Earthship Biotecture.

1.1.5 Informed Design: CFD and BIM

As epochs give way to epochs, technological advances reforms society through new problems and thus new solutions. Humans are inherently systematic, and everyone is a designer in their own right. Current practices can partly be traced back to the mid-century modern period where booming times changed the western World rapidly and design thinking processes were born,

"*Post WWII, new thoughts began to break through in the production-planning and naturally, the idea of using the new systematics on the design process itself. where this was Making the work of the architect more logical and controllable. The idea of design processes can be traced to England (RIBA) from the mid 1950s...it makes the (design) process conscious.*"[26]

By modeling a space (building component) in a program and manipulating properties, inputs and constraints etc., it is possible to plot, test and predict how a given space will thermally behave, and thus give insight into further design improvement, or further iterations. Such parametric design process is one contemporary design approach which continually inform the creator (designer), through multiple observations in the computer model.

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[24] Pennacchia, Elisa, Mariagrazia Tiberi, Elisa Carbonara, Davide Astiaso Garcia, and Fabrizio Cumo. 2016. "Reuse and Upcycling of Municipal Waste for ZEB Envelope Design in European Urban Areas." *Sustainability* 8, 610 (May 2016), 1.

[25] Freney, Martin, Veronica Soebarto, and Terence Williamson. 2013. "Earthship Monitoring and Thermal Simulation Earthship Monitoring and Thermal Simulation." *Architectural Science Review* 56:3 (February 2013), 216.

[26] Lund, Nils-Ole. 1970. *Teoridannelser i arkitekturen. Arkitekter og ideer fra 40´rne til i dag*. Arkitektens Forlag, 139-141.

1.1.6 Smart technology in ZEB. IoT and DK 5.0

Like Twitter has changed the global conversations, we cannot Imagine what the world of IoT and AI will reform society in a multitude of ways, once again. In the construction business, "IoT- sensors can be distributed through a structure and can be gathered in ´the cloud´"[27] and information can facilitate a clear picture of actual conditions and create automatization, so a house operates independent from its users and self-regulates throughout, perhaps ultimately, creating smart homes for stupid people and there are dilemmas with smart technology which are still unknown since we cannot imagine the problems of the future quite yet. Yet, smart technology has the potential to improve a buildings "encounter with natural phenomena" as Michael Reynolds defines it, through its constant collection of data and inter-connected systems which then giver the user a real-time picture of atmospheric conditions, building energy use and user comfort etc. which in turn could facilitate sustainable actions.

1.1.7 Measuring trade-offs – which parameter(s) should have priority? Particle matter pollution

Creating a DSF system out of glass containers creates a loss of input in the recycling chain which increases the need to extract virgin materials, which helps exacerbate climate change and potentially destroy local environments due to increased mining activity.

Indoor climate has multiple factors and dimensions and can be more difficult to measure than one's heating bills. The DSF system creates an air cavity which creates the opportunity to pre-heat incoming fresh air and filter it to ensure air quality is acceptable – since there is a correlation between fine PM pollution and mortality: "(*PM) particulate matter is considered to be one of the most important environmental stressors contributing to the global human disease burden.*"[28] (Fantke, Joillet, Evans et al., 2015, 277) citing Hänninen et al. 2014 and Lim et al. 2012.

1.1.8 New paradigm: exterior retro-fitted Skin is key to thermal- and indoor climate balance

Adding an additional layer to a structure, or a bunch of structures, is not new: in 1961, Buckminster Fuller suggested covering part of New York City under a dome structure, to shelter from weather and wind.[29] Many grand, awesome, utopian projects have (luckily!) not been built – making each building as efficient as possible and close to ZEB, or energy plus, is the utopian task of our time which demands new thinking and seeing society, its culture and historical building stock in a new light.

Besides creating thermal benefits to a given structure, a DSF system creates an air cavity which has the potential to create multiple benefits: (1) air is pre-heated in the cavity by the passive solar and slow-moving cavity air (along with heat-loss from Skin and or Structure), which increases the temperature of the ventilated air; and, (2) an enclosed DSF system also creates the opportunity to filter

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[27] Christensen, Bo. "Supergrønne ´smart buildings´ giver bedre indeklima." *Ingeniøren*, October 12th, 2018.

[28] Fantke, Peter, Olivier Jolliet, John S Evans, Joshua S Apte, Aaron J Cohen, Otto O Hänninen, Fintan Hurley, et al. 2015. "Health Effects of Fine Particulate Matter in Life Cycle Impact Assessment: findings from the Basel Guidance Workshop," 277.

[29] Lund, Nils-Ole. 1970. *Teoridannelser i arkitekturen. Arkitekter og ideer fra 40´rne til i dag*. Arkitektens Forlag, 182.

the incoming air that flows, through the chimney effect, from bottom to top inside the air cavity, making it possible to clean and purify your air before it comes inside the building. Much like there is a market for water filtration, one could imagine a market for clean air – since pollution can cause physical ailments in humans.

Besides created a warmer exterior Skin, a DSF that is super-imposed on existing structure keeps the exterior wall enclosed and thus protected from rain (and wind, which cools) which makes the exterior brick wet, and in certain instances, rain, wind and pressure causes moisture to travel into the cavity which increases the chances of water traveling through binders, into the interior and creating wet spots prone to fungi, mold and rot. Additionally, when wet, a brick's thermal conductivity increases, making it less insulating and therefore less sustainable. Thus, creating a DSF system keeps exterior Skin dry which ensures inhabitants a dry interior wall, in turn creating a better indoor climate since chances of BTM has been significantly decreased. A DSF system decreases rain-infiltration into the brickwork which "*wind-driven rain (WDR) loads can have a significant impact on mould growth especially at the edges of the wall... causes a significant increase of indoor relative humidity and energy consumptions for heating.*"[30]

1.1.9 Danish context: developing on Michael Reynolds low-cost concept

Can it be sustainable and reasonable to develop on Earthship bottle-wall concept? Perhaps not so much in Denmark, but potentially in certain places in India, where consumption patterns, production, thus leading to an increase in particulate pollution, especially in urban areas.

Global dilemmas such as bad air quality and lack of resources, require local solutions that must be configured appropriately and be circular in nature. According to Widder, citing UNHCR and *NY Times*:

"*Geopolitics, climate change and other extreme drivers of migration have accentuated the urgency of low-cost, location-appropriate, safe housing and settlements...if it is configured in a way that safeguards against the climatic and geostatic forces…recoverable at end of life.*"[31] Denmark is not experiencing huge amounts of migration but still have systems and buildings that mirror other parts of the modern World; and "*achieving sustainability targets would require high-performance envelopes to become the global construction standard and for refurbishment rates to double and to avoid the lock-in of inefficient buildings and their subsequent emissions*"[32] means that the general envelopes (Skin and Structure) of Danish building stock, need to transition into high-performing buildings to mitigate climate change.

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[30] Abuku, Masaru et al, "Impact of Wind-Driven Rain on Historic Brick Wall Buildings in a Moderately Cold and Humid Climate: Numerical Analyses of Mould Growth Risk, Indoor Climate and Energy Consumption". (*Energy & Buildings*, 2009) 9.

[31] Widder, Lynnette. 2017. "Earth eco-building: textile-reinforced earth block construction." *Energy Policy* 122: 762.

[32] Abergel, Thibaut, Brian Dean, and John Dulac. 2018. "2018 Global Status Report. Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector," 2018, 37.

1.2 Hypothesis (opportunities identified) Research aim and scope

1. DSF creates an air cavity (Buffer zone of air) which will reduce line-loss and create better indoor climate due to the more constant temperature of exterior wall.
2. DSF will reduce infiltration loss and create better indoor climate due to the air-tightening of the structure.
3. Rain infiltration in former façade (brickwork, Skin and Structure) is eliminated due to DSF system becoming a rain screen.
4. Extra living room (orangerie) could create a new space between inside and outside and increase home owner resilience. (but has potential to increase heat-loss due to use of space and poor insulation qualities of DSF wall as exterior Skin)

The *Writer's Pentagon* (see Fig. 1.5) is a tool to facilitate the production of academic work in the narrow aim and scope, while going broad, for mosaic understanding, and going narrow to make a specific conclusion, in a certain context. This figure is included to uncover the multiple dimensions of framing a project and its prototype potentials, which include interior walls of glass bottles and well as independent exterior Skins which are independent of existing exterior Skin, thus making a new usable, livable, space.

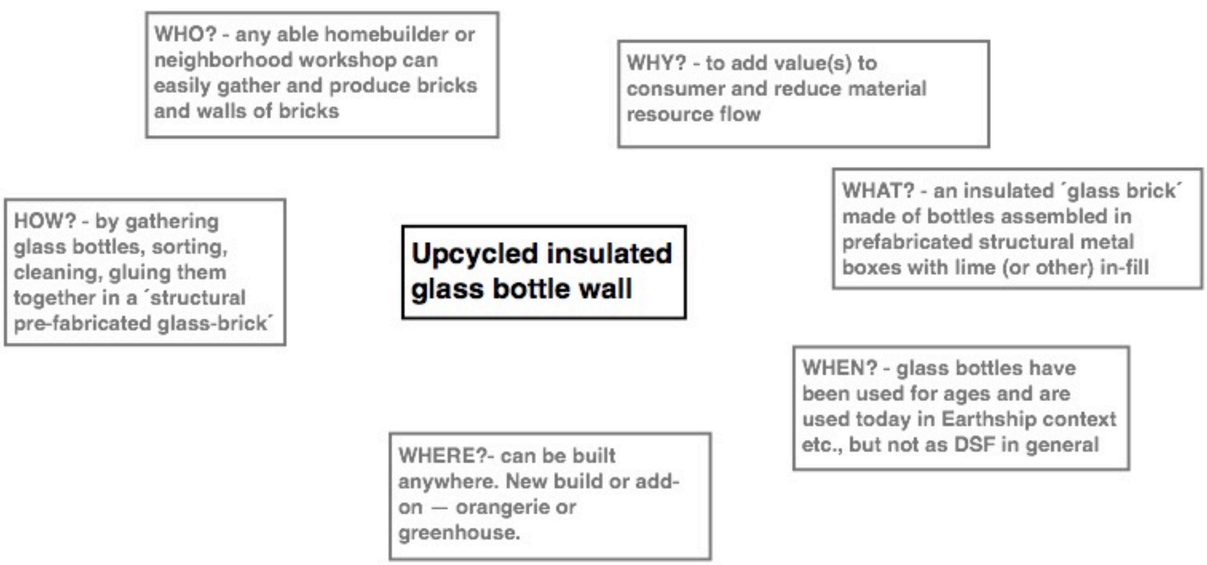

Figure 1.5: Writer's pentagon, by author

1.3 Barriers and challenges identified (tradeoff, cultural paradigms, regime lock-ins)

Recycling glass bottles locally instead of discarding whole and exporting shards, increases the need for virgin materials in production and, according to Mortensen et al., decreases the amount of energy needed in production, since adding recycled glass to the mix, reduces the melting point.[33] Therefore, it is a trade-off using used glass containers (bottles) in a DSF system instead of returning the used glass back into the well-functioning recycling system, though it does decrease the transport factor. Yet, the recycling system could be improved since, "*gentle collection of bottles and glass gives a higher degree of recycling of whole bottles*"[34] and the noise from glass breaking when deposited into the drop off container can be a constant sound pollution nuisance to others.

Additionally, the construction business is mostly conservative and is locked-in into existing standard solutions, see Fig. 1.6, which are considered 'aesthetically safe' and 'socially acceptable´, which is a typical example of the near invisible solution that silently changes the urban fabric, without any alarm: adding an exterior Skin of brick, insulated with mineral wool and bringing windows out into the new 'face' (façade) of the building, and is one of the solutions – others being: adding insulation into brick, and interior insulation. Adding a DSF as a regime-accepted option, creates a new sheathing layer of change: a 7th ´S´ (a super-structure) as a low-tech upcycled solution with minor system trade-offs compared to the local benefits of the producing consumer.

The ultimate barrier in the sustainable transition is perhaps, the many invisible social and economic barriers that prevent the public realm from being an exploratorium of unique creations, where seeds are allowed to sprout and perhaps even blossom; yet, local communal efforts to encourage business owners into creating a circular business strategy do prove that some barriers have been overcome through local communal action, facilitated by the federal government of Denmark – to meet national and global goals that require multifaceted efforts across sectors and nations. To reduce global building sector energy use, "*there are many mitigation options specifically applicable to buildings that include* (a) *High-performance building envelopes,* (b) *Energy-efficient appliances, efficient lighting, and Heating, Ventilation and Air-Conditioning (HVAC),* (c) *Evaporative cooling and solar-powered desiccant dehumidification, as locally appropriate,* (d) *Improved building automation and control systems that respond to changing conditions,* (e) *´Daylighting´- designing buildings for controlled admission of natural light, adjustable through the day using solar shading, and* (f) *Using smart meters and grids to modulate supply in real time.*"[35] Thus, creating a DSF apply to multiple of these mitigation options which creates the challenge of creating an ideal building envelope that moderates temperatures, provides good indoor

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33 Mortensen, Lone et. al., "SBi 2015:30 Genbrug Af Byggevarer - Forprojekt Om Identifikation Af Barrierer", Copenhagen, 2015, 19.

34 MUDP, and COWI. 2017. "Fordele Og Ulemper Ved at Medtage Glas Som Kildeopdelt Fraktion Til Automatisk Sortering. Opsamlende Notat." Copenhagen, 25.

35 Chalmers, Patrick. 2014. "The Physical Science of Climate Change." European Climate Foundation, University of Cambridge´s Judge Business School, and Institute for Sustainability Leadership, 7.

climate and has a long life span, and looks good, in any sustainability order: Utilitas, Firmas, Venustas. Chalmers further elaborates and reveals that:

"*barriers to such technologies include fragmented market and institutional structures, the lack of user feedback loops, transaction costs and principal-agent problems.*"[36]

Figure 1.6: Standard locked-in solution; a façade renovation in Ryparken, Copenhagen, by author

Such a standard lock-in solution for insulating a brick gable, to some degree, support the existing Danish building industry in its vernacular choice of materials; considering the high use of cement, and mineral wool still is made with fossil fuel energy – though the industry is taking steps to minimize its use of non-renewables.[37] Yet, such a solution can lead to awkward details, see Fig. 1.7, and solutions with different material patina, making it clear that a construction ´face-lift´ has occurred – which is not a bad thing, but it also alters a buildings expression, sometimes a lot, especially for those who pay keen

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36 Ibid.

37 Susanne Kuehn, Rockwool lecture presented to 1st year bachelor students, KEA (Copenhagen School of Design and Technology), March 2019.

attention to the urban fabric. Adding a DSF and thus changing a cultural paradigm such as our shared visual identity, is a large barrier and linked with upcycling waste, it become perhaps impossible even though that, "*the design of new building technologies upcycling municipal waste materials involves and additional reduction of environmental impacts.*"[38] citing Al-Temeemi and Harris, meaning that there is potential in using waste as building materials, though it is not simple. Bottle walls, see Fig. 1.8, can be used as exterior or interior walls as well.

Figure 1.7: Two examples of façade renovation in Søborg, Copenhagen. The left building looks clumsy and does not remove all line-losses, since insulations and render does not reach the doors. By author

[38] Pennacchia, Elisa, Mariagrazia Tiberi, Elisa Carbonara, Davide Astiaso Garcia, and Fabrizio Cumo. 2016. "Reuse and Upcycling of Municipal Waste for ZEB Envelope Design in European Urban Areas." *Sustainability* 8, 610 (May 2016), 3.

1.4 Problem Definition and Research Questions

DSF system of used container glass recycled – upcycled – into bottle-walls is a radical and 'far-out' idea in Danish sociotechnical landscape perspective and regime context. upcycled DSF solution which aims to create a dual-purpose benefit of saving energy on heating and cooling and improving indoor climate. And, potentially also creating a filter and BIPV (Building Integrated Photo Voltaic) which performs better when at cooler temperature. Therefore, this thesis is focused on the:

(1) numerical 'trade-offs' of using used glass containers (glass bottles) in a low-tech way, inspired by Earthship Biotecture by architect Michael Reynolds, see Fig. 2.1, instead of returning the glass back into the system; and
(2) the potential of improving thermal and hygroscopic properties of a building's Skin, thus saving energy on heating and cooling and perhaps also improving indoor climate by keeping the Skin dry and also warmer than before, since it is no longer exposed to cooling winds but instead an enclosed air cavity;
(3) the experimentation draws parallels to eco-activist Robert Greenfield and the 30 day trash challenge – creating a social sense of shared responsibility is key to 'consumer conscientious consumption'
(4)

Considering the many inter-dependent factors and socio/cultural-technical considerations, the working research questions to create a one niche in the sustainable transition in the building industry is:

How can glass-bottle walls create a new space which also increases the thermal comfort and financial bottom line of a single-family home and how can such a system be created without down-cycling the product and ensuring that those glass components can re-enter the system in optimal way?

1.5 Academic Limitations

The topic of sustainable design transition, to meet global goals and avoid a climate crisis, a sixth extinction(!) and the new geological age, the Anthropocene, in which human activity will leave a noticeable trace in the strata of geological time, is much larger than the scope of this thesis, which has its focus on a niche solution for a small part of the existing built environment by challenging existing practices and socio-technical landscapes; though a limitation in academic scope, such topics are the foundation and serve as a general framework for this thesis, which in turn, briefly covers system thinking of EU regional economic inter-dependency and the technical aspects of the prototypes created, along with the legal issues with creating a building material or component and making it eligible for the market.

Chapter 2: Theory and method

"*Integration of passive strategies into a building is fundamental in the design of sustainable buildings.*[39]"

This chapter introduces the reader to the theories used as well as the literature covered to create contextual understanding of this translated pseudo socio-realistic experimentation of using trash (used glass containers) as a building component – through prototyping and investigating the future of 21st c. architectural design aesthetic in the socio-technical systems that are inter-connected in regimes, niches and landscapes, established by professor Frank Geels from the UK,[40] claiming that societal changes can be determined or bound to a reality:

Figure 2.1: Earthship Biotecture bottle wall on social media Twitter. View is from towards west, inside the buffter zone which is an intermediate space that keeps temperatures constant. Note that bottle walls are used as exterior (furthest away) and interior (nearest) walls.

"*Social Construction of Technology (SCOT) focuses on the meanings of technologies and how these emerge from competing interpretations in relevant social groups…. Multi-Level Perspective (MLP) is the most suited socio-technical approach to understand transitions. The MLP combines ideas from SCOT with evolutionary economics. The MLP thus spans foundational social science dichotomies: agency and structure; stability*

[39] Alemu, Alemu T, Wasim Saman, and Martin Belusko, "Airflow and Temperature Modelling of Sustainable Buildings at the Design Stage Can Prevent Unintended Consequences of Passive Features" (*Procedia Engineering*, 2017), 602.

[40] Ceschin, Fabrizio. 2014. *Sustainable Product-Service Systems. Between Strategic Design and Transition Studies*. Edited by Barbara Pernici, Stefano Della Torre, Bianca M. Colosimo, Tiziano Faravelli, Roberto Paolucci, and Silvia Piardi. Uxbridge: PoliMI Springer Briefs.

and change; ideational and material dimensions."[41] Creating an experiment through prototyping of waste has been theorized and tested before:

"*the local reuse of these materials for energy efficient building structure design without particular treatments is an effective, low-cost and environmentally sustainable waste management strategy that avoids the usual recycling processes...consequentially, municipal waste could be locally reused for buildings envelope structures, guaranteeing the same thermal performance with similar or lower economic costs.*"[42]

Along with Geels´ established theoretical framework, the architectural theory of US architect Stewart Brand´s *6 S´s of Architecture* (inspired by Duffy) is covered, see Figure 2.2, to build upon an established order in the hierarchy of a buildings´ individual parts, the so-called *sheathing layers*. Using this theory to create a method to argue for each independent building component and even expand on Brand´s theory with the double-skin façade system, here termed *Super-Structure* by the author, which is similar to what Earthship builder Phil Basehart calls a *Climate Foil*[43] which is a structure that is placed above the existing structure, thus protecting from wind and weather – which in Earthship context is crucial to protect the black water botanical cells from over-flowing, which is one of the parts of the systems the compose an Earthship, which is not necessarily an established theory, but an architectural ideology which creates a new construction paradigm where the client also is the builder and payed workshops create free labor that just needs to be managed – such transition from DIY (do-it-yourself) but DIW (do-it-with) "*highlights the practice of collaborating not only with humans, but also with non-human actors: materials and spaces endowed with a regenerative potential of their own.*"[44] The theory of non-human actors and how they are used and how these artefacts is known as Actor Network Theory (ANT) which is the study of 'the field' (reality) and its' objects, its users and their complex inter-relations, habits, behaviors (practices), cultures and more – which are the foundation of understanding through observation and notation, passive observation and active engagement – potentially creating value through co-created user-inspired design that strives to solve basic and complex problems through open discussion, cooperation and (often) compromise. Such a mapping of a network can help to decrease the risk of destabilization of the network and increase the potential of good cooperation by engaging the right users at the right time in the design process to create maximum project value. In construction, any building project is a world of its own, yet projects share common ground in the many basic issues which must be addressed over time, which often span from being political, to social, to practical to logistical

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[41] Geels, Frank W., Tim Schwanen, Steve Sorrell, Kirsten Jenkins, and Benjamin K. Sovacool. 2018. "Reducing Energy Demand through Low Carbon Innovation: A Sociotechnical Transitions Perspective and Thirteen Research Debates." *Energy Research and Social Science* 40 (December 2017), 25.

[42] Pennacchia, Elisa, Mariagrazia Tiberi, Elisa Carbonara, Davide Astiaso Garcia, and Fabrizio Cumo. 2016. "Reuse and Upcycling of Municipal Waste for ZEB Envelope Design in European Urban Areas." *Sustainability* 8, 610 (May 2016), 10.

[43] Earthship Biotecture. "Full Q & A | Earthship Puerto Rico." January 19, 2019. YouTube video, 25:50 https://www.youtube.com/watch?v=Bt7PnqXb3Iw19.

[44] Vannini, Phillip, and Jonathan Taggart. 2013. "Do-It-Yourself or Do-It-with ? The Regenerative Life Skills of off-Grid Home Builders." *Cultural Geographies* 21 (2): 267–82. https://doi.org/10.1177/1474474013493577.

issues etc. and since a project team is a cluster of many minds working together in a moment in time – it is key that all are aware of the situation they find themselves in.

The situation—the early 21st c. epoch—is a post-industrial, late-capitalistic, perhaps stagnating Europe which must lower emission to mitigate climate change, all while keeping the systems going as they change in times of great changes; while ensuring national prosperity (the all-important GDP) to create equal opportunity and human rights for all. Thus, by understanding the newly created networks that arise in each construction project, and their situation, ANT and MLP can facilitate the design process and can also help nudge actors into cohesive (sustainable) political positions with one another through co-design and compromise and thus facilitating a more resilient design solution that all can be proud of while challenging existing regimes. A future format of tender is 'shared-risk contract' which means that the detail design is done together, across multiple trades (companies), and risk is shared, which encourages cooperation instead of 'trench warfare' and the blame game. Understanding the potentially complex legal framework of users, in design project, is an integral part of ANT and this soft science can contribute to a smooth process which is a value parameter according to DGNB.

Additionally, the consumer tradition has morphed into conscious consumption where consumers also produce (3D printing revolution) and have their data stored (often unknowingly) which in-turn makes for, yet again, a new form of society – *Danmark 5.0* is an example of such a proactive initiative,

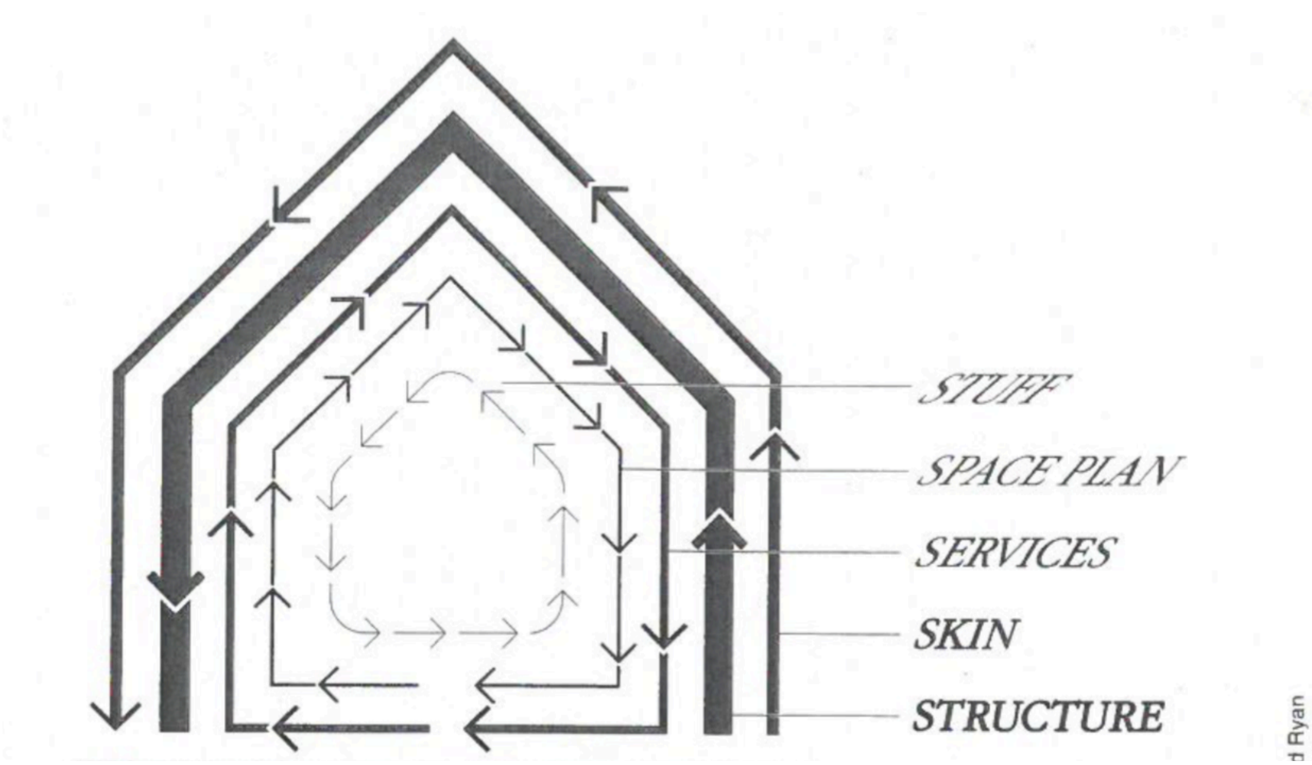

Figure 2.2: Steward Brand´s 6 S´s of architecture categorizes separate sheathing layers of architecture from slow rate-of-change (SITE) to fast rate-of-change (STUFF).

where the consequences of IoT and AI are discussed from an ethical viewpoint which is crucial to include as a parallel since technology is now interconnected with social change: "*Radical low carbon innovation involves cultural change... To alter cultural preferences, such campaigns need to go beyond information provision and aim to create positive discourses and increase competencies and confidence among (potential) users.*"[45] According to Holm et al., "*there is a need to develop political programs and planning that can progress and support transitions processes…thus there are multiple schools of thought… practice theory has its focus on the development of alternative behavior and practices that contribute with an analytical understanding of the complexity that constitutes our social practices.*"[46]

What is more is that "*in transition theory, sustainable development will imply a transition of both material and social elements: a reconfiguration of sociotechnical systems… and is a critical correction to neoliberal understandings of development- and innovation processes through its systemic perspective and its impetus in an institutional and evolutionary understanding*"[47] quoting Geels and Kemp, 2012. In order to change the system in a more sustainable way, it is important to understand the field and that "*innovations that fit into the dominating system are easier to implement than those who require changes in the system.*"[48]

The sustainable transition from the past reckless consumption behavior of the 20th c. by western culture has been sprouting since the 1970s (the first Earth Day) or earlier perhaps. Earthship biotecture, created by architect Michael Reynolds, has built actor worlds through volunteer network creation across the globe; through a drive and passion, they create Earthships from local waste and mostly recycled materials, facilitated through workshops – where people come and pay to work – stretched out in phases, depending on project scope, its location and more.

According to Holm et al., "*a central way to develop new innovative technologies and solutions will be to facilitate sociotechnical experiments, not just to support the technical maturity but also as a conscious way to develop networks and communities that develop common understandings of agendas, goals, and common learning platform in relation to the development of solutions that can create coalitions that can bring innovation onwards.*"[49] Thus the natural cooperation between actors is key to develop tangible and abstract concepts.

Additionally, "*the reconfiguration of regimes and the interplay with niches can presumably assume different shapes and thus create different challenges for both actors in the regime and the planning and politics directed towards sustainable transitions and different development paths are*

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[45] Geels, Frank W., Tim Schwanen, Steve Sorrell, Kirsten Jenkins, and Benjamin K. Sovacool. 2018. "Reducing Energy Demand through Low Carbon Innovation: A Sociotechnical Transitions Perspective and Thirteen Research Debates." *Energy Research and Social Science* 40 (December 2017): 32.

[46] Holm, Jesper, Bent Søndergård, and Inger Stauning. 2014. *Bæredygtig Omstilling Af Bolig Og Byggeri*. Edited by Jesper Ole Jensen, Frederiksberg, 37-39.

[47] Ibid, 40.

[48] Ibid, 41.

[49] Ibid, 45.

suggested… Transformation, technical substitution, deconstruction/reconstruction (de-alignment/re-alignment), and reconfiguration, "[50] quoting Geels and Schot, 2010.

The sociotechnical landscape of Denmark is composed of 98 communes who are required to oversee and manage waste operations for the Danish state – therefore, through network creation between the communes, AffaldPlus is an example (a regime) of multiple communes who have bonded together to create a company which works in many areas, thus saving costs in each commune and are responsible for picking up glass waste and transporting to recycling center. Understanding the waste resource system, see Figure 2.3[51] illustrates a DSF niche solution can integrate with existing regimes which "*need a long list of conditions to be filled before and actual transition from nice to regime can occur…such as technology, user-practice and the market, the symbolic meaning of the technology, the infrastructure, the structure of industry, politics and technological knowledge,*"[52] quoting Geels, and "*Denmark has no real sustainable building tradition to lean up against. We are settlers in a field of radically changed conditions.*"[53]

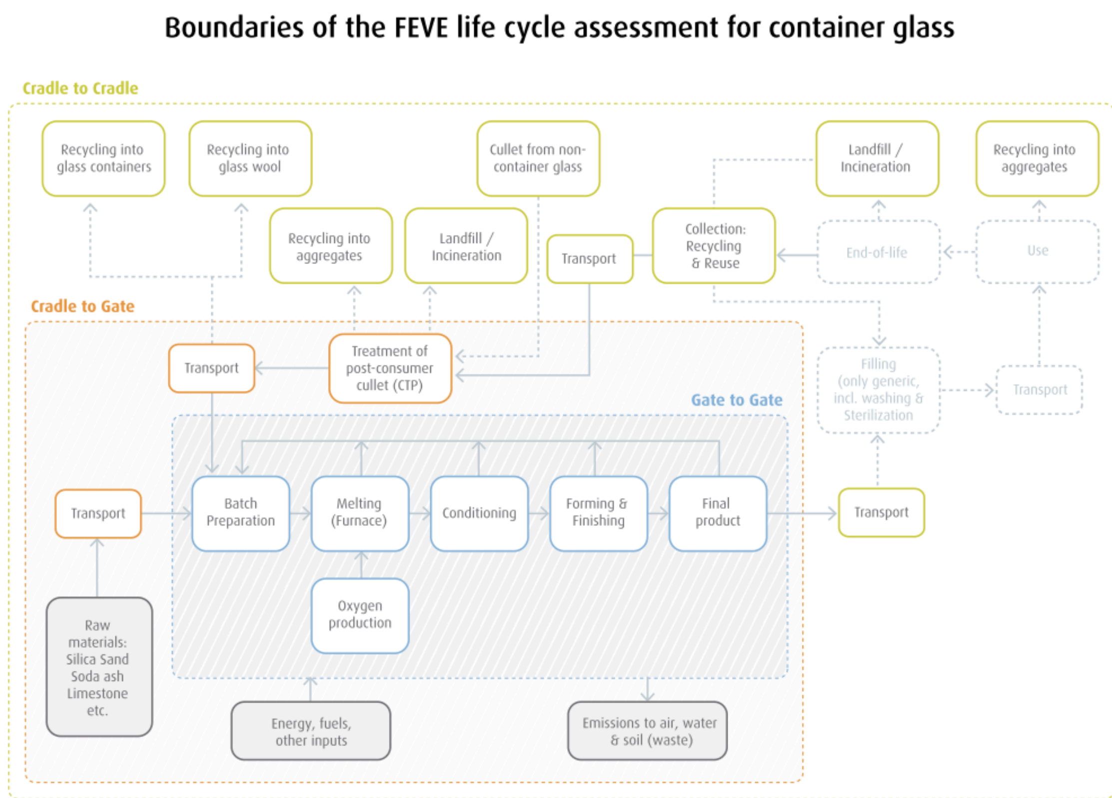

Figure 2.3: Flow-chart of life cycle assessment for container glass, by FEVE.

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[50] Ibid, 48,49.

[51] FEVE. 2016. "Recycling: Why Glass Always Has a Happy CO_2 Ending." The European Container Glass Federation. Brussels, 4.

[52] Ibid, 85.

[53] Ibid, 173.

Chapter 3: Prototyping

"*Regenerative design calls, however, for a fundamental rethinking of how architectural design is approached.*"[54]

This chapter covers the process and thermal testing of three prototypes through process of gathering, cleaning, assembling and thermally testing, See Appendic C: Thermography of prototypes; standard cement-based mortar was used as in-fill in the three different DSF prototypes

The idea is to create an additional layer that can provide additional comfort and protect existing façade from wind and, more importantly, rain infiltration – thus extending its lifetime significantly – since brick walls can have a lifetime of 1000 years[55] if properly maintained, and thus also changing its LCA calculation due to its longer-than-most lifetime variable increase, which is a significant parameter.

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[54] Zari, Maibritt Pedersen. 2018. "*Regenerative Urban Design and Ecosystem Biomimicry.*" Routledge, 27.

[55] Ganshorn, Jørgen. 2000. *Murværk i Blank Mur. Historie Og Vedligeholdelse*. Copenhagen: Landsforeningen for Bygnings- og Landskabskultur, 41.

3.1 Three proto-types of glass-bottle walls for DSF systems: Small, Medium, and Large

Building upon the example of Earthship Biotecture and Michael Reynolds´ use of bottle walls as an established practice, but transformed into a Danish context, prototypes were built and tested; while knowing the fact that current "*buildings are designed and built in a way that is not conducive to breaking down parts into recyclable let alone reusable components,*" quoting the EPA, from the United States,[56] thus any new building component must be designed for disassembly, to ensure that all individual parts can be taken apart and returned back into the system without downgrading – additionally, they must be resilient so not easily removed, such as mounting brackets with square screw holes in aluminum brackets lower risk of sabotage or theft.

All three proto-types share the same characteristics, see Table 3.1. Prototypes are interlined yet statically unstable and must be placed in a structural system to ensure their structural integrity, mounting brackets in aluminum could be one option. Additionally, when properly mounted, theses DSF systems will keep the exterior brick wall (Skin) protected from the elements such as rain and wind; structure therefore becomes dry and warmer, making it more energy efficient and potentially decreasing the chance of mold growth, due to poor indoor climate, partially caused by the cold inside of the exterior wall. The benefit of the DSF system is both dependent on the execution, the optimal air cavity is about ca. 2-8 cm, depending on local climatic conditions and specific situation.

Attribute of prototype	licorice-bottle wall	Creamer-bottle wall	Wine-bottle wall
Weight [kg]	0,680	3,240	4,320
Dimension in cm [W x H x D]	(15 x 13 / 2) x 15	22 x 22 x 16,5	19,8 x 19,8 x 37
Area [m^2]	0,00975	0,0484	0,039204
Density [kg/m^2]	70	67	110
Number of bottles	25	32	9
Number of bottles per m^2	2654	661	230
Cost of bottle [DKK]	3,75	3	37
Cost of bottles per m^2 [DKK]	9615	1983	8494
Production time [minutes]	30	25	20
Production time per m^2 [minutes]	3077	517	510

Table 3.1: Properties of the three prototypes without in-fill

56 Macarthur, Ellen. 2006. "Ellen Macarthur Towards a Circular Economy." *Journal of Industrial Ecology* 10 (1–2): 4–8. https://doi.org/10.1162/10881980677554532116.

3.1.1 Small version: Licorice-bottle wall

In order to make a small, narrow, DSF system I came across these licorice-bottle which, like the other prototypes, have no bottle deposit and thus have little or no value to consumers and therefore these types can often be found in nature, instead of in the glass container. Bottles are assembled with silicone caulk and interlink very well together, see Figure 3.1, and can be used as indoor walls as well.

Figure 3.1: Front view, side view and perspective view of Licorice-bottle DSF system without the in-fill

3.1.2 Medium version: Creamer-bottle wall

A larger DSF system of coffee creamer, Medium version, does not interlink as well as the Small version due to the form of the neck of the bottle, see Figure 3.2. Yet, because of this, the pre-fabricated component has aesthetics potentials since there are different pattern possibilities; can be used as indoor wall system as well.

Figure 3.2: Front view, side view and perspective view of Creamer-bottle DSF system without the in-fill

3.1.3 Large version: Wine-bottle wall

The largest prototype also interlocks very well due to the shape of the bottle neck and can be used as exterior and interior wall as well.

Figure 3.3: Front view, side view and perspective view of Wine-bottle DSF system without the in-fill

Chapter 4: Analysis

Conceptually, all three prototypes perform as expected. Adding water to the bottles increases the thermal mass and thus creates a more stable temperature, if so desired.

It is important to focus on technical properties since it makes no sense to introduce a terrible product to the market, only to then later realize it was a useless pursuit, yet it is difficult to test small-scale and expect a realistic result.

4.1 Comparing three prototypes

All three prototype systems, by enclosing an air cavity, help create a dryer and warmer exterior shell of the Skin and or Structure – a brick façade is *both* Skin and Structure in this example – the heat-loss through exterior wall is also decreased by reducing cold bridges in the façade and thus extending its potential life time, as previously mentioned. There are multiple glass containers which could be used and the icorice bottle-walls, wine bottle-wall, and creamer bottle-wall are mere random examples. Besides these three objects, there are hundreds more types of glass containers which are ´outside of the bottle deposit system´ and if collected, and assembled into a bottle-wall DSF, it could create a similar or improved effect since the principle remains the same, since they all create a 7th S, a so-called climate foil that decreases overall heat loss and line-loss, which is a cold-bridge in the structure where heat escapes faster than surrounding area. There are three types of line-loss which affect building performance: (1) geometric, (2) convection, and (3) point-loss. "*The cold bridges have a great influence on the corrected U-values of the primary constructs and thus also the overall transmission loss of buildings*"[57] which can be substantial, depending on specific situation. Additionally, a "b*uilding's energy consumption is not easily calculated...discrepancies between the calculated energy demand and the actual energy consumption are found. This discrepancy is commonly known as the Performance gap,*"[58] citing Van den Brom et. al (2018), and Gram-Hanssen and Georg (2018).

It is thus impossible to determine the real effects of the creation of such a DSF design solution along with the change in look, which will change a buildings general appeal and identity, for better or worse depending on the viewers general aesthetic approach and dogmatic opinions. Such tacit, socio-aesthetic barriers may first appear after a project is complete. The cost of ventilation system is an uncertainty which may prove to be too difficult and expensive to implement in the DSF, and thus not be sustainable, due to other barrier in the system, or regimes context. In order to imagine upscaling a bottle-

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[57] Kamper, Maria Gaardsted, Malene Elmbæk Knudsen, Steffen E. Maagaard, Andrea Mortensen, Einar Sigthorsson, Jens Thamdrup, Mads Hulmose Wagner, Peter Weitzmann, and Amdi Schjødt Worm. 2018. “Kuldebroer og deres indflydelse på klimaskærmens varmetab.” 141.

[58] Brøgger, Morten, Peder Bacher, Henrik Madsen, and Kim B Wittchen. 2018. “Estimating the Influence of Rebound Effects on the Energy-Saving Potential in Building Stocks.” (*Energy & Buildings)* 181, October, 62.

wall solution, a PESTEL analysis, see Figure 4.2, can create overview about sociotechnical uncertainties to understand such potential constraints and opportunities and analyse and map such potential realities.

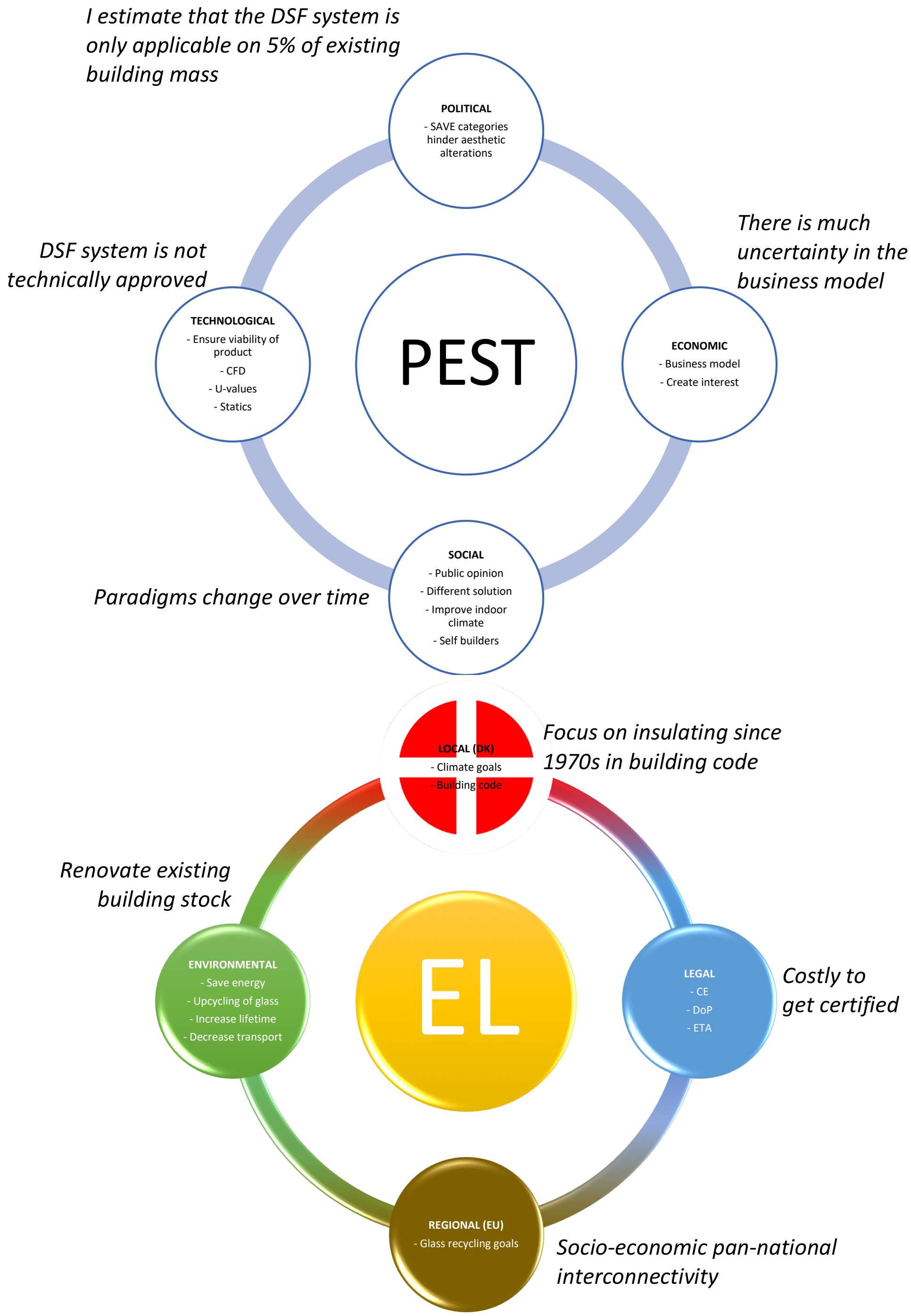

Figure 4.2: PESTEL analysis, by author

One pertinent issue when making bottle-walls is the access and storage of collected bottles. One way to gather materials (bottles) for a bottle wall is to create partnerships with a local restaurant – one local restaurant discards about 50 bottles per week, depending on the season, and will gladly save them for me to pick up, instead of them having to go to glass container to discard the bottles.[59]

4.2 Profitability analysis

Taking the profitability formula into use, see Appendix D: Cost analysis, and considering the expenses of creating a pre-fabricated glass-bottle façade system, estimated work time, renting of lift, etc. are from example wall in Søborg.

Because of the development uncertainties it makes it difficult to realistically create a clear picture of the potential profitability.

4.3 Climatic impact (potential reduction GHG emissions)

Buildings are responsible for 40% of global GHG emissions and retro-fitting existing buildings is the key to a sustainable transition to mitigate climate change. And "*retrofitting for resilient buildings will enable building or building components to be adaptable, demountable, reversible and durable.*"[60] Imagining this prototype glass-bottle solution on 1% of the current building fabric, compared to the loss of recycled glass (national export) is a trade-off worth examining and exploring the importance of. In glass production, when using recycled glass shards (cullet), it substitutes the need for virgin material; for each 1 ton of recycled glass, it saves 1,2 tons of virgin materials and 60% in CO_2 emissions.[61]

The rebound and (pre)bound effects are also one component of the mosaic sustainability picture that is put forth. And, how can you measure indoor climate? How can you measure architecture? Perhaps, considering the climatic impact of the building industry, one must make everything as sustainable and non-polluting as possible and then find the artistic expression within that new reality. Perhaps, a new trash-typology epoch awaits us all, where consumers are contentious actors in their own life expression, like Rob Greenfields 30-day TrashMe project asks: "*How are we as individuals contributing to these problems and what positive changes can we make today to live out a life that is in harmony with our beliefs? We need to put our actions front and center and inspire positive change.*"[62]

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[59] Heine Kristoffersen, interviewed by Mikkel Christensen (author) at Madhus24, 21st of May.

[60] Craft, W, L Ding, D Prasad, L Partridge, and D Else. 2017. "Development of a Regenerative Design Model for Building Retrofits." *Procedia Engineering*, 664.

[61] Selve, Michael Delle. 2015. "Glass Packaging Industry. Making the EU Circular Economy Real." Brussels.

[62] Greenfield, Rob "Watch This Man Walking Around NYC Wearing His Trash." Ecowatch, September 27, 2016. https://www.ecowatch.com/wear-trash-rob-greenfield-2019080933.html.

4.4 LCA and LCC comparison of locked-in solution and DSF prototype of glass containers

It is time-consuming and difficult to create a thorough LCA and results can deviate from person to person depending on the modeling of the analysis since, "*there is a significant correlation between building lifespan and the environmental impact from all primary building components*"[63] which is only one input variable, which is in the Temporal dimension, see Figure 4.3.[64] Component lifetime has a big influence on output; bricks can last many additional years if kept warm and dry – thereby extending the lifetime of the Structure by, perhaps, by a significant factor from 120 years, see APPENDIX A: LCA Analysis in LCAbyg. According to Vaglio, "*DSF is regularly acclaimed as a sustainable enclosure solution.*"[65] And regardless of LCA, it is a benefit to a buildings overall performance which is difficult to compare.

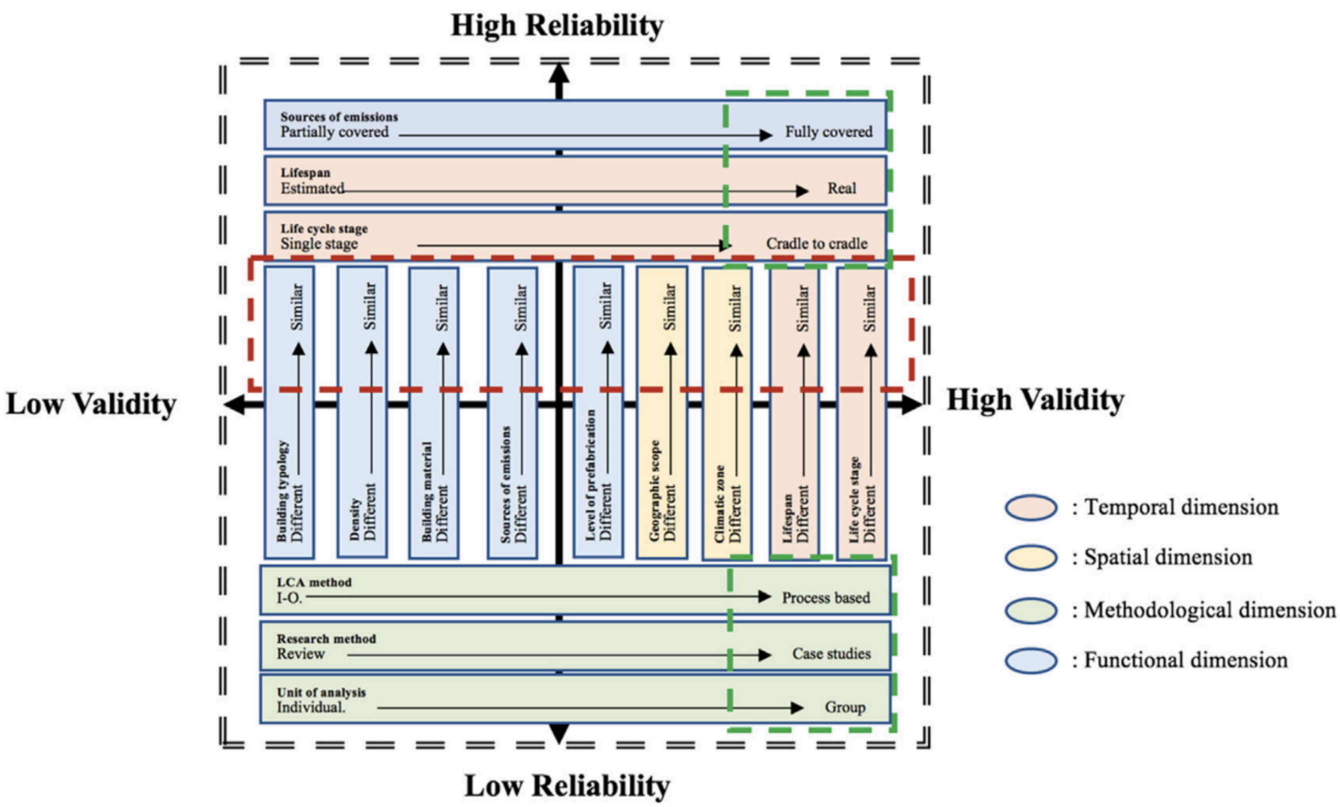

Figure 4.3: A framework for enhancing validity and reliability of buidings´ LCCa, by Pan et. al.

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[63] Marsh, Rob. 2017. "Building Lifespan: Effect on the Environmental Impact of Building Components in a Danish Perspective." *Architectural Engineering and Design Management* 2007, 97.

[64] Pan, Wei, Kaijian Li, and Yue Teng. 2018. "Rethinking System Boundaries of the Life Cycle Carbon Emissions of Buildings." *Renewable and Sustainable Energy Reviews* 90 (June 2017), 388.

[65] Vaglio, Jeffrey Craig. 2015. "Aerophysics of Double-Skin Facades: Simulation-Based Determination of Pressure Coefficients for Multi-Story Double-Skin Facades." University of Southern California.

4.5 Scaling bottle-wall solution

Glass containers are a global phenomenon which makes it possible to gather locally, thus making this low-tech solution available and democratic along with sustainable, since the transport factor is reduced by the amount of glass moved around.

Because of the relatively high glass recycling percentage in Denmark it is less obvious to use used glass containers since Denmark has established good waste practices, though not as good as Germany. Therefore, it may be more ideal to scale a place in the World where there is lots of resource streams (and air pollution) such as India or China; at least until there is a new technological leap, to create ZEB in Asia. Therefore, the used container DSF system is more apt in less-developed nations, like the member states in the pan-national association BRICS, where the Human Development Index (HDI) is lower than the EU member states in general.

4.6 Proof of Concept

In order to analyze the interconnected complexities, actors and activities and more, a business model canvas can help map a path of a new solution, see Figure 4.4.

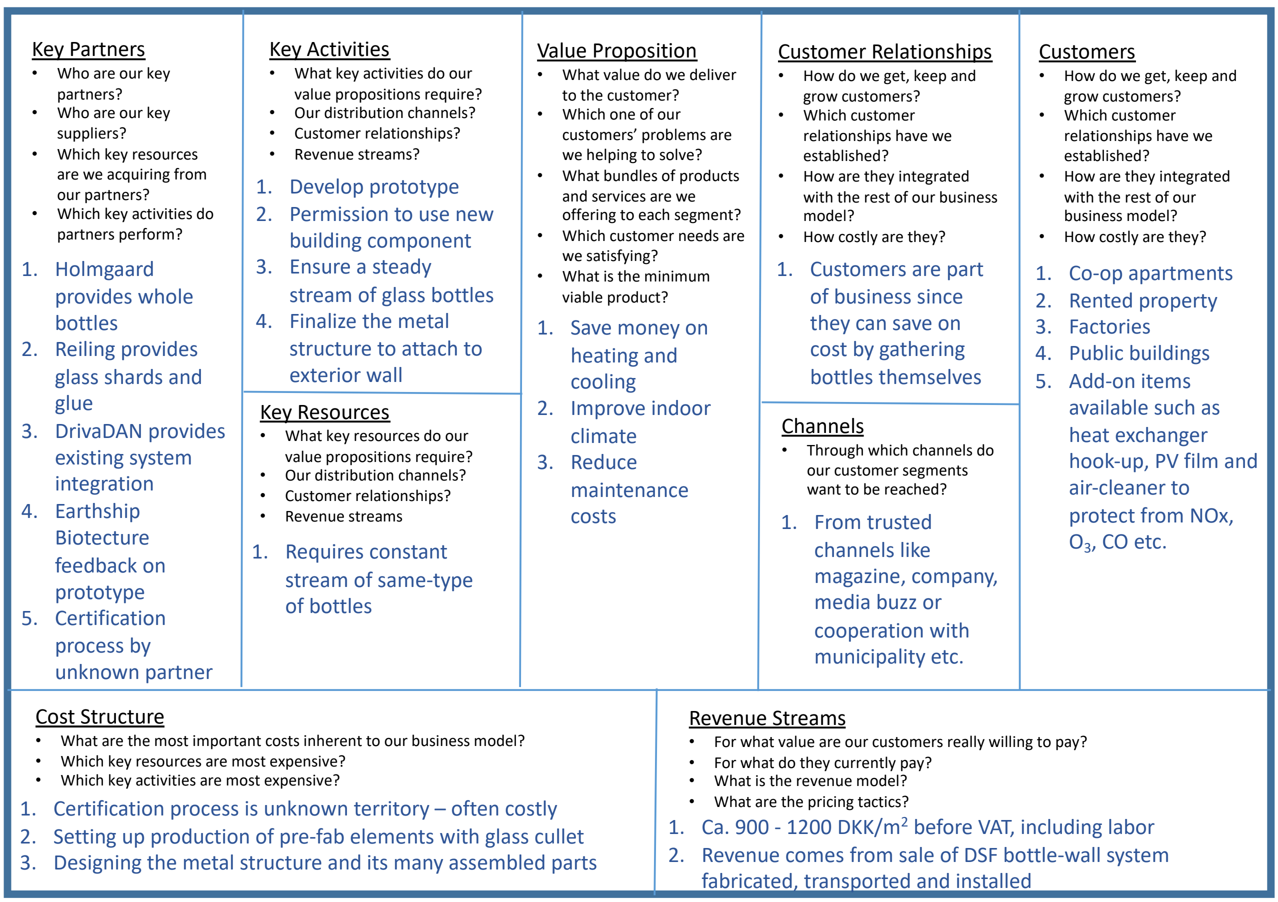

Figure 4.4: Business Model Canvas analysis of DSF system illustrates the imagined future of DSF system

Chapter 5: Reality Check

In order to ensure the technical qualities of the DSF system, I corresponded with a glass expert and presented my prototypes, he remarked that: "*it is not realistic, since heating and cooling of each bottle could risk a thermal break... Façade glass should be tempered…recycling used glass bottles into new glass bottles (instead of using as a DSF) is a much better idea.*"[66] Such a remark raises dilemmas that cross across systems: in the construction business it is a standard that façade glass is tempered and in the recycled business it is a standard that glass should be recycled.

Glass facades have before been used as a vernacular solution in Denmark but not as upcycled used container glass, but as glass plates, which has since proved a failure, despite them being tested by the Technological Institute: "*The errors are not the municipality's responsibility, says Bente D. Sejersen, project manager in the municipality's building department…We have a report from the Danish Technological Institute, which has tested the glass plates before they were set up because we would be sure that they were durable and that the adhesion method was in order. The report states that under the conditions they have tested, it is a fantastic product. When the plates then started to break, we came afterwards and said "uh, what happened here?", And then the institute replies that it cannot test for all conditions.*"[67]

Technological Institute was wrong, though they claim it is not their mistake since, "*they have tested what they were told by architects and builders, and that it was done completely after the book…When we test, it is according to all the standards in the field. But how building materials that have been tested at the institute are used is entirely up to the builders and architects. It is out of our hands.*"[68] Thus, it is unclear where the responsibility lays in this specific glass façade disaster or what steps could be made to ensure proper testing of new materials in the future, so contemporary architecture can live up to the demand of *Firmas* put forth by Vitruvius. This reveals a deeper issue in the sense of under which conditions new materials are tested. Ultimately, one does now know until you know since, "*one test is better than 10 calculations*" (Unknown) which, justifiably so, creates even more uncertainty with new solutions and technology that come unto the market.

5.1 Developing a narrative

To increase the good will, identity and interest of a project, a good narrative can support one´s idea clearly when initially presented to customer. Pragmatic problems such as storage of bottles and cleaning besides construction of elements and mounting of brackets and mounting of elements become part of the reconfiguration of how to use glass containers when empty.

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[66] Carl Axel Lorentzen, Glasfakta ApS, e-mail correspondance with author Mikkel Christensen, April 29th, 2019.

[67] Bo Nørgaard. "Energivenligt prestigebyggeri falder fra hinanden." *Horsens Folkeblad*, https://hsfo.dk/oestjylland/Energivenligt-prestigebyggeri-falder-fra-hinanden/artikel/112140, June 1, 2017.

[68] Ibid.

5.1.1 Homeowner resilience

Homeowners are passengers on their own home vessel as Spaceship Earth travels the cosmos. Thus, to travel best one must ensure that one´s own experience does not down-grade later experiences of humans to come. The low-tech solution of bottle-walls makes it available to a broad amount of users who each, surely, has their own favorite glass container product, which they routinely recycle (after cleaning properly of course); but if a sacred-geometry solution is presented, perhaps some homeowners will realize the potential of their glass waste and start collecting old glass containers, instead of depositing them, to be broken and transported out of Denmark, users collect for a time slowly prepare for their new project: creating their own DSF, a Super-Structure, or Climate Foil, to save energy, improve indoor climate, and perhaps beautify and provoke the public space through a different design solution: wearing your trash to create a sustainable solution.

5.1.2 Hygrothermal properties and aesthetic considerations of building stock

As mentioned, the building stock needs to have improved insulation and there are different ways to do so; interior insulation decreases occupants amount of m^2, it increases risks of mold, and it leaves the exterior shell of the Skin more exposed to the natural elements, since the heat from the inside protects less, making it more prone to damage from frost. It is possible to insulate on the inside of the Structure, but must be done carefully, see Appendix B: DTU lecture, the only benefit of insulating in the hydrothermally poorest way, is that it does not alter the façade expression.

When possible, it is best to insulate on the exterior side of the Structure, thus creating a warm inner core that keeps dry and free from fungi, yet many complications also can arise when insulating on the exterior side, such as: considerations about roof overhang (or lack thereof), placement of gutters and downspouts, placement of windows and their relocation to ´move out´ to a new exterior Skin, public space requirements and fire requirements and more. Yet, it is widely agreed that, in the long-run, it is best to insulate on the exterior side, except if the current façade is in such a way, that its expression cannot be altered, due to aesthetic considerations to the general area, which sadly means that a lot of quite common brick buildings from the 1930s cannot install exterior insulation because there is a focus on aesthetics over indoor climate, energy savings and general comfort. Cultural pride and nostalgia in a relatively recent past, is a huge barrier to higher quality architecture.

5.2 Dependency on other systems (partnerships)

Creating a newly-developed, low-tech, pre-fabricated system is a fragile solution to a business which is conservative and must be nudged into new more sustainable practices, perhaps with LCA documents and profitability analysis which shows realistic potential along with climate impact, along with the trade-offs of keeping the glass containers out of the EU recycling system. Along with understanding the complex reality of constraints and opportunities when trying to develop and collaborate, see Figure 4.1.[69]

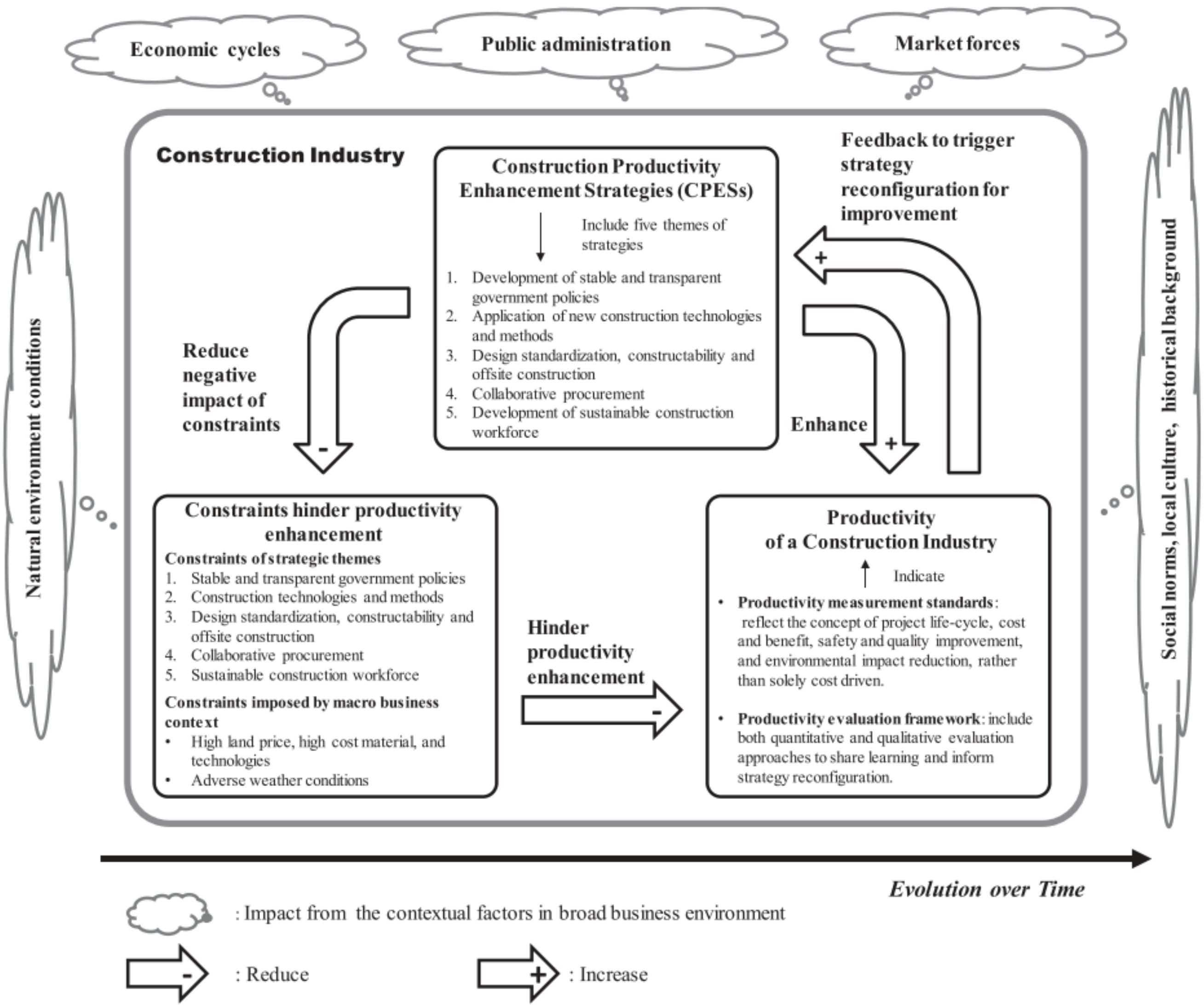

Figure 4.1: Theoretical framework of CPSEs, by Pan et al.

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[69] Pan, Wei, D Ph, Le Chen, D Ph, Wenting Zhan, and S M Asce. 2019. "PESTEL Analysis of Construction Productivity Enhancement Strategies: A Case Study of Three Economies." *Journal of Management in Engineering* 35.

Chapter 6: Discussion

Modern society in transitioning from an industrial society epoch to an epoch with regenerative and restorative Architecture, since in the past, "*industrial society can best be described as a scheme for turning resources into pollution as fast as possible. Resource depletion and pollution aren't accidental outcomes of industrialism. They are hardwired into the system: the faster resources turn into pollution, the more the industrial economy prospers, and vice versa. at forms the heart of our predicament.*"[70]

Along with the new tools of informed parametric design and LCA where the information you get **out** of the model, is only as good as the information you put **into** the model and how well you understand your variables and your sense of self-critique in the model.

Degree days and relevance in certain parts of the World makes a temporary retro-fit solution more scalable and India is perhaps large potentials, also where air quality in urban areas can be especially high. BIPV upgradable systems can be mounted on retro-fitted DSF system making room for more potential uses of the DSF system, since the air-cavity could potentially cool the PV, which improves their efficiency. Thus, the heating of the PV will heat the cavity, increasing the temperature of the fresh air from the air cavity, saving heating costs. And, the cooling of the cavity will in turn decrease the temperature of the PV, making it more efficient since cooler operating temperatures increases output of the panels. Another reason why it may be more apt in places like India is that in the EU, with its thorough regulatory framework, one must have product approved ETA and DoP to sell something as a building material. This DSF system of bottles can only be branded as a DIY solution, and not as a pre-fabricated building component; people will have to create their own solution based on their desire, integrated with their respective glass container use – to be able to gather great quantities of glass.

The in-fill in the DSF system could be a multitude of things instead of cement-based mortar; vegetable binder at Green Solutions House on Bornholm is an example of using left over glass shards as paths – such an in-fill could be possible and would be free of cement which is a GHG emitter.

Architecture is part of our shared history and must be preserved for posterity. Yet past Architecture does not live up to current demands which causes a dilemma, especially in a World where many have said: "*You cannot measure architecture*" as architect Dan Stubbegaard told me in 2015, speaking rhetorically since he agreed that certifications rely on measured element; we agreed that Architecture is difficult to sum up. The meaning being that architecture is an artform and cannot be measured. Not only is it an artform – it is the mother art. Thus, it is a certainty that architecture can be art, also true that architecture is the only art one cannot avoid yet those who inhabit these structures realize them from the inside out, not outside in, as the observer does. Since we spend most of our time indoors it is more important that buildings are healthy places instead of more aesthetic blocks where the form and surface of the Skin is all-important – yet then the ill-trained architect forgets about Vitruvius´ three words: *Venustas*, *Firmas* and *Utilitas* as a maxim for proper construction and not just

[70] Greer, Michael John. 2009. *The Ecotechnic Future*. New Society Publisher, 28.

focus on visual aesthetics since, according to Brandt: "*significant savings can often be achieved by insulating the outer walls of the building, because the area is usually large. At the same time, a better comfort is usually achieved… The existing wall becomes warmer and therefore gets more favorable moisture conditions. Cold bridges next to floor separations and interior walls are reduced, whereby the risk of formation of dust figures on cold bridges against the room is also considerably reduced.*"[71] Which means that warmer walls are also nicer to look at from the inside, since air particles do not attach as well to dry surfaces. But because of considerations of aesthetics, interior insulations systems are used – some with success – but, is risky and should only be used where other solutions are not possible, often due to architectural considerations, see conclusion remarks in Appendix B: DTU lecture, by Søren Bjarløv.

One cannot argue for good Architecture when there are poor indoor climate condition, "*from a building physics point of view internal insulation is considered as problematic... shown worse hygrothermal conditions and increased risk of moisture-induced damages*"[72] and "*internal insulation is risky and should only be considered after thorough considerations*"[73] and, on the other side, "*exterior insulation is often unacceptable since the building losses architectural value. In addition, balconies and bay windows can complicate exterior insulation significantly and the use-value can be reduced.*"[74] Such an inherent dilemma between comfort and appeal (architectural aesthetics, *Venustas*) parallels other parts of society, like fashion which also has its changing trends, contradictions and paradoxes… Ironically, cleaning a façade (to increase visual appeal) can make brickwork more susceptible to moisture[75] – which is further problematic with interior insulation, since moisture that penetrates the exterior Skin cannot as easily evaporate like before, potentially causing later moisture problems on interior and exterior side of Skin (and Structure).

Clearly, Architecture and architectural value is a term which means different things to different people and this author argues that architectural value is the balance of Venustas, Firmas and Utilitas, where the one part is compromised, in order for the other to improve, meaning more comfortable and energy-efficient buildings but perhaps a-bit-less aesthetically pleasing, or architectural value, which is a term that spans the balance but means different things to different people… Such a change is a result of cultural maturity in the eyes of transitional times. Even if an energy renovation is less appealing but it is a general improvement it is improving the architectural value. Such a mind shift is crucial since society

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[71] Brandt, Erik. 2009. *SBi-Anvisning 224: Fugt i Bygninger*. Statens Byggeforskningsinstitut, Aalborg Universitet, 2970 Hørsholm, 172.

[72] Jensen et. al. 2018. "Hygrothermal Assessment of Internally Insulated Solid Masonry Walls Fitted with Exterior Hydrophobization and Deliberate Thermal Bridge." CE Papers, 79.

[73] Tommy Riviere Odgaard, PhD., DTU Symposium om indvendig efterisolering, lecture presented at DTU, May 2019. Original quote: "Indvendig isolering er risikabelt. Bør kun overvejes efter grundige overvejelser."

[74] Munch-Andersen, Jørgen. 2008. *SBI-Anvisning 221: Efterisolering Af Etageboliger*. 1st ed. Statens Byggeforskningsinstitut, Aalborg Universitet, 2970 Hørsholm, 71.

[75] Britt Halker Høegh, Teknologisk Institut, DTU Symposium om indvendig efterisolering, lecture presented at DTU, paraphrased by author, May 2019.

needs to renovate current building stock – of which exterior insulation is only one part of the multiple changes needed to lift the general standard of the Architecture of the past. A compromise is typical in the business, and shifts are already happening since there are political talks of new laws, which will affect how the urban fabric is preserved, while others choose to insulate, no matter how ugly it is for some observers. There is even another option:

"*One compromise could be, that a historic building is insulated on 3 of 4 sides, so the public face, the façade, is unaltered, while the rest of the building is insulated properly, where the visual expression of the building is less important.*"[76] Insulating our historic building mass important, if only a small part, if we as a society are serious about mitigating climate change by decreasing the need for heating. According, to a newspaper article last year: "*Renovating a façade can save op to 65% in heating bill… It was an advantage to not have to consider the expression of the former façade.*"[77] But sadly, many historical heritage buildings are still stuck with cold exterior walls, which are nice to look at but not always achieving a great indoor climate due to their hygrothermal properties – and even those who have interior insulation, due to major risks in execution phase, may have moisture problems already, but evidence of that may not turn up until after 5 year inspection, here contractual conditions from builder normally expires.[78]

Clearly, there are multiple technical (Utilitas) and aesthetic (Venustas) problems with interior insulation as well with exterior insulation. According to Møller, most energy savings is achieved if whole single-family home is after-insulated, but practically only some parts are insulated and often combinations of after-insulation, in single-family homes, kWh/year savings are added together, indicating that DSF façade system is inherently part of changes in other systems which must be improved simultaneously, in some cases.[79]

6.1 Local efforts help solve local, regional, and global issues

Local trash is everywhere, and no one likes it. By creating a way to use glass that there is no pant on (yet, depending on EU regulation), creates added value to the glass, since much glass ends up in landfill, or nature or as slacks in the trash incinerator.

Regionally, communes cooperate to create share value in moving material around – and DK is just under 80% recycling according to EU, so DK is part of larger ´communal area´ within EU regime.

Lastly, local effort help solve global issue of climate change, thus help fulfilling national goals along with supporting regional efforts as a national example, others can be inspired by.

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[76] Tommy Riviere Odgaard, PhD., DTU Symposium om indvendig efterisolering lecture presented at DTU, comment made during post lecture discussion, paraphrased by author, May 2019.

[77] Gregersen, Rasmus. "Slidte 70´er-boliger er som forvandlet." *Ingeniøren*, October 16th, 2018.

[78] Britt Halker Høegh, Teknologisk Institut, DTU Symposium om indvendig efterisolering, lecture presented at DTU, paraphrased by author, May 2019.

[79] Møller, Eva B. 2012. *SBi-Anvisning 239: Efterisolering Af Småhuse - Energibesparelser Og Planlægning*. 1st ed. Statens Byggeforskningsinstitut, Aalborg Universitet, 2970 Hørsholm, 42-43.

6.2 New Paradigm: wear yesterday´s trash as a rain jacket for your house

Green activism such as Rob Greenfield´s TrashMe campaign, See Figure 6.1, makes is clear that careless consumption, based on fossil fuels, is not the trend of the future. The future is always uncertain, yet daily trends and activity suggests that Rob Greenfield as a successful eco-entrepreneur example in the late-capitalistic, post-industrial, mass-media manipulated digital age, who has been able to mainstream a New Paradigm of conscientious sustainable living, which empowers the individual and facilitates the creation of new (online)networks—creating a multiple-input arena, where the ´hive mind´ of many participants can create a shared opportunity space to be creative together.

"*Much as organisms are particularly comfortable and useable in biology because of their tangibility... buildings may have a similar role to play in concretising abstractions about the human social condition. Thus, buildings may be a particularly useful intellectual device for furthering our understanding of energetics and the interface between biology, sociology, and economics*"[80] Zari quoting Timothy Allen. New paradigms also create the context for linking academia and entrepreneurship through newly-created actor networks that have the ability to change existing regimes, based on dogmatic landscapes.

Figure 6.1: Rob Greenfield is his custom-made trash suit walking the streets of NYC wearing his own trash for 30 days, in 2016. https://deskgram.net/p/1980541175648818264_8166457054

6.3 Creating a DSF system niche

Pragmatically changing existing regimes is most likely with a focus on the building stock from 1960s to 80s, mostly due to their lack of ´cultural heritage significance,´ due to their relatively young age, and therefore more likely to be rated low on SAVE category – and thereby be possible to alter façade expression with a DSF system out of recycled glass bottles – and to the 1980s, when the energy crisis of the 1970s, introduced energy demand legislation into the building industry, "*causing 25 years of energy hysteria with excessive insulation of brick walls, which were not made to be filled out with insulation materials, which eventually turned out to bond the water in the wall and sink like wet newspapers.*"[81] Such unexpected negative consequences are result of a too-fast solution which exemplifies the risks which creates multiples dilemmas of change. Insulating brick

[80] Zari, Maibritt Pedersen. 2018. "*Regenerative Urban Design and Ecosystem Biomimicry.*" Routledge, 23.

[81] Ganshorn, Jørgen. 2000. *Murværk i Blank Mur. Historie Og Vedligeholdelse*. Copenhagen: Landsforeningen for Bygnings- og Landskabskultur, 41.

buildings is still a big issue today and multiple systems exist, each with their own pros and cons. One solution that is rarely seen, especially in single-family homes is a double-skin facade which in offices, "*helps create a more comfortable and eco-friendly office environment which in turn, further reduces maintenance costs as it saves the building´s energy resources...DSF systems have great potential for decrease energy consumption in wide ranges of research areas.*"[82]

And through a pragmatic approach perhaps then, "*changes on the landscape level may put pressure on the regime. This pressure, combined with a regime internal destabilisation, could bring to a misalignment on the functioning of the regime and create windows of opportunities for radical novelties.*"[83] Such is one of the paths towards a sustainable transition.

Ultimately, insulating exterior walls and creating enhanced natural ventilation, is part of a larger evaluation and contextual ´whole´, since a buildings architectural expression, size, and light will be affected. Restorative and regenerative Architecture a "*process that repairs, recreates or revitalizes its own sources of air, water or any other matter. It is sustainable system that shapes the needs of a society on the integrity and balance of nature.*"[84] The act of building can have multiple benefits in the built environment and the urban fabric, inspired by Earthship Biotecture and their ideology of sustainable autonomy for everyone (SAFE) can be part of an established regime practice, "*Humans invented concept of garbage…All buildings must provide all six things, or someone must do it…most engineers and architects have no idea how to use thermal mass to create a holistic machine that is palatable and nice to look at.*"[85]

Since most of our building stock is already built[86] and "*Regenerative design will become a necessity to support a healthy and positive ecological built environment*"[87] we must try to think about symbiotic relationships and find or create places where synthesis can be achieved; and, "*we must understand the context of technology*"[88] so we are acting correctly with one another to build a new economy since "*existing system cannot solve our current problems…we need rebellion.*"[89] Though we also need to find a middle way, since chaotic rebellion is often not sustainable in the long run, due to the

[82] Ahmed, Mostafa M. S. et. al. 2016. "Double Skin Façade: The State of Art on Building Energy Efficiency." *Journal of Clean Energy Technologies* 4 (1), 88.

[83] Ceschin, Fabrizio. 2014. *Sustainable Product-Service Systems. Between Strategic Design and Transition Studies*. Edited by Barbara Pernici, Stefano Della Torre, Bianca M. Colosimo, Tiziano Faravelli, Roberto Paolucci, and Silvia Piardi. Uxbridge: PoliMI Springer Briefs, 47.

[84] Attia, Shady. 2018. *Regenerative and Positive Impact Architecture Learning from Case Studies*. Springer International Publishing, 19.

[85] Michael Reynolds, Earthship Biotecture lecture at Valby Kulturhus, June 2017.

[86] Rasmus Helveg Petersen, Arkitektur Politik lecture presented at DAC, February 2014.

[87] Shady Attia, Towards Regenerative and Positive Impact Architecture: A Comparison of Two Net Zero Energy Buildings, (*Sustainable Cities and Society, 2016*), 405.

[88] Phil Ayres PhD., Technology in Architecture lecture presented to KADK students, (The Royal Danish Academy of Fine Arts Schools of Architecture, Design and Conservation), November 2018.

[89] Jørgen Rosted, Ibid.

lack of order and thus we must "*Find balance in a changing World*."[90] Creating a DSF system niche and finding balance it is "*crucial to regenerative design is a systems-based approach. Buildings are not considered as individual objects but are designed to be parts of larger systems.*"[91] Thus, the interconnectedness of architectural systems must be scrutinized and further analyzed so ideal solutions can flourish and have success on the market, changing regime practices since we all have a grave responsibility, "*these upcoming decades are incredibly important for the Planet´s condition…consumption and behavior matter... It commits to having knowledge and experience.*"[92] To change regime practices, a niche product can be part of a new design dynamic where academics, entrepreneurship and science overlap to co-create a sustainable future: "*architects are part of the solution and part of the problem ... we are part of a consumption culture ... need to develop a new aesthetic with a focus on the user. Architects must retrain and understand technology economics and nature…The school needs to do more research.*"[93] Central to any new construction component is to make it flexible since "*buildings should be able to be upgraded according to new needs over time, like new ways of working and living. Technical installations must be easily accessible and documented using smart information management systems.*"[94]

Challenging the established practices of the regimes is one way to create impact positive architecture, reduces transport factor and change the perception about what Architecture is and what it evolves around and why we need to adapt and transform to mitigate climate change – all while improving indoor climate and save energy. One achievable goal is to help the construction industry and its sociotechnical landscape realize the inherent paradox of using non-renewables (mineral wool made with heat from coal) as insulation, to decrease our use of non-renewables in heating our homes, when a passive solution will arguably make more sense though it does challenge the established architectural vernacular typology.

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[90] Lars Løkke Rasmussen, En Verden i Forandring – er der plads til bæredygtighed? lecture presented to Dansk Byggeri, April 2018.

[91] Zari, Maibritt Pedersen. 2018. "*Regenerative Urban Design and Ecosystem Biomimicry."* Routledge, 5.

[92] Steen Hildebrand PhD., Syn på de 17 – Dialogmøde om FNs Verdensmål for bæredygtig udvikling lecture presented to Schmidt Hammer Lassen architects, June 2018.

[93] Jakob Brandtberg Knudsen, Ibid.

[94] Shady Attia, "Regenerative and Positive Impact Architecture Learning from Case Studies" (*Springer Briefs in Energy*) 2018, 85.

Chapter 7: Conclusion

"*For centuries, housing has been built from found materials such as rock, earth, reeds, and logs. Now there are mountains of by-products of our civilization that are already made and delivered to all areas. <u>These are the natural resources of the twenty-first century.</u>*"[95]

Because of the global climate change challenges and the quadruple squeeze, it has now become crucial to transform the late-capitalistic post-industrial society through a new paradigm, transitional circular economy, but the market is locked-in to existing solutions that are based on the burning of fossil fuels and many actors are frozen due to the socio-technical regime and overall sociotechnical landscape and "*the social challenge is to facilitate a transition before significant environmental damage occurs.*"[96] The transition may not be the final form that becomes as well-working as nature but "*any new technological infrastructure of policy regime should not be seen as "the solution" to the climate problem, but another step in the development path.*"[97]

Besides creating thermal benefits to a given structure, a DSF system creates an air cavity which has the potential to create multiple benefits: (1) air is pre-heated in the cavity by the passive solar and slow-moving cavity air (along with heat-loss from Skin and or Structure), which increases the temperature of the ventilated air; and, (2) an enclosed DSF system also creates the opportunity to filter the incoming air that flows, through the chimney effect, from bottom to top inside the air cavity, making it possible to ‘clean your air’ before it comes inside the building.

This thesis has focused on the thermal improvement of brick buildings by applying a DSF system of upcycled glass containers, since these buildings often need some renovation and are not necessarily prone to cultural heritage restrictions (SAVE categories), making this building stock somewhat realistic, depending on specific situation, yet DSF system component can contribute to any architectural typology.

This thesis investigated the potential of upcycling glass into pre-fabricated double-skin façade system to decrease energy use and create a retro-fit that strives towards ultimate architectural goal of humanity: create zero energy buildings that are energy-efficient and upgradable to create resilient building owners that are capable of improving their situation, either as DIY or DIW.

Glass bottle walls have been used for over a hundred years in the American southwest and the tradition is alive and well in Taos, New Mexico, where the upcycling of glass bottles is only one component of their Earthships: a ZEB, an energy-plus building actually, that is off-grid, and also contributes to the biosphere by creating enhanced biodiversity around it.

Such a whole, or holistic view, is subject for another paper, but the author suggests the reader to study Earthship Biotecture, which is a great example of sustainable transition ideology.

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[95] Reynolds, Michael. 1990. *Earthship: How to Build Your Own, Volume 1*. Taos, NM: Solar Survival Press, 24.
[96] Unruh, Gregory C. 2002. “Escaping Carbon Lock-In.” *Energy Policy* 30: 318.
[97] Ibid, 324.

7.1 Further Study - Perspectivation

'Material passports' is becoming a key to ensuring that future generations can make informed design decisions; and, seeing each building as material bank, that can be mined, also makes for an inherent culture of reuse.

An integrated ventilation panel in the top of the DSF creates the top of the Super-structure and could be imagined all along the top the full length of the wall. In turn, the bottom ventilation panel act as the in-take and ideally self-regulate by closing and opening, depending on temperatures in the air cavity; air in cavity will naturally rise due to the chimney effect and the thermal flow, since warm air rises. Additionally, if photovoltaic panels are applied on top of bottle-glass wall, then perhaps the temperature will increase even more, and the passively-ventilated solar panel will gain in effect when kept cool. For such a system to perform at its most optimal, sensors must be placed throughout and automatically move the mechanical parts in the top and bottom ventilation panels. Additionally, ventilation holes would have to be created in the façade, to move pre-warmed in take air into living space – which is a dilemma this thesis did not cover.

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Glossary

Desiccant	A drying agent.
Embodied energy	Energy used from process of producing a material.
Energy Frame	The amount of energy a building uses, measured in kW/m^2.
Performance gap	The gap between estimated energy savings and actual savings.
Resilience	"*The capacity or ability to absorb disturbance and to retain the same structure function and feedbacks*." (Brian Walker. Stockholm Resilience Center TV)

Appendices

Appendix A: LCA Analysis in LCAbyg

Appendix B: DTU lecture slide about interior insulation

Appendix C: Thermography of prototypes

Appendix D: Cost analysis

Appendix E: 2nd semester essay: Upcycling of Glass. Making old bottles and jars into different ´glass-bricks´

Untitled

Miljø profil

LCAbyg 3.2.0.4

Miljøvej 99, 9999 Fremtidsbyen

SBi

Bygningstype: Bolig-parcelhus

Opvarmet etageareal: 150 m^2

Samlet brutto etageareal: 150 m^2

Start år: 2015

Betragtningsperiode: 100 år

Energiforbrug - el: 2.6 kWh/m^2 år

Energiforbrug - varme: 37.1 kWh/m^2 år

Drift varmeforsyning: Fjernvarme

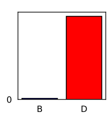
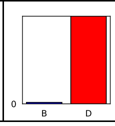
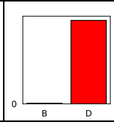
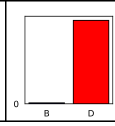
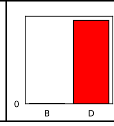
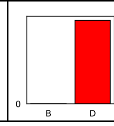
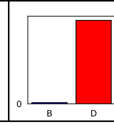
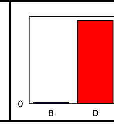
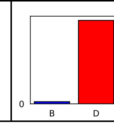
Drift scenarie: 2015 data

Nærmere beskrivelse af bygningen: Huset er et typisk nyt 1-plans længehus. Huset opfylder lavenergiklasse 2015 i BR 2010.

SAMLET RESULTAT - BYGNINGSDELE OG DRIFT

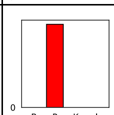
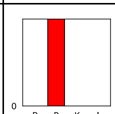
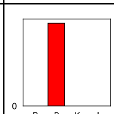
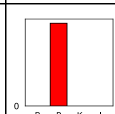
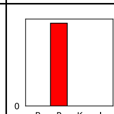
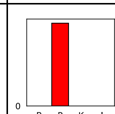
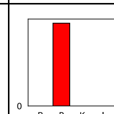
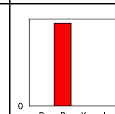
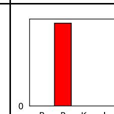
Fordelt på 9 indikatorer* samt individuelle indikatorresultater fordelt på henholdsvis bygningsdele(B) og drift(D)

NB. De individuelle indikatorresultater kan ikke sammenlignes på tværs, da hver indikator har forskellig enhed.

	GWP	ODP	POCP	AP	EP	ADPe	ADPf	PEtot	Sek
Enhed	kg CO_2 eq/m^2 år	kg R11 eq/m^2 år	kg Ethene eq/m^2 år	kg SO_2 eq/m^2 år	kg PO_4^{-3} eq/m^2 år	kg Sb eq/m^2 år	MJ/m^2 år	kWh/m^2 år	kWh/m^2 år
Drift(D)	7,860	0,139 x 10^{-9}	0,004	0,018	0,005	0,099 x 10^{-3}	78,743	30,355	0,285
Bygningsdele(B)	0,097	0,002 x 10^{-9}	0,025 x 10^{-3}	0,203 x 10^{-3}	0,027 x 10^{-3}	0,200 x 10^{-6}	1,133	0,351	0,007
Sum	7,957	0,141 x 10^{-9}	0,004	0,019	0,005	0,099 x 10^{-3}	79,876	30,706	0,293
									

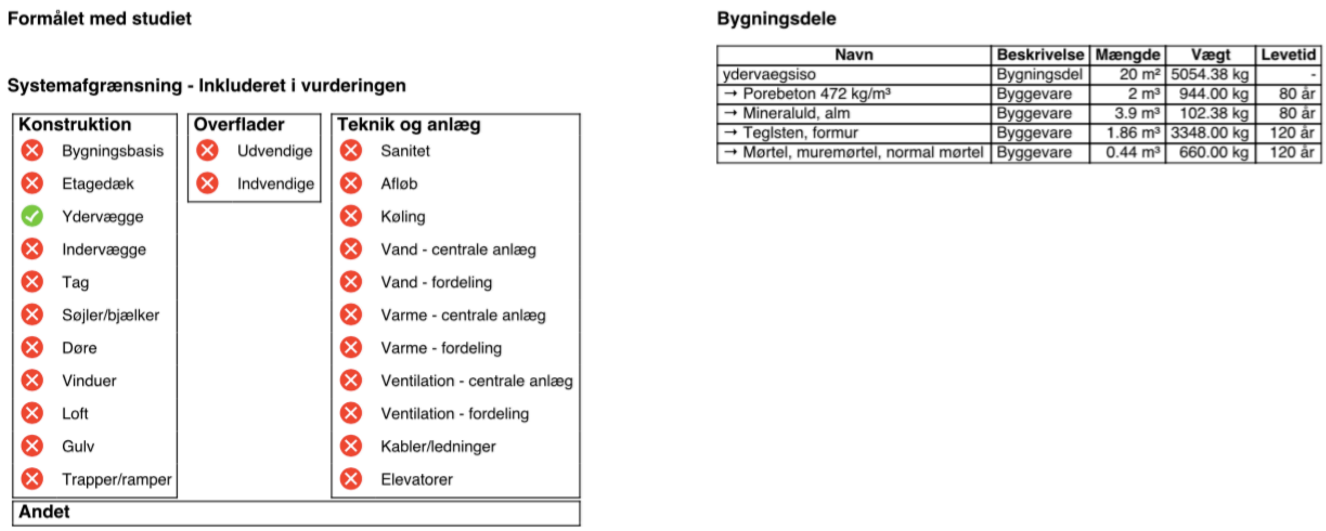
HOVEDRESULTATER - BYGNINGSDELE

Fordelt på 9 indikatorer* samt individuelle indikatorresultater fordelt på følgende hovedkategorier:

	GWP	ODP	POCP	AP	EP	ADPe	ADPf	PEtot	Sek
Enhed	kg CO_2 eq/m^2 år	kg R11 eq/m^2 år	kg Ethene eq/m^2 år	kg SO_2 eq/m^2 år	kg PO_4^{-3} eq/m^2 år	kg Sb eq/m^2 år	MJ/m^2 år	kWh/m^2 år	kWh/m^2 år
Bygningsbasis (B)	0	0	0	0	0	0	0	0	0
Primære bygningsdele (P)	0,097	0,002 x 10^{-9}	0,025 x 10^{-3}	0,203 x 10^{-3}	0,027 x 10^{-3}	0,200 x 10^{-6}	1,133	0,351	0,007
Komplettering (K)	0	0	0	0	0	0	0	0	0
Installationer (I)	0	0	0	0	0	0	0	0	0
Fordelt på andel af bygningsdelenes samlede resultat									

*De 9 indikatorer

- GWP: Global Warming Potential – Global opvarmning
- ODP: Ozone Depletion Potential – Ozonnedbrydning
- POPC: Photochemical Ozone Creation Potential – Fotokemisk Ozondannelse
- AP: Acidification Potential – Forsuring
- EP: Eutrophication Potential – Næringssaltbelastning
- ADPe: Abiotic Depletion Potential, Elements – Abiotisk ressourceudtømning, grundstoffer
- ADPf: Abiotic Depletion Potential, Fossil fuel – Abitoisk ressourceutømning, fossil
- PEtot: Primary Energy – Primærenergi, samlet tal for primærenergi fossil og vedvarende
- Sek: Secondary Energy – Sekundære brændsler, samlet tal for sekundærenergi fossil og vedvarende



Formålet med studiet

Systemafgrænsning - Inkluderet i vurderingen

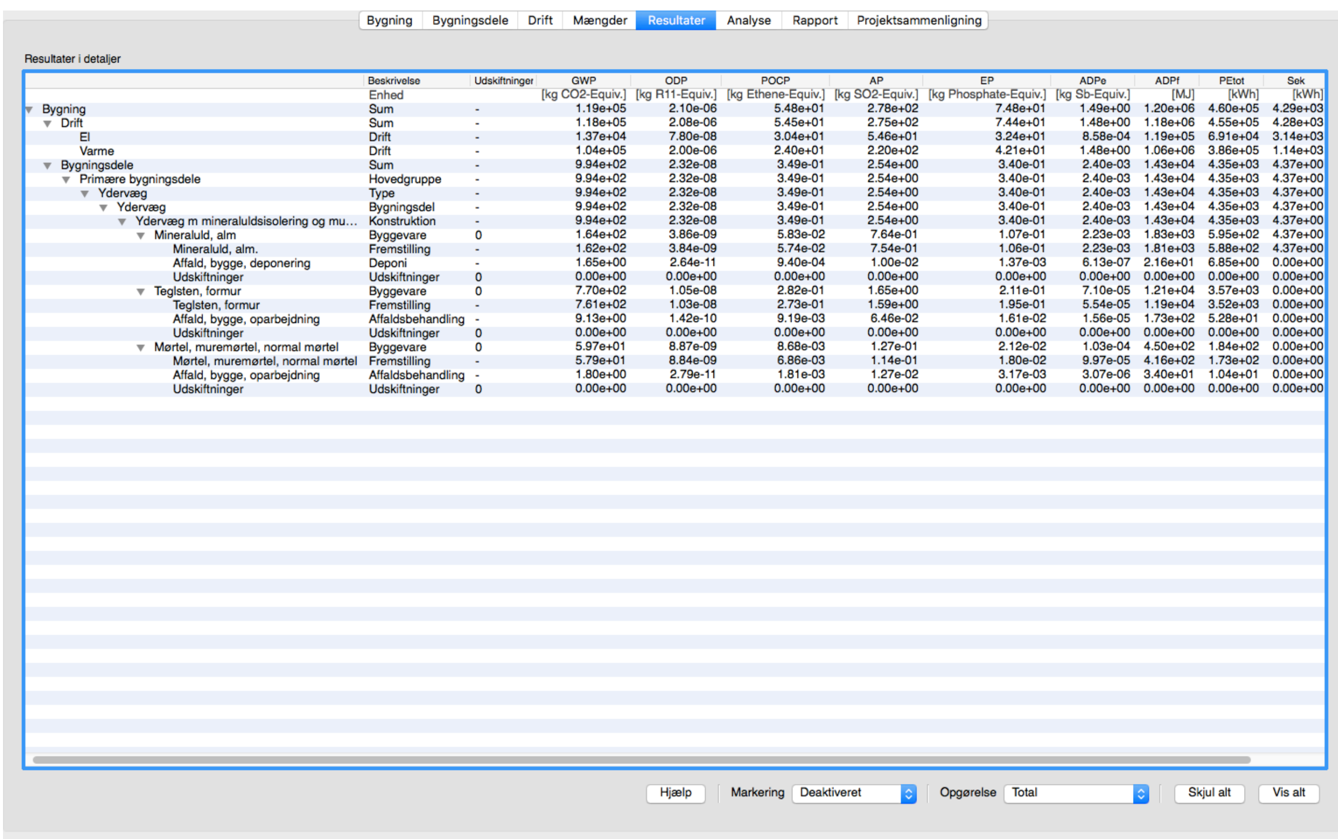
Konstruktion	Overflader	Teknik og anlæg
✗ Bygningsbasis	✗ Udvendige	✗ Sanitet
✗ Etagedæk	✗ Indvendige	✗ Afløb
✓ Ydervægge		✗ Køling
✗ Indervægge		✗ Vand - centrale anlæg
✗ Tag		✗ Vand - fordeling
✗ Søjler/bjælker		✗ Varme - centrale anlæg
✗ Døre		✗ Varme - fordeling
✗ Vinduer		✗ Ventilation - centrale anlæg
✗ Loft		✗ Ventilation - fordeling
✗ Gulv		✗ Kabler/ledninger
✗ Trapper/ramper		✗ Elevatorer

Andet

Bygningsdele

Navn	Beskrivelse	Mængde	Vægt	Levetid
ydervaegsiso	Bygningsdel	20 m²	5054.38 kg	-
→ Porebeton 472 kg/m³	Byggevare	2 m³	944.00 kg	80 år
→ Mineraluld, alm	Byggevare	3.9 m³	102.38 kg	80 år
→ Teglsten, formur	Byggevare	1.86 m³	3348.00 kg	120 år
→ Mørtel, muremørtel, normal mørtel	Byggevare	0.44 m³	660.00 kg	120 år

Figure A.1: An example of 20 m^2 of typical brick insulation with mineral wool.



Bygning | Bygningsdele | Drift | Mængder | Resultater | Analyse | Rapport | Projektsammenligning

Resultater i detaljer

	Beskrivelse	Udskiftninger	GWP	ODP	POCP	AP	EP	ADPe	ADPf	PEtot	Sek
	Enhed		[kg CO2-Equiv.]	[kg R11-Equiv.]	[kg Ethene-Equiv.]	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg Sb-Equiv.]	[MJ]	[kWh]	[kWh]
▼ Bygning	Sum	-	1.19e+05	2.10e-06	5.48e+01	2.78e+02	7.48e+01	1.49e+00	1.20e+06	4.60e+05	4.29e+03
▼ Drift	Sum	-	1.18e+05	2.08e-06	5.45e+01	2.75e+02	7.44e+01	1.48e+00	1.18e+06	4.55e+05	4.28e+03
El	Drift	-	1.37e+04	7.80e-08	3.04e+01	5.46e+01	3.24e+01	8.58e-04	1.19e+05	6.91e+04	3.14e+03
Varme	Drift	-	1.04e+05	2.00e-06	2.40e+01	2.20e+02	4.21e+01	1.48e+00	1.06e+06	3.86e+05	1.14e+03
▼ Bygningsdele	Sum	-	9.94e+02	2.32e-08	3.49e-01	2.54e+00	3.40e-01	2.40e-03	1.43e+04	4.35e+03	4.37e+00
▼ Primære bygningsdele	Hovedgruppe	-	9.94e+02	2.32e-08	3.49e-01	2.54e+00	3.40e-01	2.40e-03	1.43e+04	4.35e+03	4.37e+00
▼ Ydervæg	Type	-	9.94e+02	2.32e-08	3.49e-01	2.54e+00	3.40e-01	2.40e-03	1.43e+04	4.35e+03	4.37e+00
▼ Ydervæg	Bygningsdel	-	9.94e+02	2.32e-08	3.49e-01	2.54e+00	3.40e-01	2.40e-03	1.43e+04	4.35e+03	4.37e+00
▼ Ydervæg m mineraluldsisolering og mu…	Konstruktion	-	9.94e+02	2.32e-08	3.49e-01	2.54e+00	3.40e-01	2.40e-03	1.43e+04	4.35e+03	4.37e+00
▼ Mineraluld, alm	Byggevare	0	1.64e+02	3.86e-09	5.83e-02	7.64e-01	1.07e-01	2.23e-03	1.83e+03	5.95e+02	4.37e+00
Mineraluld, alm.	Fremstilling	-	1.62e+02	3.84e-09	5.74e-02	7.54e-01	1.06e-01	2.23e-03	1.81e+03	5.88e+02	4.37e+00
Affald, bygge, deponering	Deponi	-	1.65e+00	2.64e-11	9.40e-04	1.00e-02	1.37e-03	6.13e-07	2.16e+01	6.85e+00	0.00e+00
Udskiftninger	Udskiftninger	0	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
▼ Teglsten, formur	Byggevare	0	7.70e+02	1.05e-08	2.82e-01	1.65e+00	2.11e-01	7.10e-05	1.21e+04	3.57e+03	0.00e+00
Teglsten, formur	Fremstilling	-	7.61e+02	1.03e-08	2.73e-01	1.59e+00	1.95e-01	5.54e-05	1.19e+04	3.52e+03	0.00e+00
Affald, bygge, oparbejdning	Affaldsbehandling	-	9.13e+00	1.42e-10	9.19e-03	6.46e-02	1.61e-02	1.56e-05	1.73e+02	5.28e+01	0.00e+00
Udskiftninger	Udskiftninger	0	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
▼ Mørtel, muremørtel, normal mørtel	Byggevare	0	5.97e+01	8.87e-09	8.68e-03	1.27e-01	2.12e-02	1.03e-04	4.50e+02	1.84e+02	0.00e+00
Mørtel, muremørtel, normal mørtel	Fremstilling	-	5.79e+01	8.84e-09	6.86e-03	1.14e-01	1.80e-02	9.97e-05	4.16e+02	1.73e+02	0.00e+00
Affald, bygge, oparbejdning	Affaldsbehandling	-	1.80e+00	2.79e-11	1.81e-03	1.27e-02	3.17e-03	3.07e-06	3.40e+01	1.04e+01	0.00e+00
Udskiftninger	Udskiftninger	0	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00

Figure A.2: An overview of the different emissions from this solution.

APPENDIX B: DTU LECTURE SLIDE ABOUT INTERIOR INSULATION

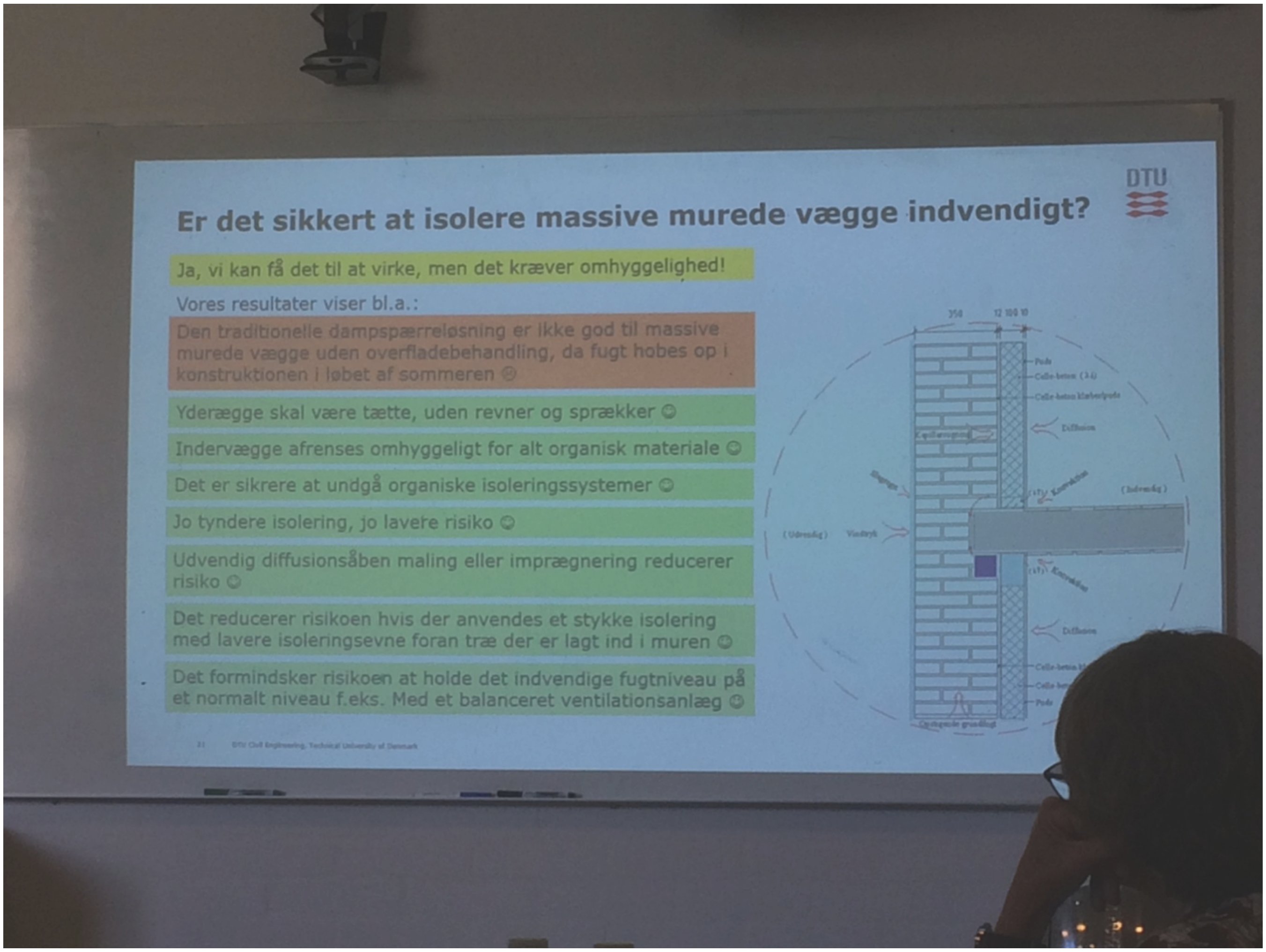


Figure B.1: Picture from DTU Symposium that concludes that it is possible to successfully insulate solid brick walls from the inside, but it difficult and takes great care.

APPENDIX C: THERMOGRAPHY OF PROTOTYPES

Prototypes are placed in a plastic container (Figure C.1) with ice to represent real conditions on a winter day; thermal test is done indoors, temperature ca. 24 °C, over a period of 3 hours (Figure C.2).

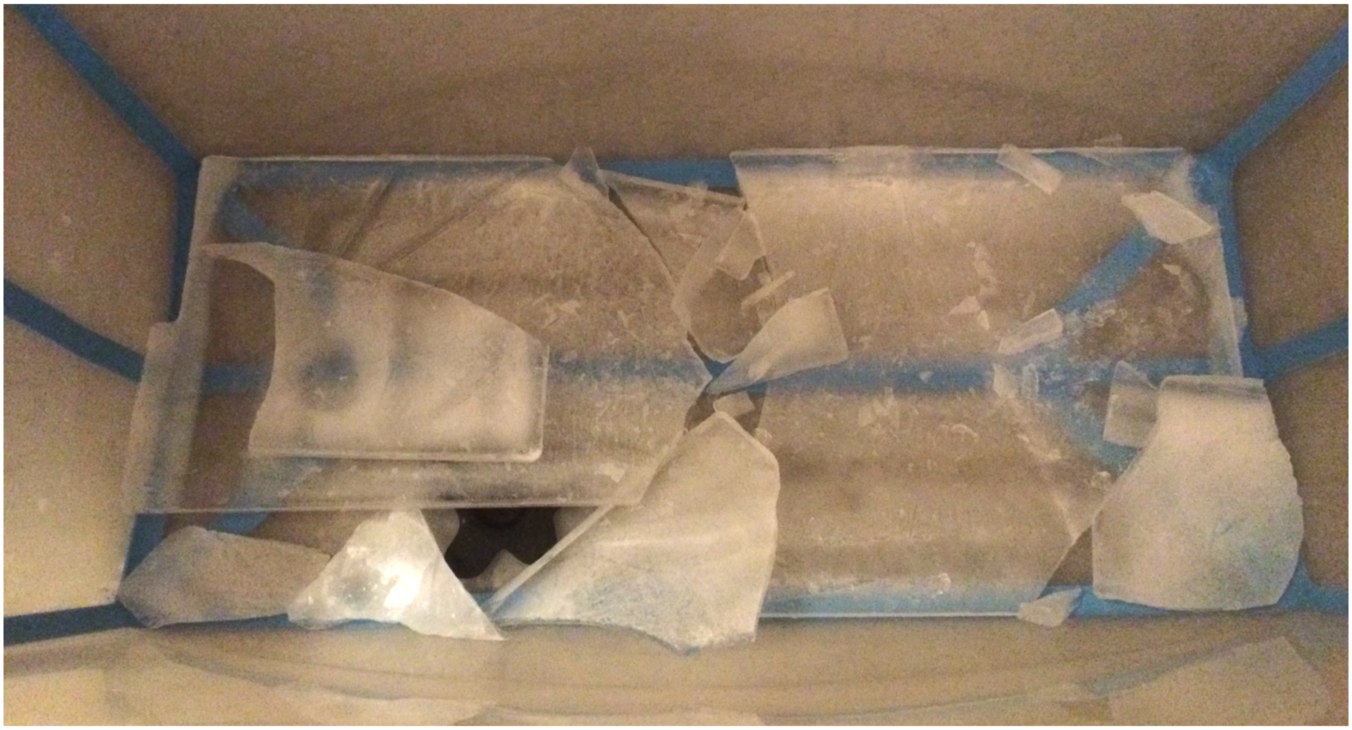


Figure C.1: A flat layer of ice does not cover completely the surface of the container but that is of little significance since the prototypes are on each ice sheet and gets consistent cooling.

Figure C.2: Prototypes are placed in container with ice cubes around them to reduce thermal influence from indoor environment.

At 0 hours, thermal pictures are taken to establish a baseline for vodka shooters (Figure C.3) and creamer bottle walls (Figure C.4).

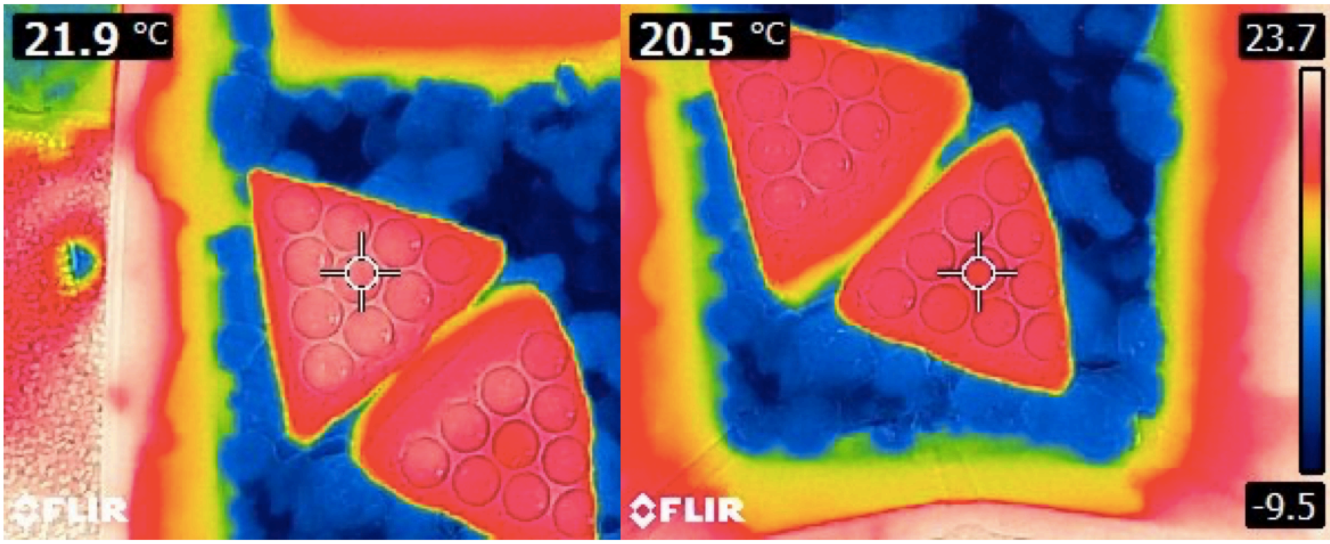


Figure C.3: At beginning, temperatures on the two different prototypes are similar.

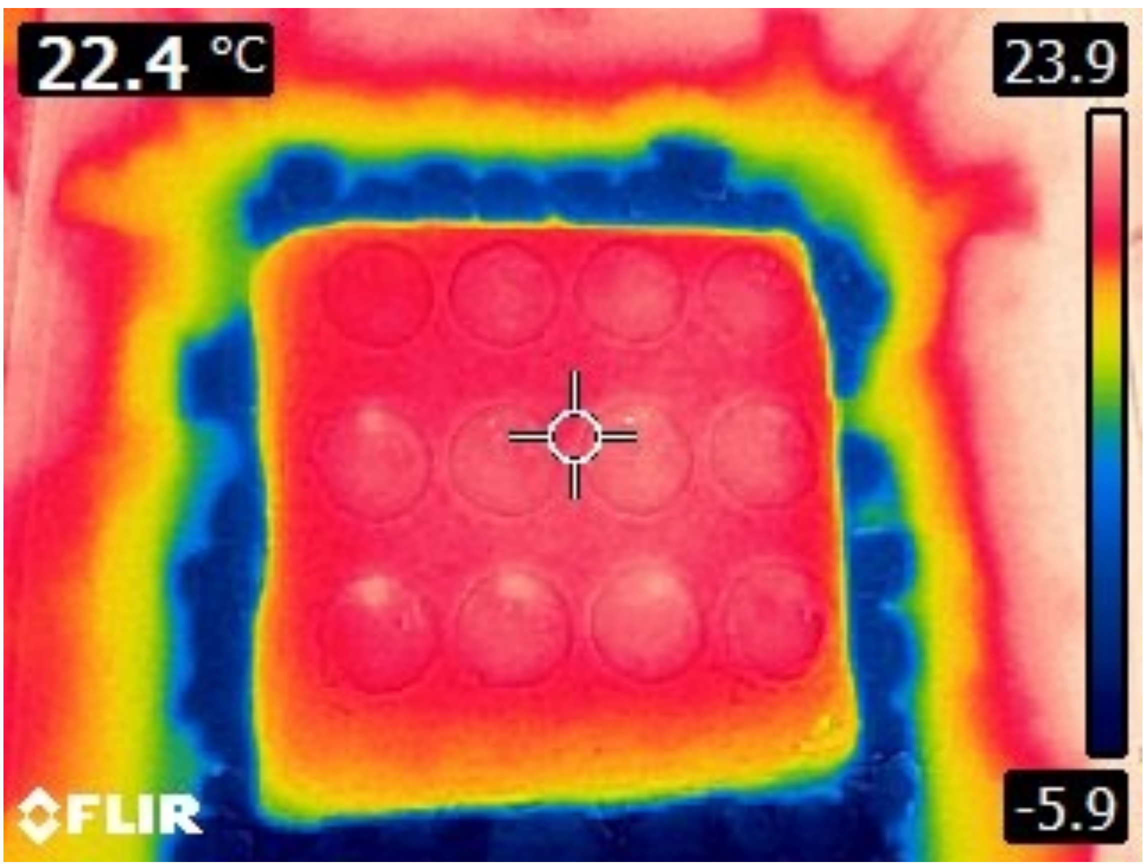


Figure C.4: Creamer bottle wall prototype at zero hours.

After one hour, thermal pictures are taken of vodka shooters (Figure C.5) and creamer bottle walls (Figure C.6).

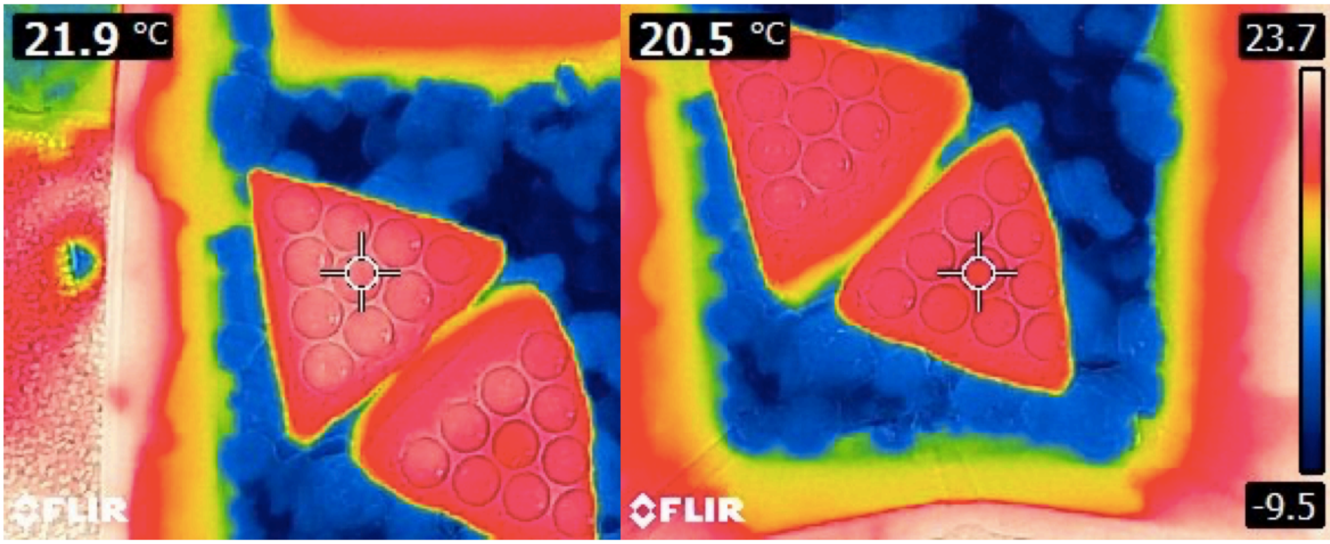


Figure C.5: At one hour, temperature has decreased slightly.

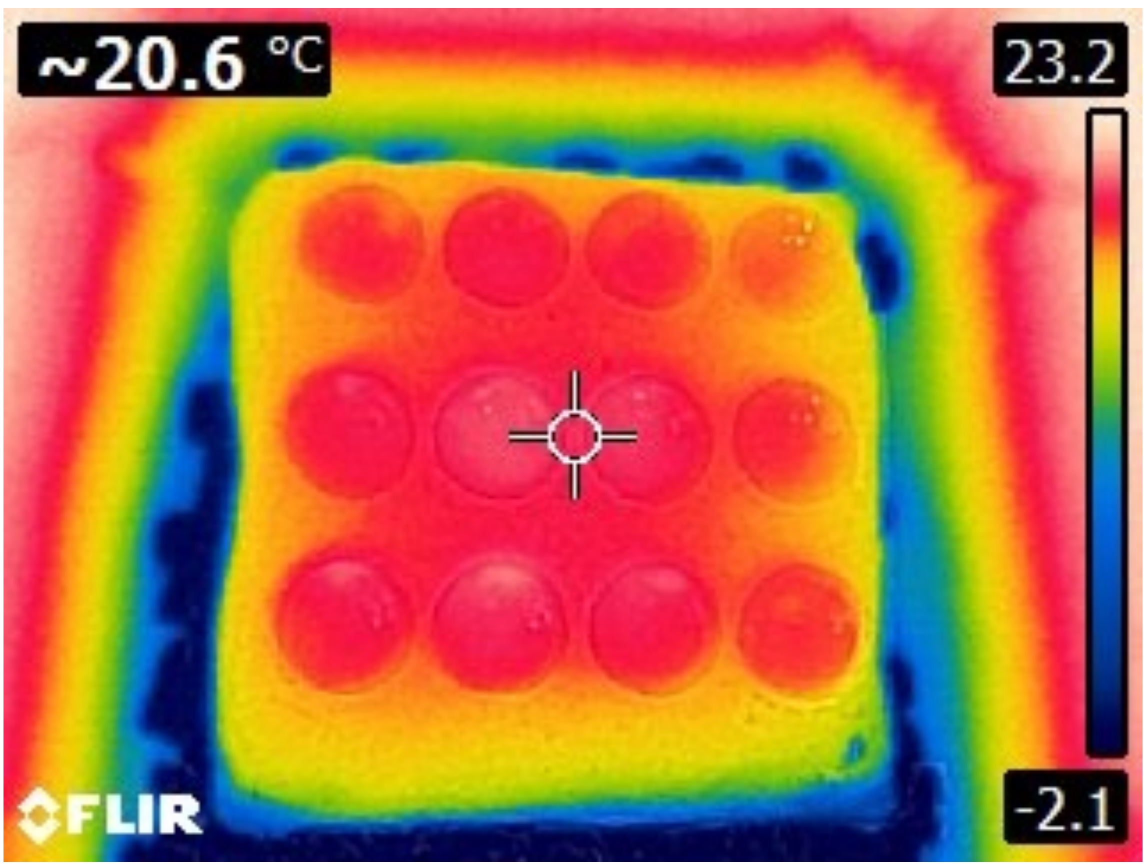


Figure C.6: At one hour, temperature has decrease by almost 2 degrees.

After two hours, thermal pictures are taken of vodka shooters (Figure C.7) and creamer bottle walls (Figure C.8).

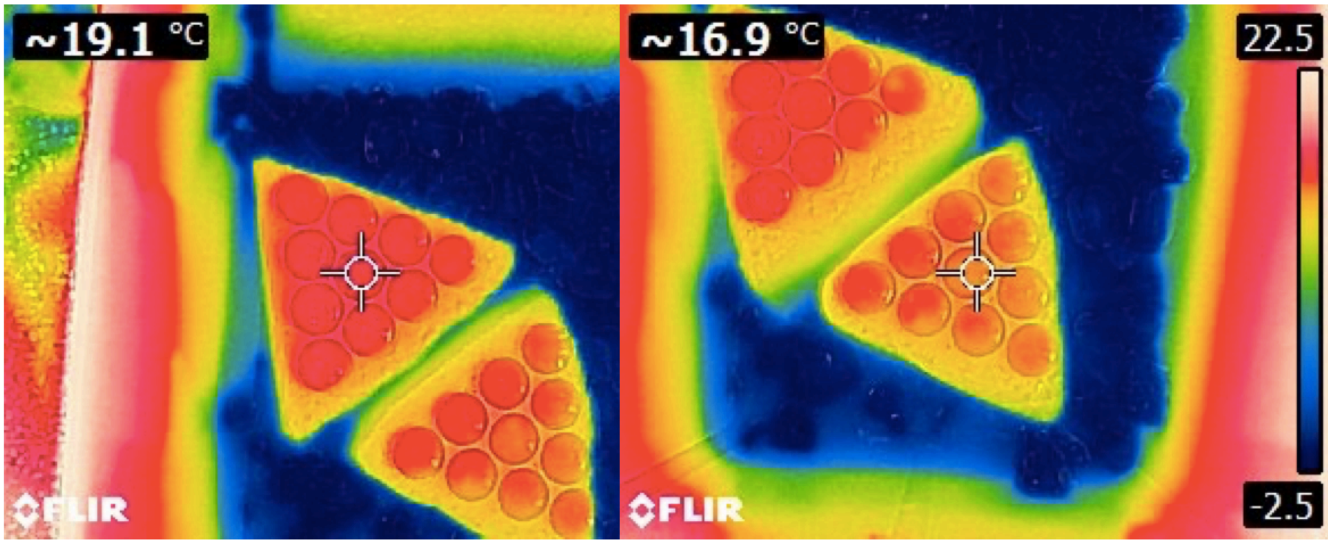


Figure C.7: At two hours, temperature has decreased even more.

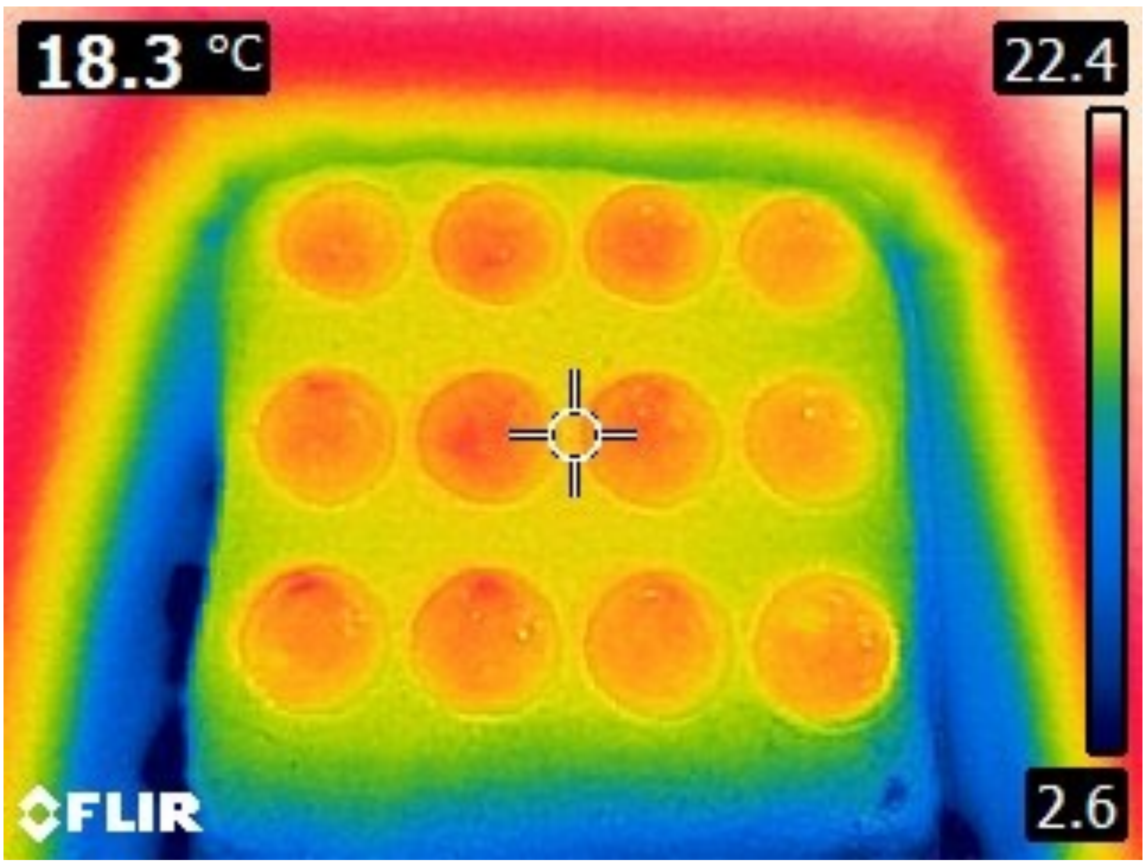


Figure C.8: At two hours, temperature has decrease even more.

After three hours, thermal pictures are taken of vodka shooters (Figure C.9) and creamer bottle walls (Figure C.10).

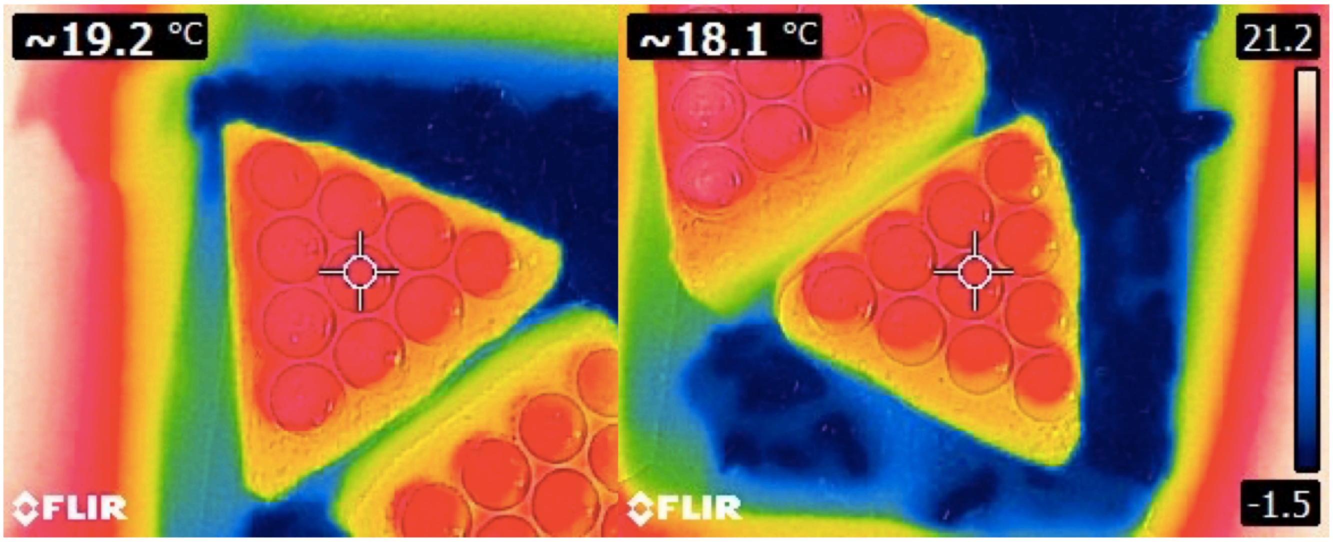


Figure C.9: At three hours, thermal equilibrium has been reached and cooling has stopped.

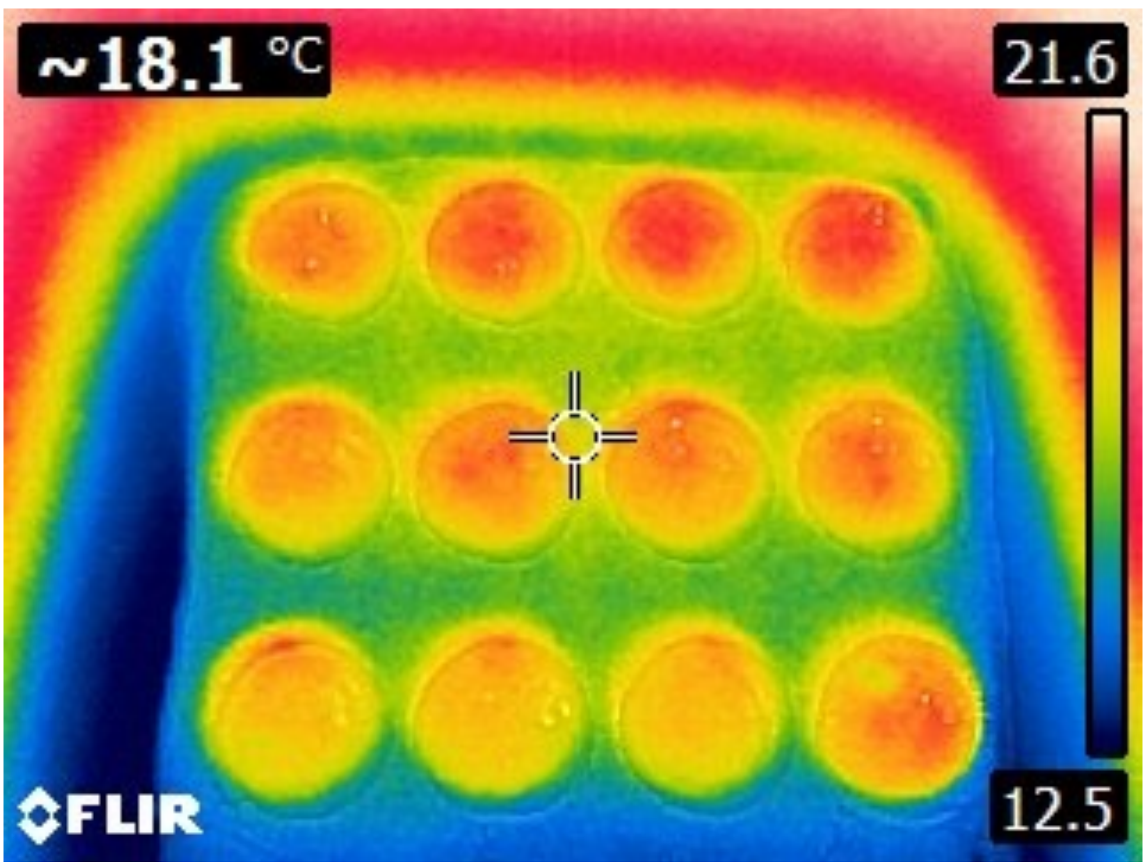


Figure C.10: At three hours, temperature has decrease a bit more.

Appendix D: Cost analysis

Design Strategy for creating a ***modular double-skin facade system*** *from used glass containers*

Contributions to problem area:

1. Indoor climate improvement *(no BTM from cold exterior walls)*
2. Decrease heating and cooling demand in buildings *(save $ maybe)*
3. Natural ventilation gives pre-warmed fresh air *(warm fresh air)*
    - filter (NOx, CO, O_3) upgrade due to particle matter *(clean air)*
    - BIPV upgrade – air cavity passively cools PV *(save $ maybe)*
4. View local waste as ressource – change of mindset *(less transport)*

Cost Analysis = Yearly savings * lifetime/investment > 1,33

- Glass-bottle wall m^2 price (installed) is estimated at 500 kr/m^2 for a suggested a surface of ca. 100 m^2

3.000 kr. * 30 years /50.000 kr. = <u>1,8</u> > 1,33
With such a cost estimate, design solution is viable

Figure D.1: Cost analysis formula has three variables which must be greater than 1,33 to be considered a viable solution

Appendix E: 2nd semester essay: Upcycling of Glass. Making old bottles and jars into different ´glass-bricks´

Upcycling of Glass

making old bottles and jars into different 'glass-bricks'

2. Semester research project in Sustainability Challenges

By Mikkel Gavin Christensen
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Master's Programme in Sustainable Design
Copenhagen
June 7th, 2017

Abstract

The recycling of glass in Denmark lives up to the demands imposed by the EU, but here are many opportunities for Denmark (and the World at large) to increase the sustainability for glass recycling by (1) better consumer recycling culture, (2) gathering glass bottles more systematically and efficiently, (3) sorting and organizing glass bottles better and (4) enhancing and facilitating and engaging ANT to 'close-the-loop', creating circular and symbiotic socio-economonic relationships.

Yet, this paper investigates the possibility of, instead of donating glass in bins, one organized used container glass such as wine bottles and jars into 'bottle bricks' which in turn would make 'bottle walls.'

Parallel with European rules for recycling, the Danish State has goals for a CO_2 decrease in the built environment in Denmark which accounts for a large amount of national emissions — the author argues that bottle walls, in certain situations, can serve as 'buffer zones' (or sun room) that helps moderate the temperature, thereby enhancing indoor climate, and lowering heating and cooling expenses (and lower emissions) and proposes 3 different low-tech DIY methods to upcycle glass: (1) an insulated wine bottle-brick, (2) an un-insulated wine bottle-brick and (3) an uninsulated jar-brick, which all could be easily assembled by a consumer, thus making them into empowered producers; this upcycling of glass lowers CO_2 emission decreased transport of glass — in recycling process much which is broken and becomes shards.

Thus the author argues that it is sustainable to upcycle wine bottles and jars into bottle walls, where the lifetime of the glass is increased, since it is permanently incorporated into a built structure, and the author argues that with a potential lifetime of 30 years, a bottle wall (or hexagonal window) will have reduced CO_2 many folds.

Besides creating less waste, the opportunity to create a building components out of easily found materials, can empower individuals who are firstly, keen to construction and secondly, want to save money on their construction project. By collecting glass and making one's own building component, it can increase sense of ownership which could result in increased quality of life and happiness in the individual as well as the community.

<u>Key words:</u> building components, CO_2 decreasing activities, consumer to producer, Earthship Biotecture, empowerment theory, experimental window, glass bricks, low-tech construction, practice theory, recycling, sandwars, upcycling

Foreword

This research paper is the final result of the 2. semester project and was done in the time from the 1st of february to the 7th of june, 2017, with *u-wert.net* calculations attached in Appendices.

Preface

The topic of this research paper is largely inspired by the work of architect Michael Reynolds and his Earthship Biotecture principles and design guidelines, which includes building with glass bottles and other upcycled materials; originated in Taos, New Mexico in the 1970s, Earthship Biotecture has been teaching their methods for years in their Academy and have been working and volunteering abroad and are currently building an 'eco village' on an uninhabited island in Indonesia, where bottle walls are primary part of outer shell of structure. (see front page image and you may notice that some 'bricks' are plastic bottles — which can also be used)

Table of Content

Glossary

U-Value: measure of how well a component insulates, called thermal resistance, and is measured in W/m^2K.
Linear thermal transmittance: measured in phi (Ψ), as the name suggests, this is the linear thermal bridge.

1. Introduction

Glass is a large part of our everyday lives and recycling is regulated by the EU; Denmark lives up to EU recycle demands, yet many Danes do not take the time to properly recycle, probably because they don't realize the many potentialities in recycling glass along with need for natural resources, which need to go back into the system, and not into the landfill.

There are three types of glass: Soda lime glass (used for bottles and jars which this research project deals with), Crystal glass and Borosilicate glass; the composition of elements of Sode lime glass is:

> "typically produced from 70–75% quartz sand (SiO_2 , particle size 0.1–0.4 mm), 12–16 % soda (Na_2O, Na_2CO_3), 10–15 % lime (CaO, $CaCO_3$) and traces of other materials."
> (Christensen 2010)

Furthermore, is it vital that we recycle glass (Sandwars) since coastal sand mining can have unforeseen, and potentially destabilizing economic, social and environmental effects (UNEP 2014) — the recycling of glass in Denmark does live up to EU standards and has done so for a long time (EC 2001), yet there are many areas where a larger degree of sustainability can be achieved, such as (1) better consumer recycling-culture, (2) gathering glass bottles more systematically and efficiently, (3) sorting and organizing glass bottles better and (4) enhancing and facilitating and engaging ANT to 'close-the-loop', creating circular and symbiotic socio-economonic relationships, especially in plastic since:

> "*Proper recycling of plastics is a bigger problem than glass, though they are interconnected and there is no incentive to separate low-quality plastics from other types of waste."* (Michael Elgaard 2017, pers. comm. 20 april)

Yet, the author of this paper decided to investigate the possibility of, instead of donating glass in bins, one organized used glass to make 3 different 'glass bricks': (1) insulated wine bottle-bricks (2) un-insulated wine bottle-bricks, and (3) un-insulated jar-bricks for exterior and/or interior walls; this research paper argues that, by adding a wall of used glass at strategic area of a structure, one could possibly save money on heating and cooling one's house due to the creation of a 'buffer zone' (or green house) which coule decrease building emissions and empower indiviuals and communities — decreasing emissions from the built environment is one of the main concerns in lowering CO_2 emissions, must which come from heating and cooling.

Upcycling glass-waste (waste meaning empty containers) creates a permanent use (up to 30 years for windows) for the many different types of glass containers available, and can be used in even more different function; it has been argued that jars and bottles were made to be jars and bottles — and taking them out of their system is not sustainable.

This author argues that by incorporating the extended life-time of the glass, the decrease in transport, and the potential increase in energy efficiency, it is a trade-off that is well worth the trouble to further invest time and resources into; the sustainable dimensions of recycling are complex and bound by subjective constraints and many variables, which can be hard to understand, but this is clear:

> *"CO_2 savings from recycling glass occur both at the glass plant, and all along the supply chain. Recycling glass containers minimizes waste, preserves natural resources, reduces energy use and creates jobs in the recycling industry."* (FEVE 2016)

Ultimately, any type of sustainability analysis should broaden their scope to properly realize the interconnectivity of waste materials and the inherint complexities which are only true, or partly true, within a certain context:

> "glass performs better than PET, on a unit mass basis, with reference to almost every environmental burden. But again, if the container production is taken into account, since lower quantities of PET are needed to produce a same-size container, the result is the opposite." (Savioli 2008)

1.1. Delimitation — plastics, lids, labels and pallets

Because of the many different types of materials in the glass recycling system, this essay will focus only on glass and exclude the environmental issues of lids, labels, and pallets as well as glass with deposits (can be exchanged for cash).

1.2. Problem definition

How can upcycling of glass decrease waste, save money and empower individuals and communities?

1.2.1. Research question

How is it sustainable to build green houses with used container glass and how does this upcycling in construction save energy and empower consumers?

1.3. Use practice and structure of paper

We all consume goods out of glass containers and we all therefore have this user-artifact relation, especially if glass container is old cognac bottle one has had for a year, or more. This practice of opening up a container, emptying it, and later cleaning it, means we have laid grounds for great relationship — one which should not go to waste. Building with upcycled glass container can increase ownership and create individual and community empowerment, which can lay the path for systemic changes in consumer use practices, making them into practicing producers.

Section 2 explains the methods used constructing glass bottles out of wine bottles and jars, with a low-tech thermal experiment to test one of the solution.

Section 3 creates an overview of the problem analysis with the flows of glass containers in Denmark and the EU along with the socio-technical market relationships and the pervasive cultural habits consumers have in Denmark, that can be altered both tacitly by enabling recycling of glass at regular bins and explicitly by further educating the public and organize events.

Section 4 presents how the three concept developments, inspired by Earthship Biotecture's bottle walls, can help save on the emission of the existing building stock and empower individuals and communities.

Figure 1: *Overview of regional flows — the keen reader might ask: how and where would upcycling fit into this circular economy illustration.*

Section 5 reviews the results of the intervention with outcome, modification and analysis and reflection.

Section 6 discusses the lessons learned and the individual empowerment factor in creating and building with customized components along with the economy of this upcycling process.

Section 7 concludes that upcycling container glass and bottles is a sustainable action that lowers CO_2 emissions by decreasing transport and lowering energy use of certain structures along with potentially leading to individual and community empowerment.

2. Methods (intro to the three concepts)

Apart from searching for academic material, online and in hard copy, I have been inspired by Earthship Biotecture and their long history of recycling materials which include wine bottles; I experimented with a combination of different jars and wine bottles to create 3 different solutions to make a glass brick which illuminate the many possibilities of each.

2.1. Construction of Insulated wine bottle-brick

The construction of the insulated wine bottle-brick (see Fig. 2) was a process which included material gathered in the public, as well as my own glass waste. I purchased a glass cutter to score the wine bottles with, placed scored glass in cold and hot water to separate them, and gathered the cut pieces together in alternative fashion with some silicone to adhere and rubber (see Fig. 3) to help secure a proper seal the cut pieces of wine bottle with.

2.1.1. Collection and cleaning of wine bottles.

When actively aware of the amount of glass one uses daily, one can very quickly gather a wide array of different wine bottles; therefore, it is important to realize the size and color desired, and then systematically gather *that* glass, that would work well together, depending on availability, distance, quantity, size and color — once collected, the wine bottles are cleaned with warm water and soap to get stickers off and prepare for scoring.

2.1.2. Scoring wine bottles

A bottle was placed in a wooden toolbox (see Fig. 4) and was scored using a glass cutter; scoring the glass on a straight line was done, by resting glass cutter on tool box and free-handing as I turned the bottle.

After bottles were scored, I placed wine bottles in cold water and then boiled water and poured gently over the scored line, thus stressing the glass and fracturing it — in some cases very well along the scored line and in other cases not at all.

Cutting the bottles precisely proved very difficult since I am novice and perhaps impatient with the method

Figure 2: *Three air compartments separated with rubber seal and silicone arguably makes this wine botle-brick insulated.*

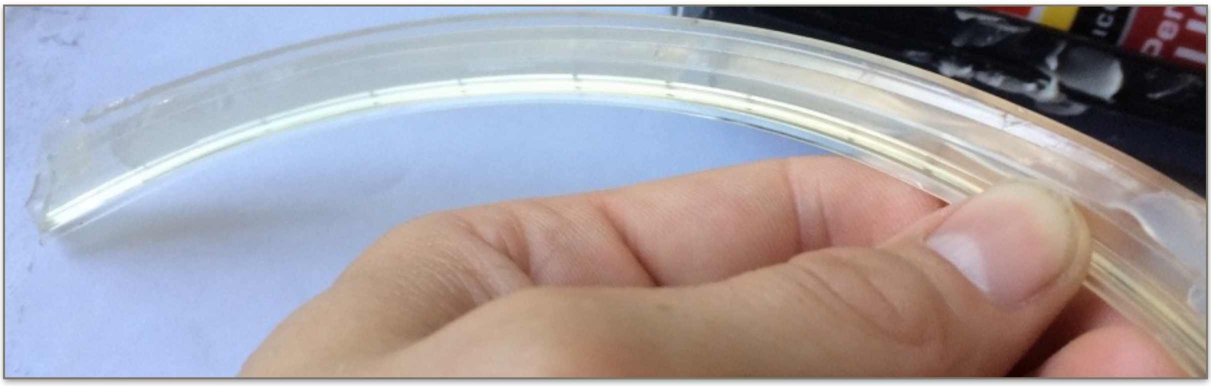


Figure 3: *Rubber seal from an old window is used to make tight connection.*

of alternating cold and hot water; alternatively, one can dry cut the bottles with a saw, but this makes a lot of dust and did not seem possible due to need for machine and blade etc.

2.1.3. Assembling insulated glass brick

By cutting bottles at the base of the neck, it made it possible to attach the two cut tops and glue those together, 'inside' the two remaining bottom pieces, thus resulting in three separate air spaces in the glass brick — I dare to call this insulated since the three independent compartments would result in a cold exterior side and a warm interior side with a moderating air compartment in the middle.

Figure 4: *Bottle is placed in a toolbox which acts as a jig — coincedentally this height proved to be ideal due to* the curve of the neck of the bottle.

2.1.4. Silicone and rubber seals

To 'glue' the glass together I used silicone (approximated as 2 mm layer in the u-wert.net calculations) and a rubber sash from an old window frame which worked well since most window glass i 4 mm thich, so it fit snugly around the wine bottle cut edge.

2.1.5. Calculating U-value of insulated glass brick

I contacted Technological Institute to inquire on a price to do a U-value test for this experimental wine bottle-brick hexagonal window I was creating, and was told that it:*"would make no sense to* *test,"* (Bent Lund Nielsen 2017, pers. comm. 23 february) because that the total amount of glass involved in this hypothetical window would create a big linear loss and therefore not reach the theoretical result I had calculated using the webpage u-wert.net— this is due to the amount of glass which, despite the insulating air gaps, would dominate the building component and would be affected by solar heat gain and more.

Because of this news, I decided to try to test the insulated wine bottle-brick brick myself, by using a thermographic camera I was able to borrow.

2.1.6. Thermographic Analysis

By placing the insulated glass brick (see Fig. 5) onto a surface of ice, surrounded by 5 jars full of ice to further mimic a cold exterior surface, I hoped to achieve insight to the thermal behavior of the insulated wine bottle glass brick.

Because the glass brick is standing vertical, there is likely to be a better transfer of energy — thereby less insulating — due to the increase in convection which would be less if test was done with bottle laying down.

2.1.7. Results

Theoretically the calculations made in *u-wert.net* (see Appendices) which is an online U-value calculator and more; sadly it cannot truly represent conditions in Denmark since it only has locations in Germany (but its material library has many components which are same as in Denmark) — the climatic differences between Denmark and Germany are arguably large, but marginal when considering latitudes a difference of a couple of latitudes.

Therefore, the results were inconclusive; when looking at the thermal behavior of the insulated wine bottle-brick, which is surrounded by jars with ice, one can see at the different cm marks and time, what one would expect to find: the temperature slowly decreases on the surface of the wine bottle, as the ice slowly increases temperature due to the thermal equilibrium reached by the warm air of the room.

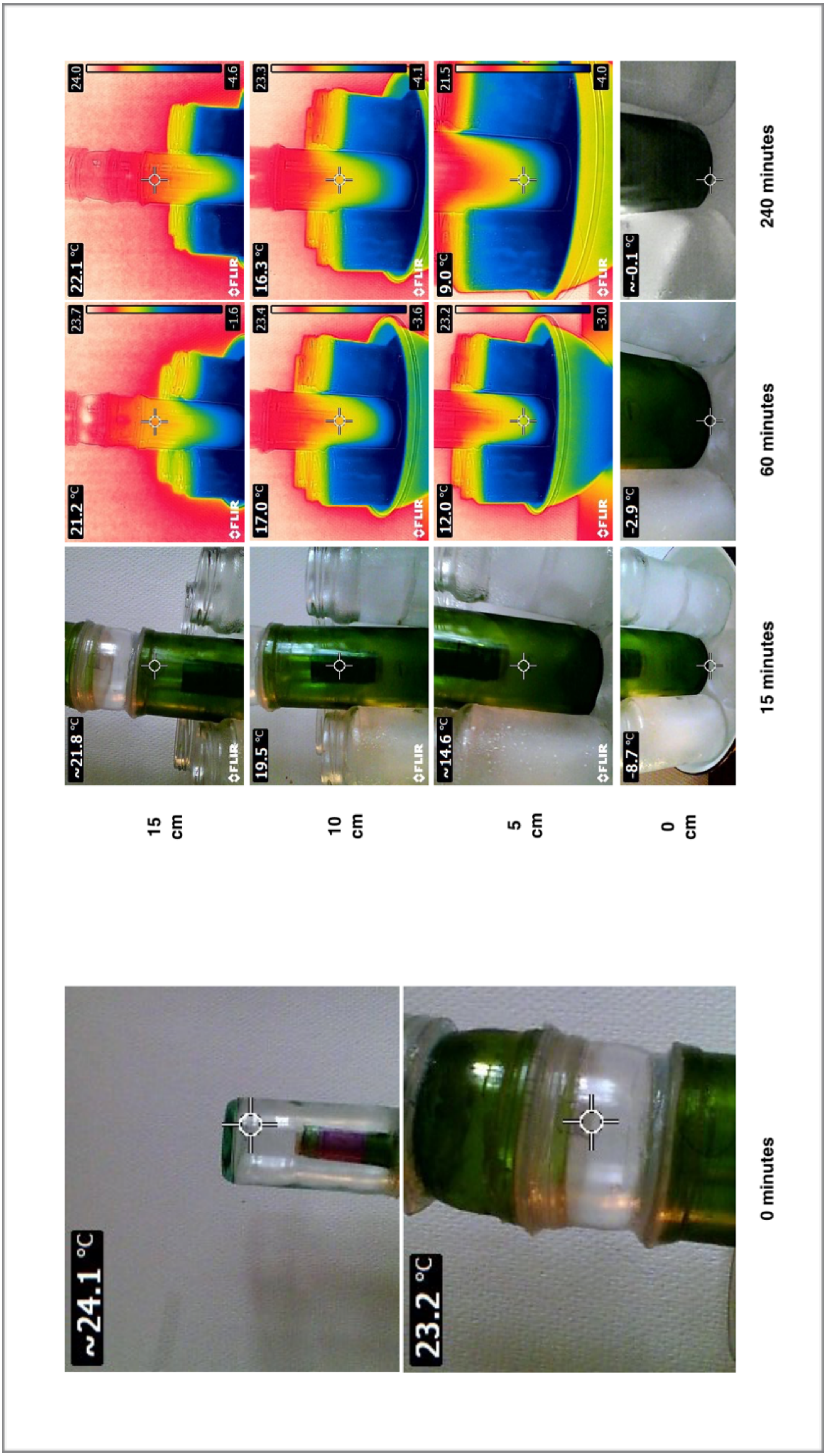


Figure 5: *Temperature rangef from 23.2 - 24.1 C° at 0 minuntes and was measure da after 15 minutes, 60 minutes and 240 minutes at 0 cm (where bottle brick meets ice), at 5 cm, at 10 cm and at 15 cm.*

2.2. Construction of un-insulated wine bottle-bricks

The un-insulated wine bottle-brick represents merely a clean wine bottle which is part of a system, where wine bottles of equal diameter are layed horizontally and glued together with silicone and offset at each opposite side and at each strata, creating a grid which does not have the extra air chamber and also lets less light through due to the nature of the configuration.

This method was chosen as an exampe since it could be considered a 'light-version' of the insulated wine bottle-brick since it does not require cutting the bottles or gather rubber sealant, thus making it easier to build for the unexperienced but empowered producing consumer.

2.2.1. Collection and cleaning of wine bottles.

The method of collecting and cleaning of wine bottles is identical as described above: it is important to realize the size and color desired, and then systematically gather *that* glass, that would work well together, depending on availability, distance, quantity, size and color — once collected, the wine bottles are cleaned with warm water and soap to get stickers off and prepare for assembly.

2.2.2. Assembling and glueing wine bottles together.

When cleaned, the wine bottles are glued together with silicone and layed in rows next to one another; as layer dries, another layer can be stacked on top of previous layer; due to the geometry, the bottles alternate as they inter-lock (see Fig. 6).

Figure 6: *These four bottles illustrates how the necks of the bottles allign together.*

2.3. Construction of Jar-bricks

Once multiple jars have been gathered (see Fig. 7) and organized it becomes easy to see which ones might fit well together — resulting in one jar acting as a 'male' and one as 'female,' and for the bricks with same diameter, one could alternate them when building a bottle wall.

2.3.1.Collection and cleaning of jars

The method of collecting and cleaning of jars is similar as described above: it is important to realize the size and color desired, and then systematically gather *that* glass, that would work well together, depending on availability, distance, quantity, size and color — once collected, the wine bottles are cleaned with warm water and soap to get stickers off and prepare for organizing and assembly (glueing).

2.3.2. Organizing

With jars I realized that the many different types of containers gathered, would make it difficult to standardize one type of jar-brick of similar diameter, to build with; I organized jars into 'male' and 'female' as many jars of similar diameter, had different tops, meaning that many fit perfectly into one another, therefore needing to organize to keep oversight of the many different possibilities.

2.3.3. Reflections

I only achieved around 30% success rate when scoring and separating wine bottles (see Fig. 8) into two pieces; next time I would cut them dry, instead of scoring

Figure 7: *These many different jar-bricks are made of 2 jars with similar diameter and tops fit nicely together; notice here that one has an exterior and interior surface, but only one air chamber.*

and then alternating between hot and cold water to make a clean cut — a clean cut is essential to a proper seal and overall thermal integrity and also ensures that no fractures and in the glass, making bottle prone to extra cracks due to the constant change of thermal expansion.

Additionally, when scored and broken, small fractures in glass edge could potentially become large cracks, as glass brick interacts with natural phenomena, making it expand, thus stressing the glass, leading to a crack which is unacceptable.

Lastly, there is a difference in the quality of the different types of bottles which one should consider when deciding which bottles to build with; champagne bottles are heavy and thick and this author did not achieve success in scoring and separating.

Figure 8: *My first efforts proved no good — the bottle on the left broke no where near the scored line.*

3. Problem analysis

3.1. Problem to existing designs and practices

Though Denmark currently lives up to EU standards, there are opportunities to further increase the recycling of glass. These opportunities are scattered over different sectors which all have a marginal effect; this makes it difficult to see potential as well as political hindrances such as the lack of glass pant.

By understanding the value and inherent opportunities for glass, the consumer can better understand the potential for upcycling and perhaps even empower themselves to upcycle glass into bricks from internal or external walls.

3.1.1. Private enterprise (visible field, invisible market forces)

The free market makes private enterprise able to choose how, where and when to have their business. Perhaps Denmark's glass industry and recycling system will be dramatically different within a decade due to factors currently unknown to us.

3.1.2. Culture of recycling in Denmark

Though Denmark is on the top of the list of glass recycling in the EU, there are still many places that can bed improved such as optimization of the gathered glass, the industrial process and to the consumer.

3.1.2.1.Optimizing gathering of glass

Many bottles break in the recycling process (loading and transportation), which is not sustainable because then new bottles will have to be made since the embodied energy in the glass is worth recycling. The consumer also has responsibility by handling bottles carefully when dropping off in the ´cube,´ though often bottles are tossed in general trash bins (see Fig. 9) or even in nature; In 2002, the average amount of gathered glass per citizen was 23,6 kg (Nejrup 2002); in 2014 total household container glass gathered equalled 111 thousand tons, an increase from 100 thousand tons the year before. (Bøjeson et. al 2016)

3.1.2.2. Optimizing the industrial cleaning of wine bottles

Many bottles break in the recycling process, due to loading, transportation and unloading, which is not sustainable because then new bottles will have to be made, since the embodied energy in the glass is worth recycling; about 50% of total sorted glass is wine- and liquor bottles and ca. 1 - 2% cannot be recycled. (BFFG, n.d.)

I contacted *Krogh Flaskegenbrug A/S*, who cleans container glass after it has been gathered; I spoke with a production manager, and I asked if there was any way to 'save' some of the bottles from becoming shards, by perhaps tuning their machines, so less would break in the process — the response was that though some glass did break in the production hall where glass is cleaned, by far the most glass gets broken long before arriving at *Krogh Flaskegenbrug A/S.*

Individual citizen — local identity and people power

Individuals are a big part of the solution, especially if they (consumers) feel like their efforts actually makes a difference in the larger recycling system. Individuals have a very important role to play.

> “In many Member States, householders are asked to separate their waste into different material types (paper, glass, plastics, metal, garden waste and so on). This approach helps to ensure that the highest possible quality material is produced at the end of the recycling process. This maximizes the value of the materials and increases the number of products that can be made from them…[W]e need to design eco-friendly products and encourage prudent and environmentally responsible consumer behaviour to reduce the amount of waste we produce. And we need to improve recycling to increase the supply of raw materials to European industry”. (EC 2010)

About 1/3 of container glass in the EU is not properly recycled (FEVE 2016). The amount of glass which is not sold as shards — for an estimated between 50 to 70 DKK/ton (AffaldPlus 2016) — will probably end up as slag, a useless material, which ends up in landfills; until the consumer meets a real crisis which makes them realize the value of glass, this will probably continue — unless money (pant) becomes motivating factor.

Individuals are the solution if they feel like their effort makes a difference in the larger recycling system. Quite often individual efforts are deterred when the larger system disappoints.

Figure 9: *Typical view in a trash bin in Copenhagen — here three wine bottles are visible which should have been placed in ‘cube’ and not in this bin.*

3.2. Dominant sociotechnical networks and practice

Glass in Denmark is part of a larger international trade network that ensures quality of initial product, as well as providing the legal framework for recycling percentages.

3.2.1. The European Union (EU)

The EU demanded a while ago that all Member States recycle 60% of all glass by weight (EU 1994) and have also regulated the Member States public buildings with demands of registration of the building stock and the energy renovations which:

> "Member States shall require that central government buildings with the poorest energy performance be a priority for energy efficiency measures, where cost-effective and technically feasible". (EU 2012)

These demands for recycling efficiency of glass along with the later building stock energy requirements, align very well together with the upcycling of glass which could be used to decrease the energy use of certain structures with right pre-conditions such local site conditions such space for 'buffer zones' as well as general solar access — site is free from other structures, hills and or trees , etc.

Despite the call from the European Commission, Denmark does not source-separate according to colour, which lowers the amount of glass which is ultimately able to be recycled due to the difficulty of the optics in the processing machines to differentiate between non-glass and very dark glass; according to an industry expert:

> "besides mixing different colors of glass together, Vojens Commune, as first in Denmark, allows mixed fraction, which may increase their recycling numbers by weight, but it lowers the end quality — once you mix it in, it can be hard to get out again, but in short, Denmark is a little country and does recycling very well, compared to the EU and the rest of the world." (Kim Lykke 2017, pers. comm. 25 april)

Yet this method of mixing different waste together, is diametrically apposed to the European Commission's ideas:

> "The crucial point in increasing recycling rates is the extension of collection as well as the improvement of the collection quality, with regard to colour-separation and impurities. From a technical point of view, a further increase in glass recycling is possible provided that collection is carried out with colourseparation and the level of impurities is low… [I]n all Member States collection of disposable glass packaging is done mainly through bottle banks. An essential

> prerequisite for efficient glass recycling is the source-separation according to colour, and a low content of disturbing materials such as ceramics, porcelain, metals and others. Most Member States have therefore established systems where glass is at least sorted according to non-coloured and coloured glass." (EC 2001)

3.2.2. The Danish State (DK)

Denmark demands that its Communes meet this criteria and Affaldsbekendtgørelsen 2010 has the goal that 60% of all glass is recycled in Denmark (BFFG 2010) as well as the law requires that everything that can be recycled, must be so. (Roulound 2008)

In 2011, changes to the law made 7 Communes stopped to recycle bottles and instead send bottles to be sold as shards — such downcycling is a result of the market forces which, at the time, meant that:

> "It is now economically more profitable for some municipalities to sell the bottles that come forward to deliver them to sorting plants and to sell some of them as recyclable bottles. The reason is that in the government's latest spring package it was decided that the levy on

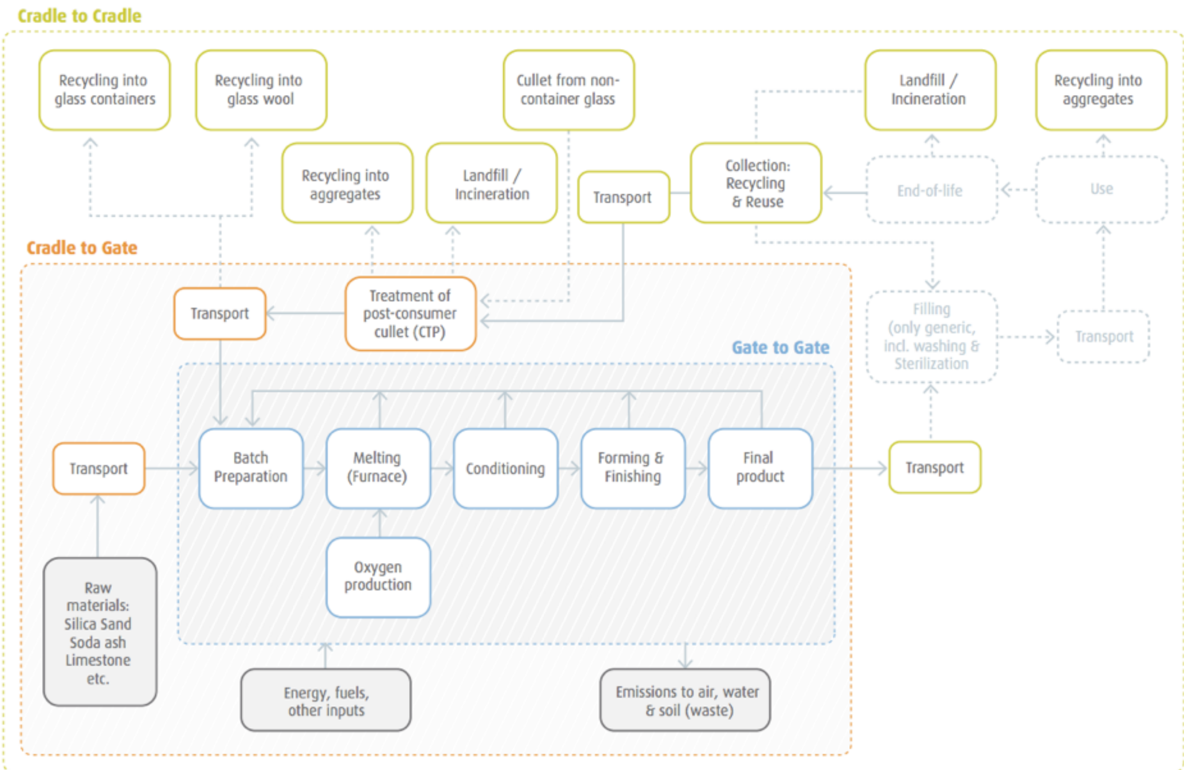


Figure 10: *Boundaries of the FEVE life cycle assessment for container glass. This illustrates the complex system that container glass is part of; the flows are organized with arrows going to different coloured sub-boxes.*

> packaging of wine bottles would be halved per. January 1, 2011. Thus, the economic basis for recycling bottles is impaired." (SN 2011)

The move to change this started in 2009 where the Danish Parliament agreed to half the levy from 1,60 øre per bottle to 80 øre; the government has pointed out that the reduction gives a surplus to the treasury of between 40-80 million. (Svenningsen 2011)

In 2013, Miljøstyrelsen, the Danish EPA, made an overview of the recycling possibilities for the Communes based on 13 scenarios, each with cost-benefit analysis and ranks the scenarios, where 1 is best: Greenhouse effect, Acidification, Nutrient salt load, Photochemical ozone formation (smog), Ozone depletion, Human toxicity via air, Human toxicity via soil, Human toxicity via water, Ecotoxicity in water, Ecotoxicity in soil, Stored ecotoxicity in water, Stored ecotoxicity in soil and Damaged groundwater resources: this work was meant to create an inspirational catalogue for the Communes to use as evaluation for their future recycling efforts. (Jakobsen 2013)

3.2.3. The 98 Communes (KL)

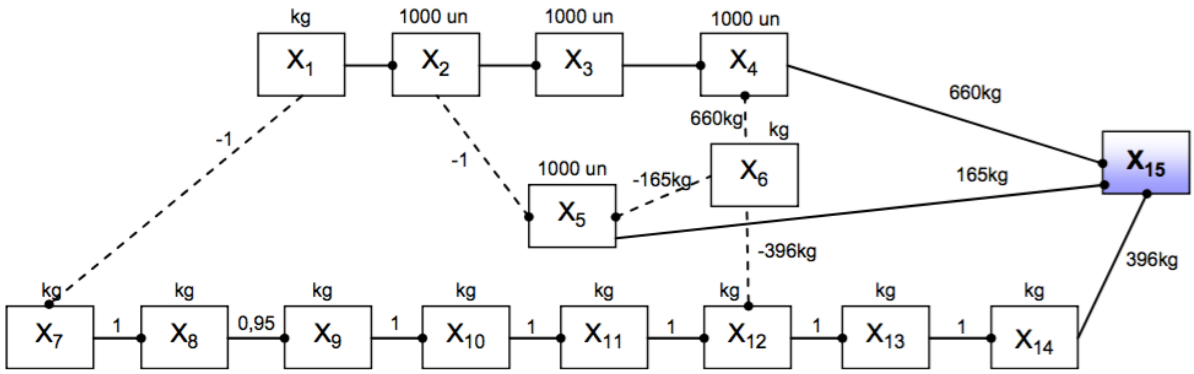
Multiple Communes have made companies that cross the communal borders to make the recycling process more sustainable, especially in the economic sense; some Communes have made companies that cross the communal borders to make the recycling process more sustainable, especially in the economic sense.

There are multiple platforms in which communes are currently trying to close to loop into a circular economy like the new 'green hub' Ressource City, located in a former industrial paper factory site in Næstved, which is prospected to be a place of innovation, production and education. (Slotved 2015)

Copenhagen Commune has voiced an interest in adding deposits on wine and liquor bottles to help create incentive to properly discard glass containers, which can be found everywhere, both whole and broken, in nature and in urban areas; such a hypothetical increase of 50 - 70 øre per bottle is enough to prove catastrophic for consumer, according to the independent merchants (DSK 2016) who argue that instead of monetary incentive (deposits on glass), the city of Copenhagen needs to increase its amount of glass containers, which does seem to have some credence since a survey from 2006, mentions that people do want to recycle glass correctly, and do discard in regular waste bin, only when it does not fit with their daily schedule to properly recycle. (Epinion 2006)

3.3. Reframing the problem — "there is no trash, only resources."

It can be relatively easy to recognize that waste, or trash, can be a resource to someone, somewhere; this new language of the sustainable transition implies that there is always a recipient of some waste-product available, and is willing to pay;



X_1 glass container production from virgin materials
X_2 produce/pack/deliver 1000ml glass container
X_3 fill/pack/deliver 1000ml glass container
X_4 sell mineral water in 1000ml glass container
X_5 re-use of 1000ml glass container
X_6 solid waste – glass container
X_7 glass container production from recycled cullet
X_8 transport treated cullet
X_9 cullet treatment
X_{10} long distance haulage of cullet
X_{11} local cullet handling
X_{12} local transport from obttle banks
X_{13} bottle bank recovery of bottles
X_{14} consumer transport of scrap glass
X_{15} glass container usage (25%- re-use; 60% recycling)

Figure 11: *Flow chart illustrates the complexities of glass recycling.*

those symbiotic business relationships can be more or less sustainable if one argues transport time and the gained production value that this waste represents along with the gained jobs that this process would potentially create.

This part of the problem analysis is part of the larger paradigm which we must slowly learn to navigate through — in fashion especially, one can easily recognize the recycling trend of using old things in new ways; this author aligns with this mantra that there is no trash, only resources since all this 'glass trash' can be used to decrease to energy use of structures and empower the passive consumers, making them into active producers.

3.3.1.Circular Economy — LCA and closing the loop

Because of the new nature of business after the ´Great Recession´ of 2008, regions, nations, cities, citizens and the market has had to adjust to the realities of an interconnected globe with finite resources; recycling of glass is important to the GDP of many EU nations and the use of shards, also called cullets, reduces the amount of virgin materials needed as well as the total amount of energy needed (Banks et. al. 2004), alongside ensuring that the jobs lost from the mining are created in the circular economy elsewhere (FEVE 2015).

Instead of having to go and recycle wine bottles, or throw them out, you can get excited because you now have ca. 450 grams of high-quality glass to build with; and with proper teaching and training, trash is easily seen as a resource which is part of a larger system (see Fig. 10), where glass and PET can be compared as for what is most sustainable solution, ultimately depending on the reuse factor:

> "The most interesting result is that, given the extremely small mass of PET needed for a 1 L container production, as compared to a glass container (0.660 kg of glass and only 0.030 kg of PET), the benefits stemming from reuse and recycle with factors a 1⁄4 0.25 and F 1⁄4 0.8 are not enough to overcome the gap between glass and PET in terms of environmental impact, PET being still more environmentally benign than glass. However, rising the reuse factor it is possible to bridge this gap…[a] correctly implemented environ- mental policy therefore must adopt either of the two materials taking into account the actual reuse and recycle expectations, bearing in mind that glass is currently preferable to PET only with rather high, but not impossible, reuse percentage." (Savioli 2008)

Therefore it can be concluded that it is really only sustainable to use glass container when it is reycled back into the system (see Fig. 11), which does seem to be a bit of a problem since people do not always recycle glass correctly — and neither does some of the Communes, as mentioned earlier, due to economic market forces, which means that it is cheaper to sell whole bottles as shards, which seems backwards considering the embodied energy in the bottles, that is wasted, due to the lack of proper circular opportunities with this glass.

Figure 12: *By creating an easy alternative, consumers will be more apt to recycle. Here a plastic box for glass next to bin shown in Christiania.*

3.3.2.Nudging - tacit manipulation

Because of the regional and national economic incentive, it is important to remind the public of their individual responsibility; thus one can attempt to encourage correct recycling by creating easy access (see Fig. 12) to proper separation of general waste and container glass; a study in how one can improve the recycling culture of consumers by encouraging ´the good style,' meaning, doing what is right and convenient for the consumer — recycling and upcycling — is trendy and contemporary and is a project worthy of future study.

3.3.3. Education - explicit cooperation

By making consumers more directly feel the impact of their waste, then perhaps it would engage users to recycle properly since most people will do the right thing, especially if it is clearly expressed and one is rewarded; workshops along with trash pick-up days help create focus on the glass and waste that can be found in nature and cities — in 2016, 182 tons of waste was collected in one day, many of the collectors were school kids. (Nielsen 2017)

4. Concept Development

By gathering, cleaning, and sorting container glass of different sorts, three different possibilities emerge where a consumer can upcycle glass into glass bottle windows and/or walls that, beside lowering transport, also lowers emissions of certain structures apt to this method; truly, all these 3 concepts are abstractions of the same thing (a hexagonal structure), which is upcycling of container glass used to create a vertical wall, which in turn, would partially help insulate a structure, meaning less heating and cooling costs and emissions.

4.1. Insulating properties of insulted bottle-brick window

Due to the hexagonal shape made by the 7 circular bottles or jars, there are gaps between the glass which needs to be 'filled-in;' to ensure best results, hemp shards (mixed with lime as bonding agent) would, theoretically, be an acceptable material that would be acceptable — thus to make one window 14 bottels is needed.

Theoretically, I used a german webpage to calculate the U-value (see Appendices) of an insulated bottle brick, which was so well insulated that it ensured

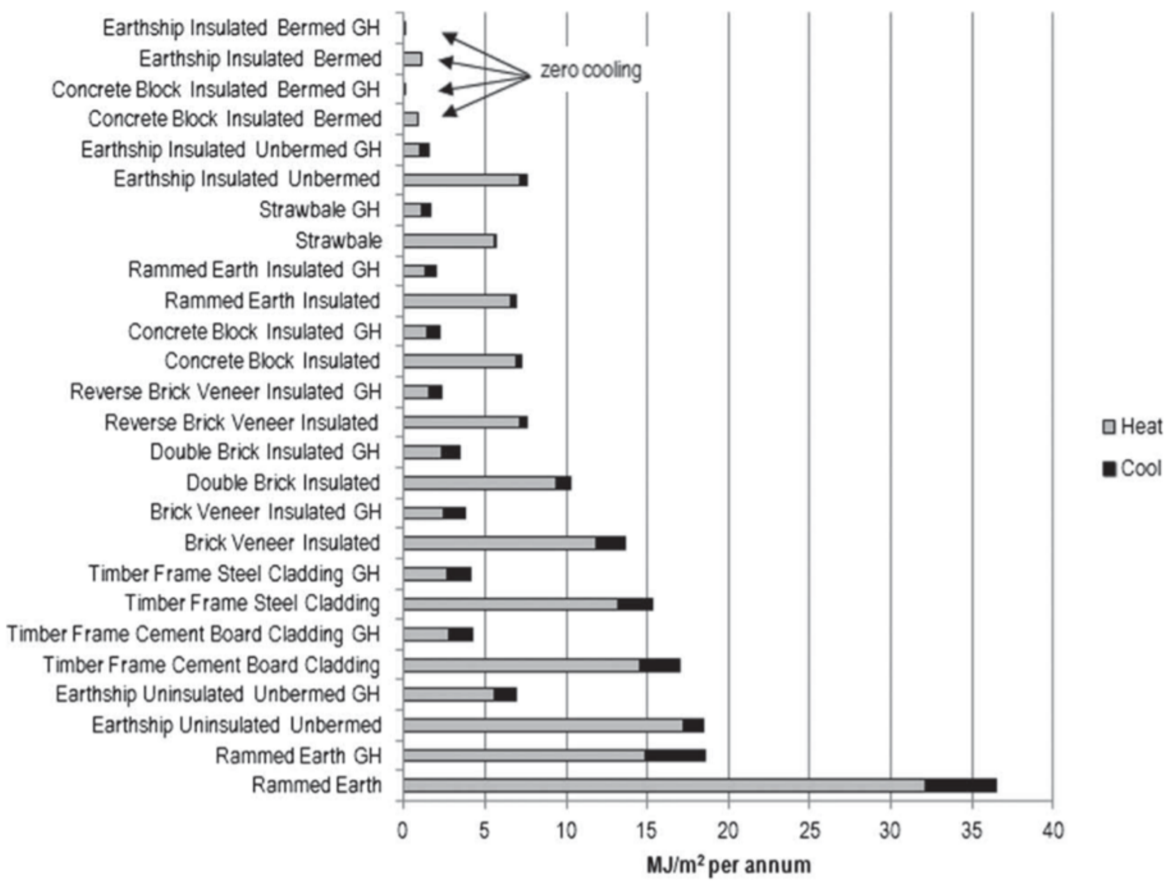


Figure 13: *An overview over different wall typologies and comparing their heating and cooling load in MJ/m² per year. Notice that GH (green house) consistently lowers to need for heating and cooling, since it acts as a 'buffer zone', moderating the interior temperatures.*

that no condensation would occur on the inside; this is crucial, since condensation gives good conditions for fungus, which is bad for the structure and the inhabitants.

4.1.1.Linear thermal loss

Appendice IV illustrates the theoretical linear-loss at 1,28 W/m^{2}K, which was calculated to show the practical realism of this method; the law, Building Code 15, has requirement of 1,4 W/m^{2}K, (BR15 2015) which is higher, and thus less insulating.

4.2. Possible bonding agents and in-fill material options

Because of the circular form of the glass-bricks, infill must be added to the glass structure, unless one preferes it open, which would result in free air movement from the exterior into the 'buffer zone,' which would alter the insulating capacity.

4.2.1. Hempcrete

To fill in the air gaps in the hexagonal glass bottle brick window, the shards from industrial hemp are known to be hygroscopically ideal for transferring humidity through a structural component; additionally, hemp, when mixed with lime, creates a strong and flexible mortar which becomes quite hard yet flexible.

4.2.2. Insulated-lime mortar

Technological Institute is experimenting with a lime mortar that is full of small glass spheres which insulate well, due to the still-standing air within; I had hoped to use this in this research project, though at this moment, production difficulties and other uncertainties mean that it is not currently in production.

4.3. The Greenhouse Effect

Anyone who has been in a greenhouse, knows how the air can be different than outside — often warmer and more moist, a greenhouse creates an opportunity to extend the season, by keeping frost out in start and end of season, and keeping plants warmer at night; such a concept of uniting a greenhouse to a structure as a permanent part, is the idea of architect Michael Reynolds, who may or may not, have been inspired by the many orangeries and greenhouses in Europe, and decided to make this a part of his Earthship typology, since he recognized the power of passive heating, back in the 1970s.

This greenhouse effect has been studied by Michael Reynolds and his team for decades, who have used every house as an experiment into natural (and cosmic) phenomena; and, only recently, thermal tests have been made to properly understand the benefits (see Fig. 13) of adding a greenhouse to a southern facade, or northern facade, if one is in the southern hemisphere.

4.4. Construction

In order to create a bottle wall, out of wine- or liquor bottles or jars, to save energy on your home, it is important that certain prerequisites exist, as mentioned earlier; one cannot expect to use less energy through solar gain, if there is not adequate access to free cosmic energy (the Sun).

4.5. Materials

4.5.1. Availability

The export of empty bottles (see Fig. 14) also show an increase of import of glass bottles which highlight the possibilities and barrioirs for increasing the reuse of whole wine bottles in Denmark and abroad; a more gentle recycling process, so less bottles become broken would increase the sustainable action. (Nejrup 2000)

These exported bottles can in the future secure a place in a 'buffer zone' greenhouse on the south-facing facade of a progressive and able homeowner

4.5.2. Quantity

Taking into acount the insulated bottle-brick: the export of empty bottles (see Fig. 13) show a great potential to use this glass locally instead of using energy to transport it back across the border; If one imagines 50 million bottles available for construction, it could build many 'buffer zones' in Denmark, but how many?

Imagine a 2 m by 7 m south-facing facade on a small house; a potential 'buffer zone' would need ca. a perimeter of 2 + 2 + 7 m — total length of 11 m, and

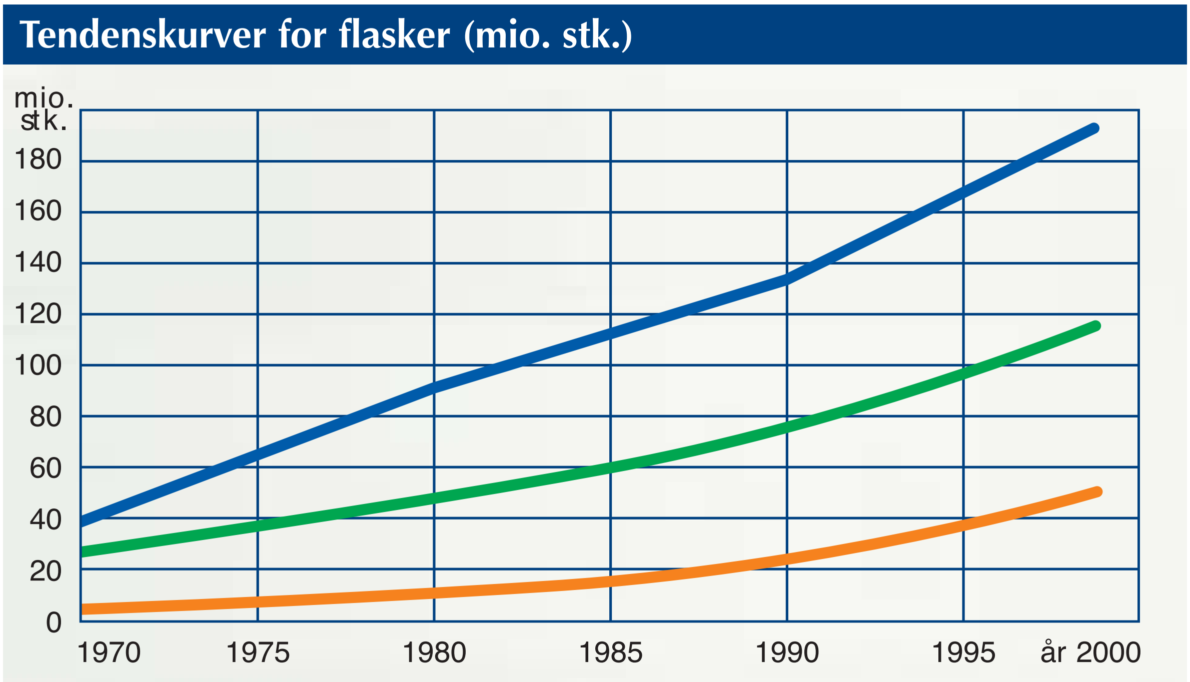


Figure 14: Import (blue), recycling (green) and export (orange) of wine bottles to Denmark. The ca. 50. million wine bottles that were exported illustrate the excess material flow that is available to the empowered and producing consumer.

making the bottle wall 2,5 m tall would conclude a need of 27,5m^2, or 30m^2 with waste material included.

Ca. 264 bottles are needed for 1m^2, thus to build a 30m^2 wall, the numbers are multiplied by one another. 264 bottles * 30 m^2 = 7920 bottles (or 8000 for ease of calculation) needed for a small house per 'buffer zone'

Then 50 million exported bottles is divided by 8000 bottles needed for small green house, which equals 6250 houses could have had improved living conditions if all exported bottles were used in bottle walls; to estimate the potential savings refer to Fig. 12, which illustrates the heating and cooling effects of a greenhouse attached to your house.

4.5.3. Quality

The quality of the glass is of fair importance, since low-quality with filth and cracks may turn out to be not worth the effort — such parts can go to the recycling system to substitute the virgin material in the making of glass.

5. Intervention

I caught up with some of my colleagues, two construction worker, in their lunch break and sat down and discussed the mock-up (see Fig. 2) I had brought along.

5.1. Outcome

The outcome of the discussion was especially the interest to one construction worker, was to clarity exactly how many bottles and/or jars one would have to gather to create a bottle wall, which at first seems very daunting, but if one systematically starts to collect the right glass, it is quite reasonable to attempt; his first comment was that, millions of bottles would be needed to build a wall, depending on size and method used.

5.2. Modifications

The construction worker noticed to poor cuts and asked how I had cut the glass and I explained my method of scoring and alternativ between cold and hot water to break the bottle along the line; I had some difficulty with getting nice and even cuts, so we concluded that a better cutting technique would ensure less broken bottles, along with more precise cuts, making final bottle brick of higher quality.

5.3. Analysis and reflection

Though the author still believes that upcycling of bottles and jars is a sustainable action, it has become clear that making good-quality bottle bricks can be a demanding struggle, where one must organize where to store the glass as well as what glass to store, depending on one's pragmatic ability and need.

6. Discussion

To properly engage the market, these upcycled glass components need to be part of a larger socio-technical experiment, such as the building of an eco village, where people are keen on their role in the sustainable transition and become empowered by their common purpose and individual abilities.

6.1. Individual carelessness to personal and communal empowerment

Being able to construct part of ones own home is a wonderful empowering feeling that gives confidence in the individual who is thereby better able to contribute to a given community; such responsible action can be contagious and will lead us away from the carelessness of poor glass recycling (see Fig. 9) to empowered people who are contientiously aware of their actions and their responsibility to one another and the Planet and who engage in ‘barn-raising’ activities, which could be argued is a natural part of our instinctual herd mentality.

The Earthship Biotecture movement is clearly the brighest example of progressive ‘punk-hippies’ (that is anti-culture, but pro-nature) that have bonded together and built with recycled materials, that include glass bottles; this movement has been a catalyst for a new sustainable building typology, soon available everywhere around the World today.

This gathering of individuals who come and go, and those who stay to further educate the next class, are part of an organizational empowerment (OE) structure which is invisible connected to individual empowerment, or psychological empowerment (PE), Peterson explains:

> “Empowerment at the individual level may be labeled psychological empowerment (PE). Zimmerman (1995) proposed one way to conceptualize PE as intrapersonal, interactional, and behavioral components. At the organizational level, OE refers to organizational efforts that generate PE among members and organizational effectiveness needed for goal achievement. Empowerment at the community level of analysis—community empowerment—includes efforts to deter community threats, improve quality of life, and facilitate citizen participation. This framework is useful because it extends empowerment theory and asserts that there are specific processes and outcomes across levels of analysis, and that these need to be developed in more detail to delineate a nomological network for OE. To date, empowerment theorists have not developed a clear and coherent nomological network for OE that articulates a clear differentiation from PE.” (p.130)

This notion of threat is interesting and could mean many things — as myself a human with some interpersonal experience, I would imagine a main threat to a community, to be the lack of stability of the social hiearchy, since often it seems that when certain people do something, others follow and some leave; creating a pseudo symbolic connection between people, that really is only dependent on the illusion of power and posiiton within the group.

Peterson expands on a potential briding construct:

> “OE, on the other hand, explicitly attends to features of collective action, while also incorporating ideas from multiple perspectives such as resource mobilization theory. Resource mobilization, for example, is a vital construct for OE as it is represented across all three components, but it has not been linked to either social capital or collective efficacy. Collective efficacy may be a bridging construct, however, between individual (psychological) empowerment and OE because it links individual outcomes (willingness and intention to intervene) with group processes (mutual trust and cohesion). As variables facilitating cooperation and joint action, both social capital and collective efficacy are constructs that may be relevant to intraorganizational, interorganizational, or extraorganizational empowerment.” (p. 140)

Collective efficacy is definitely a bridging construct, since it unifies people around a project, making the team behind that project, even more connected and stronger, due to the gained trust and respect which usually follows from working together. Thus, by building a south facing ‘buffer zone’ out of upcycled glass, the

Figure 15: Earthship Academy graduates in the EVE house in Taos, New Mexico.

consumer (now a producer) will save money on both material and labor, enabling them to free themselves a bit from the wage-slave routine, many Westerners have struggled with; by educating oneself in the Earthship Biotecture principles and becoming a graduate, one can personally save on one's future construction projects — so far ca. 600 people have graduated in the 6 years that founder Michael Reynolds has run this student program. (Earthship Biotecture 2016)

7. Conclusion

By systematically keeping and organizing used container glass, a consumer can at a low cost built insulated glass bricks that keeps less waste off of the roads and thereby decrease CO_2 emissions, along with potentially decreasing the amount of energy a structure uses in heating and cooling costs by building a sun room out of glass bricks.

7.1. Further research

My goal for further research is firstly to improve this hexagonal bottle brick window by: making more accurate U-value calculations, improve construction process, standardize a high-quality bottle brick (low-tech made), better thermal measuring and finally, test in the field.

7.1.1. Plastic bricks

Making these bricks out of plastics could also be a sustainable action, especially since there are many low-quality plastics that cannot be recycled, especially when they are intermixed; the life-time of such a potential plastic-brick is probably going to be much shorter due to the possibility of decay from UV rays, depending on local climate.

7.1.2. Need for better glass separation in Denmark

Besides the many bottles that break in the drop-off process, the mix of clear, green and brown glass can give factory dilemmas due to the optical machines, which in turn lowers the quality of the shards, since it is difficult to separate and distinguish between the different types of glass.

This author noticed on a trip to Germany, that there they do separate glass into more fractions which may need to also be implemented in Denmark to increase the quality of the collected material — which:

> *"can maximum have impurities of 20 grams/ton."* (Kim Lykke 2017, pers. comm. 25 april)

7.1.3. EU rules for deposits on glass and plastics

The missing deposits on multiple glass and plastics does not help encourage consumers to recycle properly across EU borders.

> *"I urge the EU to form a joint pantry system for both plastic and glass. This requires legislative change and will take a long time, but subsequently a very high level of recycling could be achieved. I do not feel there are actions in this direction in the EU at the moment."* (Kim Lykke 2017, pers. comm. 25 april)

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Postscript

The complex reality of market realities and political agendas must be aligned to ensure a true sustainable transition where short-term profit do not rule over long-term sustainable living.

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List of Images

Figure 14. Image by BFFG, n.d., Processbeskrivelse. http://www.danskflaskegenbrug.dk/grafik/Brancheforeningen2.pdf

Figure 15. http://earthship.com/blogs/2015/12/earthship-academy-2016-update-2/

Appendices

Appendice I: *Glass bottle brick U-value*
Appendice II: *Glass bottle brick hemp in-fill U-value*
Appendice III: *Glass bottle brick lime in-fill U-value*
Appendice IV: *Glass bottle brick linear loss (Ψ)*
Appendice V: *Relative humidity, condensation and evaporation quantity*

Worksheets

Milestone 1: Problem Analysis
Milestone 2: Concept Development
Milestone 3: Intervention with mock-up