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Sustainable Dwellings and Intergenerational Equality - New Applications for Ecological Economics

A Systems Thinking Approach

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- uttak av masteroppgave

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Merknader **1 uke ekstra p.g.a påske.**	

"A radical is one who advocates sweeping changes in the existing laws and methods of government. These proposed changes are aimed at the roots of political problems which in Marxian terms are the attitudes and the behaviors of men. Radicals are not interested in ameliorating the symptoms of decay but in drastically altering the causes of societal conditions".

- Hillary D. Rodham (1969: 10)

Preface

This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science in Industrial Ecology; it was prepared and completed in connection with the Faculty of Industrial Economics and Technology Management, the Institute of Energy and Process Technology and the Industrial Ecology Programme at the Norwegian University of Science and Technology (NTNU).

Academic freedom and creative license are two terms for describing the same rare gift; one afforded to me in the undertaking of this project. For this I am eternally grateful to my supervisor Cecilia Haskins. Thank you for your encouragement, guidance, and support - and most importantly, for giving me the freedom to explore my academic curiosities. I would also like to thank all of the respondents who agreed to be interviewed; this project would not have been possible without your time and expertise. A special thank you also goes out to Oddbjørn Dahlstrøm for providing the necessary information for conducting the life-cycle cost-benefit calculations in this report.

This thesis is dedicated to my family. Words cannot adequately express my gratitude for their support of my academic pursuits in Norway. This two-year process would have been impossible without the knowledge that they fully believed in my decision and capacity to achieve my goal. I would also like to thank my friends in the Industrial Ecology student community with whom I've shared so many unforgettable experiences. I will miss each and every one of you.

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Abstract

A systems thinking based approach was used to define and investigate the current state of knowledge in the academic disciplines related to sustainable residential dwellings via literature review. Semi-structured interviews were conducted with respondents connected to the system definition. The goal of the study was to determine the extent to which the academic disciplines, as well as the respondents, incorporated the social, economic, environmental and intergenerational aspects of sustainability. Significant variation was found in both the disciplines as well as in the responses of interviewees. Life-cycle cost analysis of dwellings built to the Norwegian passive house standard was used to investigate the implications of using alternative discount factors for extended assumed life spans. The results indicated that alternative discount factors have the potential to significantly reduce rental costs while fulfilling the potential Pareto optimality criterion. The alternative discount factors used in the life-cycle cost analysis were later shown to have flaws which limit their usefulness; a methodology for deriving a representative multigenerational discount rate was proposed.

Keywords: sustainability, residential dwellings, systems thinking, multigenerational discounting, ownership models, ecological economics, life-cycle cost-benefit analysis.

Sustainable Dwellings and Intergenerational Equality – New Applications for Ecological Economics

1 Introduction

Sustainability is undoubtedly *the* challenge of the twenty first century. While the basic tenets of sustainability were formalized more than two decades ago in the *Brundtland Report: Our Common Future* (1987), industrial growth has continued at unprecedented and unsustainable levels. This economic growth, and its associated carbon dioxide (CO_2) emissions, has also contributed to anthropogenic climate change. In 2007, the Intergovernmental Panel on Climate Change (IPCC) stated "…warming of the climate system is unequivocal [*…based on*] observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea levels" (IPCC 2007: 2). There is "high confidence" that increases in the atmospheric concentration of CO_2 will cause a range of irreversible impacts including: increases in the frequency of extreme hot weather events, ocean acidification, and decreases in water availability in semi-arid and arid areas (ibid: 8). Recent studies have also conclusively linked increases in anthropogenic greenhouse gas (GHG) emissions with increases in heavy precipitation events (Min et al. 2011). Ultimately, the impacts caused by future warming will be determined by atmospheric CO_2 concentrations at stabilization; a function of when anthropogenic emissions finally peak (Figure 1).

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Figure 1 - Characteristics of post-TAR stabilization scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only (IPCC 2007: 20).

Investigating the major sources of global carbon dioxide emissions, Allwood and Cullen (2009) identified three key sectors: (i) industry, (ii) buildings and (iii) transport. Globally,

buildings and the building sector emitted 8.8 Gt of CO_2 in 2005; a staggering 33% of total anthropogenic CO_2 emissions (IEA 2008: 99). Direct emissions accounted for 38% of the previously listed figure; with indirect emissions (62%) accounting for the rest (ibid). While these results were among the first to provide quantitative emissions figures, academics have known that buildings are important sources of emissions since the 1970s. Despite this knowledge, and the existence of a variety of academic disciplines dedicated to creating sustainable buildings, the global building stock remains a significant source of environmental impacts. This is also the case for residential dwellings. The purpose of this study is to determine why this is the case. Using a systems thinking approach, this study will attempt to ascertain the current state of knowledge in the academic fields with a connection to the subject of sustainable residential dwellings. The research question can be formulated as:

What is the current state of knowledge in the academic disciplines related to sustainable residential dwellings and to what extent do they incorporate the social, economic, environmental and intergenerational aspects of sustainability?

2 Research Methodology

2.1 Systems Thinking

"The whole is more than the sum of its parts" – Aristotle

2.1.1 Background

Systems theory is one of the oldest concepts known to European philosophy. Originating in the 6th Century BC; it has gone through periods of both prominence and discredit over the millennia (Bertalanffy 1972: 407). In developing general systems theory, Ludwig von Bertalanffy (1968) cited his frustrations with the dominance of reductionism in modern scientific inquiry as a motivation. He maintained that it was "… necessary to study not only parts and processes in isolation, but also to solve the decisive problems found in the organization and order unifying them, resulting from dynamic interaction" (ibid: 31). Thus, systemic structures provide a framework for understanding complexity.

Meadows (2009: 11) defines a system as "… an interconnected set of elements that is coherently organized in a way that achieves something". Systems exist within geographic, historic, and temporal boundaries; however, they also exist within other systems. Boardman and Sauser (2008: 25) use the term *system of systems* to describe this phenomenon; the term

holon can be used interchangeably. The concept of systems existing within systems increases the difficulty of properly defining a system boundary. Brattebø and Kjelstrup (2007: 2) suggest that this process can be simplified by using the *importance principle*; if a component "is important with respect to the formulation or the achievement of the purpose [*then it*] should be regarded part of the system".

2.1.2 System Under Investigation

The system being investigated can be defined as *sustainable residential dwellings in the Trøndelag region of Norway*. The purpose of the sustainable residential dwelling system can be defined as providing adequate shelter for inhabitants of aforementioned region at an acceptable price, in adherence with all applicable legislation, with an acceptable environmental performance. Following the "importance principle" mentioned above, components of the system include: population, local consumer attitudes and preferences, local and national legislation, ownership models, government policy, and the concepts and tools related to ensuring adequate environmental performance.

2.2 Mixed-Methods

Mixed-methods research involves the use of both qualitative and quantitative methods where appropriate. A mixed-methods approach was chosen for this paper because it granted the freedom to choose "the methods, techniques, and procedures of research that best [*met the project's specific*] needs and purposes" (Creswell 2002: 13). Being a systems thinking based project, the interplay between seemingly unrelated factors need to be investigated in order to gain an understanding of the *holon*. Mixed-methods research fits this description by integrating two established, yet disparate, methods of knowledge generation. In this project, quantitative methods were used to examine the economic factors that influence the widespread adoption of sustainable dwelling while qualitative methods were used to investigate societal factors and ascertain expert opinions. Qualitative problem-based interviews with academic, legislative and industry experts were utilized for their ability to provide additional insight into these barriers. The findings from both qualitative and quantitative investigations were then compared using triangulation.

2.3 Data Collection and Analysis

Data collection and analysis, also known as content analysis, is defined as "… a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff 2004: 18). The first step involves the collection of data that falls within the scope of the research question; followed by a systematic evaluation

process. Data sources used in this report include peer-reviewed academic journals, books and websites. Additional data was gathered from unpublished academic sources including master theses and original research from interviews. This paper includes data collected on the following theories: (i) sustainability, (ii) industrial ecology, (iii) eco-design, (iv) quantification of economic costs and benefits, (v) ecological economics, (vi) housing discourses, (vii) zero emission buildings, (viii) building information modeling, (ix) city planning, (x) smart growth, (xi) land tenure, (xii) residence models, and (xiii) Trøndelag specific information related to residential preferences, environmental performance of buildings and the extent of community involvement in the planning process. Data analysis involves the critical review of data and identification of relevant issues; using the respective guidelines of tools and methods used to gather the data.

2.3.1 Literature Review

As is the case with both quantitative and qualitative research, correctly conducting a literature review is the first step for both the identification, and subsequent investigation, of a selected topic. A well structured literature review should: "… frame the context of [*the*] research problem, provide a "…rationale for [*its*] selection", and prove that the researcher has a firm grasp of the historical developments and "… critical theoretical and research issues" (Hesse-Biber 2010: 36). Selection criteria for literature was based on importance; with recent papers, commonly cited authors, multiple viewpoints, and critiques included. Likening the literature review process to a lost art form, Dilevko (2007: 451) asserts that academics should begin the literature review process by "… browsing and reading widely in journals and books" even if they initially seem unrelated, outdated, or old. Incorporating "highly diverse sources … [*in an imaginative way*] may be the difference between a ground-breaking study" and an ordinary study based on "…easily located, predictable, and therefore pedestrian sources" (ibid). Reading widely from diverse research backgrounds is also necessary to avoid falling victim to *fragmentation of knowledge*; a phenomenon which describes the unintended side-effects of knowledge creation in universities. "The scope and intensity of specialization is such that scholars, even scientists, have great difficulty keeping up with the important developments in their own subspecialties, not to mention their field in general" (Gregorian 1996: 598).

Researchers should also avoid the mistake of simply *summarizing* literature. Rather, they should critically review the methods and assumptions using the guidelines set forth in Section 2.6 to maximize reliability and validity. Mixed-methods literature reviews can be structured either qualitatively or quantitatively. Creswell (2002: 35) asserts that if a study

has "…an equal weight and emphasis on both qualitative and quantitative data, then the literature may take either qualitative or quantitative forms". With a majority of qualitative tools used herein, the literature review section of this project takes the qualitative form.

2.3.2 Conducting Qualitative Interviews

Interviews should never be conducted to get questions answered, test a hypothesis, or evaluate a set of statements (Seidman 2006: 24). In order to avoid making this mistake, the interview format and topic questions were selected and reviewed to ensure that leading questions were absent. Negotiated access, reciprocity in the research relationship, researcher's behavioral characteristics, informed consent, anonymity, confidentiality and representation are other issues that can adversely affect the quality of research conclusions when they are not negotiated beforehand (Lewis 2003: 62-68). Following standard interview protocol, words were replaced with fictionalized equivalents in square brackets when dealing with sensitive or confidential topics; "parentheses [*were*] used to denote words which [*were*] incomprehensible in a recording" (Schostak 2006: 53). Finally, validation and collaboration methods covered in Section 2.6.2 were used to reduce possible contamination of participant responses. Full length transcriptions of all interviews can be found in Appendix B.

Unlike analysis applied to data collected via literature review, researchers cannot extrapolate meaning from interviewee responses post-hoc. "No standard method exists, no via regia, to arrive at essential meanings and deeper implications of what [*was*] said in an interview" (Kvale 2007: 102). Rather, analysis must be "built into the interview itself"; with researchers attempting to "confirm or reject" their interpretations throughout (ibid: 103). As a result, clarifying statements were used to remove ambiguity and ensure that questions were understood using the intended *meaning-frame*. Finally, follow-up questions were used to gain additional information and contexts.

2.4 Interview Style Selection & Process

All interviews are designed to deliver insight into hidden and oppressed realities. This is why anthropologists use the term *informant* to describe their subjects (Seidman 2006: 14). While traditionally used in the sociological and anthropological sciences, interviews also have the potential to generate significant findings when used to investigate subjects traditionally dominated by quantitative tools. The decision to conduct interviews was based on a number of factors including: the mixed-methods and systems thinking foundations discussed in Section 2.1 and 2.2, the dominance of quantitative tools in the study of sustainable buildings, and the lack of interview based research focusing specifically on the

system as defined in Section 2.1.2. Interview formats range in the rigidity of their structures; with traditional question-answer and open-response styles comprising opposite ends of the spectrum. Researchers who intend to conduct interview-based research need to familiarize themselves with these differences; carefully selecting one based on the specific requirements and challenges they expect to encounter. A problem-centered interview format with a semi-structured approach was selected for this project. This variant of the guided interview was specifically chosen for its ability to elicit open-ended responses from professional and expert informants.

2.5 Participant Selection

Expert – "a) One who is expert or has gained skill from experience b) One whose special knowledge or skill causes him to be regarded as an authority; a specialist" (Oxford English Dictionary 2011).

Influence – "The capacity or faculty of producing effects by insensible or invisible means, without the employment of material force, or the exercise of formal authority; ascendancy of a person or social group; moral power *over* or *with* a person; ascendancy, sway, control, or authority, not formally or overtly expressed" (Oxford English Dictionary 2011).

Following Seidman's (2006: 55) advice concerning the maximum number of participants; twenty five was chosen as the upper limit. Likewise, the minimum number of participants was determined using the *sufficiency principle*, which states: the process of data collection continues until the researcher is confident that a wide range of viewpoints have been captured. Using a reflexive process to decide when this principle had been fulfilled, a total of seven interviews were conducted between May 19th, 2011 and June 15th, 2011. Given that a *problem-based* interview format was selected to investigate the research question (Section 2.4), academics capable of commenting on factors within the system boundary were sought for questioning. Both *expertise* and *influence*, as defined above, were chosen as the required criteria for participant selection. The sub-criteria for each interview segment defined in Section 2.4 can be found in Table 1.

Table 1 - Criteria for Academic Respondents

Expertise	*Influence*
- Position - Certifications - Titles - 5+ years studying element within system definition	- Having a "presence" in the academic literature - Link to projects and competitions related to element of expertise

2.6 Role of the Researcher – Validity and Reliability

For mixed-methods endeavors, the role of the researcher is to ensure the validity and relevance of their work. Due to the vagueness of this term, "Mays and Pope (2000) suggest procedures and principles such as triangulation, respondent validation, clear detailing of methods of data collection and analysis, reflexivity and fair dealing" (Malterud 2001: 483). With methods of data collection and analysis covered in Section 2.3, triangulation, respondent validation and reflexivity will be discussed below.

2.6.1 Triangulation

Researchers should never "impose a point of view on the data"; instead, triangulation should be used to see "whether his or her particular research findings are supported" (Hesse-Biber 2010: 39). The qualitative definition of the term, adapted from the land surveying tool with the same name, implies that validity can be improved by using a "… combination of methodologies in the study of the same phenomenon" (Malterud 2001: 487; Jick 1979: 602). Contradictions and exceptions found during the triangulation process should not be feared as they "do not pose a threat to researchers' explanations; they merely provide further scope for refining theories" (Barbour 2001: 1117). For this paper, data sources for triangulation include: reviewed literature, original interview transcriptions, and original economic model scenarios for multi-generational housing. Discussion on the findings from this process can be found in Section 5.

2.6.2 Respondent Validation

Respondent validation, a prominent method for improving the validity and reliability of interview results, "… involves cross checking interim research findings with respondents"; their "… reactions to analyses are then incorporated into study findings" (Barbour 2001: 1115) (Mays and Pope 2000: 51). Also known as *member checking*, its purpose is "to establish the level of correspondence" between researchers and their research subjects (Mays and Pope 2006: 88). For this report, respondents were given transcripts of their interviews; providing them with an opportunity to ensure confidential and sensitive information had been properly removed. Next, respondents were given draft copies of sections that included excerpts from their interviews. This provided the chance to review, confirm or challenge the context in which responses were used.

2.6.3 Reflexivity

Reflexivity requires a rejection of the traditional notion of researcher objectivity. "In its most elementary form, reflexivity presupposes that, while saying something about the 'real'

world, one is simultaneously disclosing something about oneself" (Pels 2003: 158). Thus, who researchers talk to, what they read, and whose opinions are given privilege will be influenced by their conscious, and subconscious, preferences and attitudes (Finlay 2002: 531). Malterud (2001: 484) suggests that "… bias in the sense of undesirable or hidden skewness" can be accounted for by constantly reflecting on the effect of one's ideological convictions and pre-held notions. These effects need to be presented when discussing "… the limitations and strengths of the study" (Malterud 2001: 484). Following this advice, a short essay covering the author's ideological convictions and worldview has been included in Appendix A.

2.7 Quantification of Economic Costs and Benefits

Economics has long been defined as the "…study of the allocation of scarce resources" (Simon 1962: 1; March 1962: 662). Theoretically, when considering how to spend scarce capital resources, several types of organizations including for-profit firms, non-profit firms and government organizations strive to maximize the *utility* of their investments. Utility rests on the idea that individuals and agencies are "…rational, which means they are efficient and unbiased processors of relevant information and that their decisions are consistent with [*value*] maximization" (Byrne and Brooks 2008: 1). The potential Pareto optimality (PPO) criterion explained in Section 3.3 is one such method for ensuring maximization of utility; vis-à-vis the production of profit (*producer surplus*) and/or costs-savings (*consumer surplus*). The two previously mentioned types of surplus are also known as *net social benefit* (Mishan and Quah 2007: 24-6).

When conducting the analyses described in Sections 3.3.2 and 3.3.1, distinguishing between the different types of costs and benefits is imperative. Starting with *opportunity cost*, economists define it via contrasts; i.e. the "…cost of doing any one thing is measured by what is lost in not doing something else" (Van Sickle and Rogge 1954: 95). Opportunity costs can be somewhat difficult to quantify as they are impossible to accuracy ascertain in modern, highly-specialized economies, "…they are [*nevertheless*] reflected in the prices that the firms must pay to secure resources" (ibid). Costs can also be divided into *fixed* and *variable* subcategories. Fixed costs "… [*remain*] constant… regardless of changes in the level of activity" (Brewer et al. 2009: 47). These include annual amortizations for building and land purchases, long term bond yield payments, compensation for top-management and initial set-up costs. In contrast, variable costs can be changed and are correlated with the volume of production (Koller et al. 2005: 250). Finally, when measuring the benefits consumers derive from consumption, demand via *willingness-to-pay* is used; this is

determined by the price of the good, consumer income, the prices of related or substitute goods, consumer preferences and the number of consumers (Kingma 2001: 30).

2.7.1 Cost Benefit Analysis

Cost benefit analysis (CBA) is the practice of measuring a project or policy's potential costs and benefits for the purpose of ensuring that utility and other criteria are met. In the private sector, CBA is used to ensure that projects will maximize profits for shareholders. In the public sector, CBA is more complicated; it involves the "…systematic identification of policy consequences, followed by valuation of social benefits and costs and then application of the appropriate decision criterion" (Fuguitt and Wilcox 1999: 35). If two or more projects are in direct competition, CBA can be used to reveal the superior option or disqualify both (Kingma 2001). The formulae presented in Figure 2 are used to measure the present value of cost and benefit streams which determine the utility of a potential project. Despite their widespread use, CBAs are imperfect and subject to the assumptions made by practitioners; inaccurate assumptions can lead to sub-optimal outcomes (Flyvbjerg, Holm and Buhl 2002 and 2005).

$$PV_C = C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_n}{(1+r)^n}$$

$$PV_B = B_0 + \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^n}$$

$$NPV = PV_B - PV_C$$

Figure 2 – Formulae for Determining the Present Values of Costs, Benefits and Net Present Value

Recently, environmental externalities have been incorporated into CBA methodology. Ecosystem services, health and life risks are already considered CBA best-practice in many OECD countries (OECD 2006). Depending on the scale and type of project, these issues may have to be considered. Environmental externalities related to global warming, namely greenhouse gases, also qualify for inclusion in CBAs. The development of carbon taxes in Norway, with an average price of $21 USD per metric ton of carbon dioxide, increases the ease by which it can be included in CBA studies (Bruvoll and Larsen 2004: 498). After quantifying the expected costs and benefits of a project *over time*, a discount rate must be

chosen; this number is represented as *r*. Typical values for a discount rate are "…in the range of 3 to 8%" (Rabl 1996: 137-8). This rate is used to calculate the *present value of costs* (PVC) and the *present value of benefits* (PVB) using the formulae presented above. *Net benefit* is determined by subtracting PVC from PVB. If this number is negative the project should be rejected.

2.7.2 Life-Cycle Cost Analysis

Based on critique that *purchase price* only constitutes a small fraction of a product's cost over its lifetime, a number of economic tools have been developed to more accurately quantify total cost (Ellram 1993: 3). Tools which fall under this category include: *annual cost analysis*, *total cost of ownership analysis* (TCO) and *life-cycle cost analysis* (LCC). While TCO and LCC were designed to address the same problem, LCC has been used to a greater extent by the Norwegian Directorate of Public Construction and Property (Statsbygg). Starting on "… 1 September 1998 Statsbygg made life cycle costing mandatory in all their building projects. In order to systemize and ease the calculations, Statsbygg developed a tool called LCProfit" (Haugbølle 2003: 1002). At the same time, LCC became a requirement for all public procurement projects with the revision of the Norwegian Public Procurement Act of 2001 (Norwegian Ministry of the Environment 2007).

Table 2 – Key Terms Defined in Standard Norge 3454 (2000: 4-6)

Term	*Original Norwegian Description*	*English Translation*
Annual Expenses	beregnede eller registrerte kostnader for de enkelte år	calculated or recorded costs for each year
Life Cycle Costs	kapitalkostnader pluss årlige kostnader til forvaltning, drift, vedlikehold, og utvikling (FDVU)	capital costs plus annual costs for management, operation, maintenance, and development (MOMD)
Lifetime Costs	summen av kapitalkostnad og nåverdien av alle utgifter til forvaltning, drift, vedlikehold og utvikling (FDVU) i brukstiden, dvs nåverdien av livssykluskostnadene	sum of capital cost and the present value of all expenses for management, operation, maintenance and development (MOMD) in life, i.e. the present value of lifecycle costs
Annual Costs	annuitet av levetidskostnaden. MERKNAD Årskostnaden beregnes ved å multiplisere levetidskostnaden med årskostnads faktoren. Må ikke forveksles med årlige kostnader	annuity of life cost. NOTICE Calculated annual costs by multiplying the lifetime cost of annual costs factor. Do not be confused with annual expenses

In Norway, there have also been attempts to integrate these costs into economic decisions through the creation of *standards*. NS 3454 "Annual Costs for Buildings", was published in 1988; this standard was later updated in 2000 under the title "Life Cycle Costs for Building and Civil Engineering Work, Principles and Classification". While the standard number remained the same, the central item of consideration changed considerably (see Table 2). *Annual cost* focuses on the period starting immediately after purchase and ending before demolition*; life-cycle cost* extends the boundary to include initial investment, maintenance, construction, and demolition costs. Despite containing the term cost in its title, LCC can incorporate life-cycle benefits; a number *life-cycle cost benefit analysis* studies can be found in the academic literature (Carter and Keeler 2008; Padgett et al. 2010). Life-cycle cost analysis is similar to cost benefit analysis in that costs and benefits are projected into the future and discounted to determine whether the project is efficient based on the PPO criterion. The main difference between CBA and LCC is that LCCs use a longer time-span which extends beyond the delivery of a product or service; hence the term life-cycle.

3 Theory

3.1 Sustainability

Sustainable – "a) Capable of being borne or endured; supportable, bearable b) Capable of being maintained at a certain rate or level" (Oxford English Dictionary 2011).

3.1.1 Background

As can be seen from the definition above, the word "sustainable" does not contain a reference to the environment nor an environmental qualifier. Despite this fact, the word is regularly used to describe, characterize, and frame environmental issues. The addition of an environmental component is a recent phenomenon with roots in the paradigm shifting report titled *Our Common Future* (WCED1987); more commonly known as the Brundtland Report. The culmination of four years of work, the authors were charged with the task of designing an environmental framework capable of achieving "…common and mutually supportive objectives that take account of the interrelationships between people, resources, environment, and development" (WCED 1987: 5). The solution was *sustainable development*; development that "… meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: 15). *Intergenerational equality* is also central to the concept (Jenkins and Bauman 2009: 133).

Sustainability can trace its development through the transcendentalist movement of the 1800s, the publication of *Silent Spring* (Carson 1962), and the resulting environmental movements of the 1960s and 1970s (Edwards 2005: 14). Survivalist publications like *The Limits to Growth* (Meadows et al. 1972) and *A Blueprint for Survival* (Goldsmith et al. 1972) were also instrumental in envisioning alternatives to the current socio-economic system; thus laying the foundations for sustainability. Described as an attempt to create a *stable society*, four principle conditions were identified (Table 3). Many of these themes were later included in *Our Common Future*; *Agenda 21* (UNCED 1992) and *The Earth Charter* (ECIC 2000); the final two items in the list defined the ethics and steps for realizing sustainable development (Jenkins and Bauman 2009: 7).

The concept of sustainability also has a history dating back to the indigenous populations of North America. Historically, the Iroquois made decisions based on *the seventh generation principle* which states: it is the duty of "… chiefs, to make sure and to make every decision …

relate to the welfare and well-being of the seventh generation to come" (Lyons 1980: 173). This principle is based on an indigenous oral tradition that says "… the faces of coming generations are looking up from the earth. So when you put your feet down, you put them down very carefully - because there are generations coming one after the other. If you think in these terms, then you'll walk a lot more carefully [*and*] be more respectful of this earth" (Lyons 1995).

Table 3 – The Four Principle Conditions of a Stable Society (Goldsmith et al. 1972: 35)

Condition	*Description*
#1	Minimum disruption of ecological processes;
#2	Maximum conservation of materials and energy – or an economy of stock rather than flow;
#3	A population in which recruitment equals loss; and
#4	A social system in which the individual can enjoy, rather than feel restricted by, the first three conditions

3.1.2 The Three Aspects of Sustainability

Based on the definition provided in the Brundtland Report, sustainability is understood to have three aspects: ecologic, economic and social. These three aspects are also commonly referred to as the *3 E's of sustainability* when 'equity' is used as a replacement for 'social'. Ecologic sustainability refers to the long term health and functioning of plant Earth, its major ecosystems, biogeochemical cycles, biodiversity and inhabitants. Economic sustainability refers to the ability of market economies to operate in perpetuity; with financial and national resources allocated to ensure the stability of the system and its key components (Common and Perrings 1992: 31). Finally, social sustainability refers to improving people's quality-of-life. This includes respect for human life, as well as the fair distribution of "food, affordable housing, health care, education, job training and professional opportunities" (Edwards 2005: 23)..

3.1.3 Sustainability as a Discourse

Sustainable development is also referred to as the *sustainability discourse*. According to Dryzek (2005: 15), the sustainability discourse is defined by its *reformist* and *imaginative* elements (Figure 3). Reformist frameworks attempt to solve problems by modifying existing political-economic systems while imaginative ones attempt to redefine systems by resolving old dichotomies (Dryzek 2005: 15). Thus, sustainability fits both categories by resolving the environment-versus-development debate; framing the necessary changes within the existing

world system. The sustainability discourse also utilizes the idea of *limits* popularized by the book *The Limits to Growth* (Meadows et al. 1972); albeit in a different way. Instead of an *absolute* view of limits based on physical resource availability, sustainability accepts that technology and social organization can increase the abundance or usefulness of Earth's resources (WCED 1987: 16). The sustainability discourse even accepts that limits may eventually be *bypassed* altogether (Doyle 1998: 774).

	Reformist	Radical
Prosaic	Problem Solving	Survivalism
Imaginative	Sustainability	Green Radicalism

Figure 3 - Classifying Environmental Discourses (Dryzek 2005: 15).

3.2 Industrial Ecology

Industrial ecology is "the study of the flows of materials and energy in industrial and consumer activities, of the effect of these flows on the environment, and of the influence of economic, political, regulatory and social factors on the flow, use and transformation of resources" (White 1994: v). This viewpoint is represented on the left-hand side of Figure 4 under the title of *systemic analysis*. The goal of industrial ecology is "to understand better how we can integrate environmental concerns into our economic activities" (White 1994: v). This viewpoint is represented on the right-hand side of Figure 4 under the title of *ecodesign*.

"Most industrial ecologists have a transformative agenda. Their explorations, descriptions, and explanations are all in the service of use" (Andrews 2003: 15). Thus, industrial ecology can be described as both a descriptive and prescriptive science; one capable of describing and proposing solutions to environmental problems (ibid). Braden Allenby, a pioneer of the field concurs and defines industrial ecology as "…the means by which a state of sustainable development is approached and maintained" (O'Rourke et al 1996: 90). Lifset and Graedel (2002: 11) and Korhonen (2001: 257) also share this viewpoint. In Figure 4 presented below, sustainability is placed above industrial ecology to symbolize the relationship between the two concepts.

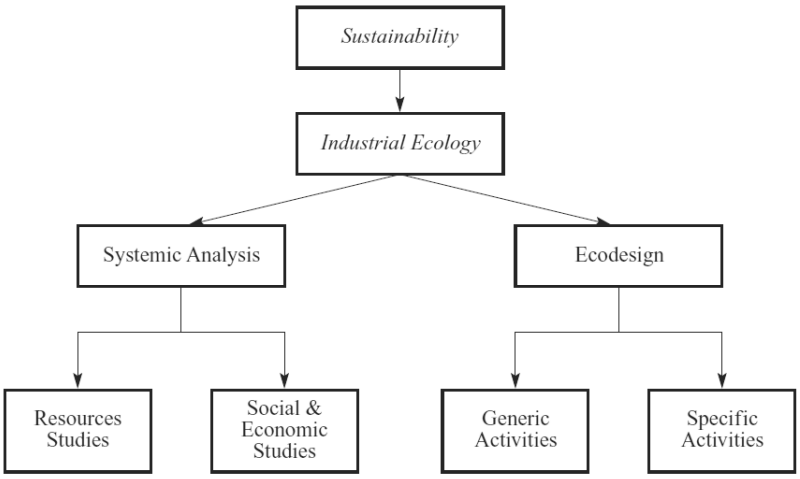

Figure 4 - Industrial Ecology Conceptualized in Terms of its System-Oriented and Application-Oriented Elements (Lifset and Graedel 2002: 11).

3.2.1 Background and Metaphors

In 1644 Descartes used a mechanical metaphor, "nature is a machine", to investigate the workings of natural objects (Johansson 2002: 75). More than three centuries later, Frosch and Gallopoulos (1989) reversed the metaphor; they used their knowledge of the environment to propose a new way of understanding and reducing the impact of modern industrial production. Like a Russian babushka doll, the *industrial ecosystem metaphor* they developed contains within it a number of sub-elements derived from the principles of ecology (Andrews et al. 1994: 471). First, the industrial ecosystem metaphor transfers the systems thinking foundation of ecology to the study of industrial production (O'Rourke et al 1996: 91). Secondly, it implies that industrial production systems can be understood as *living organisms*.

Diving deeper into the metaphor, the living organism analogy contains two additional metaphors. First is the *metabolism metaphor*; whereby biota consume "…natural resources, material and energy, [*'digest'*] them into useful products and [*'excrete'*] waste" (Johansson 2002: 73). Ayres and Kneese (1969) were the first to use metabolism as a framework for explaining environmental externalities; their work resulting in the development of *industrial metabolism*, *industrial symbiosis* and *bulk material flow accounting* (Ehrenfeld 2004: 826 ; Fischer-Kowalski 2002: 24). Secondly, the *life-cycle metaphor* is based on the different phases of life experienced by living creatures. Expressed another way, "…all that lives is born to die" (Page et al. 1969). Industrial ecology tools based on this metaphor include *life-cycle analysis* (LCA), *life-cycle costing* (LCC) and *material flow analysis* (MFA).

3.2.2 Environmental Performance of Residential Dwellings

Life-cycle impact assessment (LCIA) is the systematic analysis of product life cycles or functional chains which include all technical processes related to the given product or service (Heijungs et al. 2007). LCIA is used to compare different options for fulfilling the same functional unit and in identifying *hot spots* in a product's life cycle (Heijungs 2007). According to Saur (1997: 66) the three main environmental themes of LCIA include human health, environmental health, and resources. Impact categories include climate change (CC), human toxicity (HT), photochemical oxidant formulation (POF), particulate matter formation (PMF), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), and metal depletion (MD). For a detailed methodology on how to conduct an LCIA study, see Strømman (2008).

LCIAs have recently been used to compare the impacts of various building standards in Norway for an assumed lifetime of 50 years. In a 2011 study, Dahlstrøm (2011) compared the environmental impacts of both the passive house and TEK 2007 standards (Figure 5). The results revealed that the passive house standard reduced environmental impact by an average of 20% compared to TEK07. It should be noted that the previously mentioned study did not take into account the reduced carbon reductions from the 50% renewable energy requirement in the passive house standard. As a result, CO2-eq emissions from passive houses may be up to 50% lower than stated in Figure 5. Findings from this study also revealed that the construction phase accounts for an average of 19% of total environmental impacts associated over the lifetime of the dwelling; in comparison, the use phase accounts for an average of 58%. A similar LCIA study on residential dwellings in the United States of America by Ochoa et al. (2002: 135) quantified the environmental impacts associated with construction at 5% of total. These stark differences are attributable to the different energy efficiency standards and electricity mixes between the two countries.

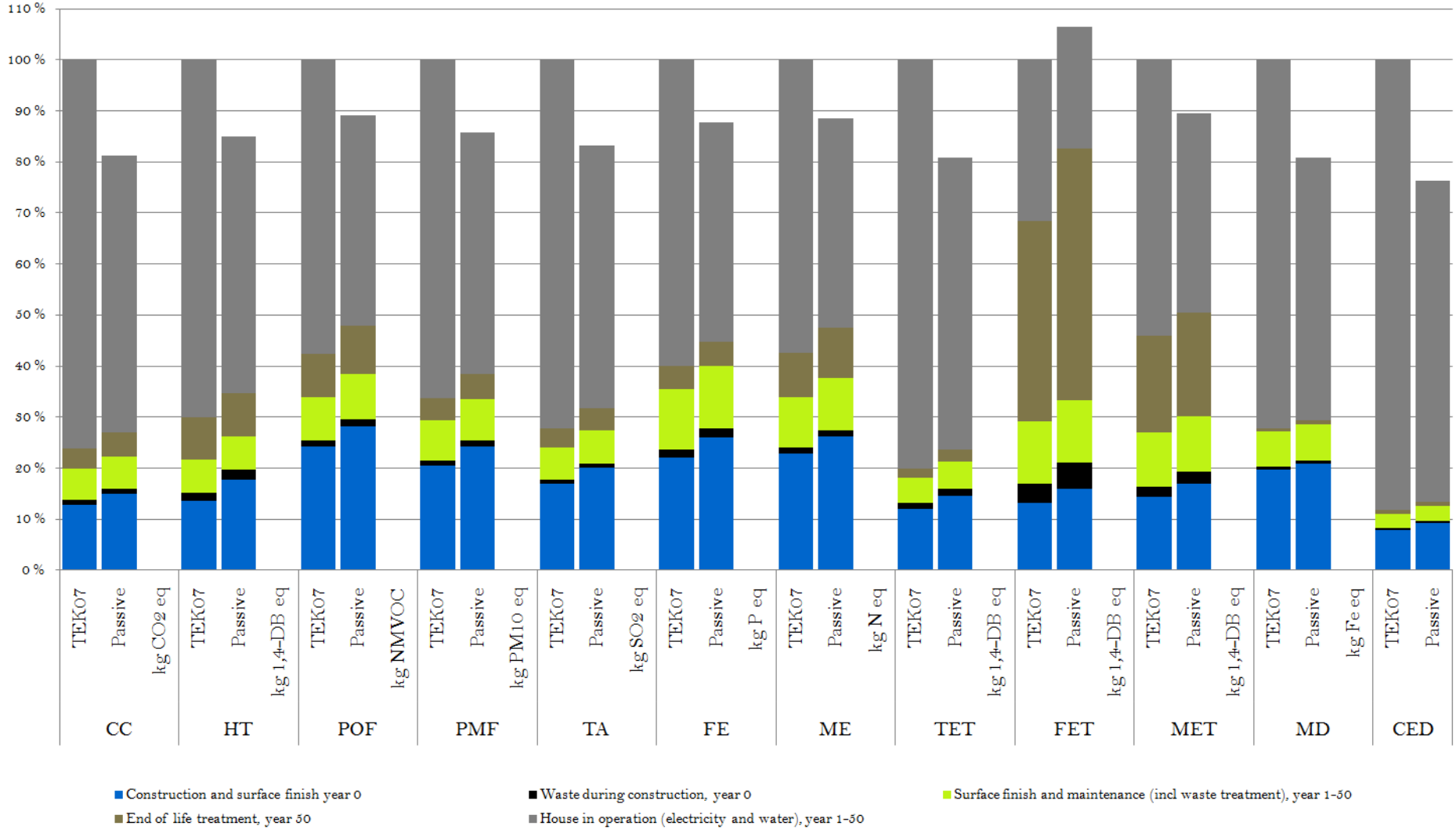

Figure 5 – Life Cycle Impact Analysis Comparison of the Norwegian Passive House and TEK07 Housing Standard Using a 50 Year Assumed Lifetime (Dahlstrøm 2011)

3.2.3 Eco-Design

"In many ways, the environmental crisis is a design crisis. It is a consequence of how things are made" (Van der Ryn and Cowan, 1996: 24)

Eco-design is a design philosophy which "…has constantly borrowed ideas and terminology from ecology and environmentalism"; evolving ever since its inception in the late 1980's (Madge 1997: 44). Commonly referred to as design for environment, life-cycle design, and design for eco-efficiency; all are attempts to integrate "…environmental, health, safety, and sustainability objectives" into the design of products (Fiksel 2009: 6-83). McDonough and Braungart (2002: 70-76) ardently disagree with the idea of design for eco-efficiency; arguing that attempts to increase material efficiency, i.e. "…being less bad", cannot solve the problem. They critique eco-design philosophies for accepting the idea of waste inherent in the cradle-to-grave life-cycle concept. Instead, they advocate design for sustainability; asserting that products should be designed to safely re-enter *both* technological and biological cycles (ibid, 104). Also known as *cradle-to-cradle*, this design concept shares a number of similarities with *design for disassembly* (DfD); a concept which asserts that products should be designed to optimize material recovery during the *end-of-life phase* (Kriwet et al 1995: 15). This includes a focus on strategies for separating parts and the materials contained within them (ibid). The goal of design for disassembly is the creation of a closed-loop production system that mimics nature's ability to efficiently recycle materials. Table 4 includes a list of benefits that companies can realize by incorporating design for disassembly principles. Although absent from the table below, *competitive advantage* can also be achieved using the design for disassembly framework (Esty and Porter 1998: 38). *Reuse without remelt* is another concept which shares many similarities to design for disassembly. While design for disassembly advocates the integrating of end-of-life concerns in the design phase, reuse without remelt is a strategy for *extending the functional lifetime* of structural building components. When buildings are demolished, "… mechanical sheers badly deform the steel. If a steel beam is removed carefully from an old building, there is no physical reason why it cannot be relocated and used again in a new building" (Allwood et al. 2010: 6). Developers prefer demolition due to time and cost constraints, however, this practice damages leads to environmental impacts from remelting and recasting. This is a critical barrier because it is estimated that 50% of construction steel has the potential to be reused without remelting (ibid: 7).

Table 4 - Design for Disassembly Benefits and Criteria (Jovane et al 1993: 654)

Benefits	*Criteria*
Less Disassembly Work	• Combine elements • Limit material variability • Use compatible materials • Group harmful materials into subassemblies • Provide easy access for harmful, valuable and reusable parts
Predictable Product Configuration	• Avoid ageing and corrosive material combination • Protect subassemblies against soiling and corrosion
Easy Disassembly	• Accessible drainage points • Use fasteners easy to remove or destroy • Minimize number of fasteners • Use the same fasteners for many parts • Provide easy access to disjoining, fracture or cutting points
Easy Handling	• Leave surface available for grasping • Avoid non-rigid parts • Enclose poisonous substances in sealed
Easy Separation	• Avoid secondary finishing (painting, coating, plating etc) • Provide marking or different colors for materials to separate • Avoid parts and materials likely to damage machinery (shredder)
Variability Reduction	• Use standard subassemblies and parts • Minimize number of fastener types

3.3 Ecological Economics

Environmental Externality – "uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism" (OECD 2003).

Ecological economics is an academic discipline that critiques *neo-classical economics* (NCE) for failing to include a modern conceptualization of nature; negative environmental externalities and social equality problems are attributed to this omission (Faber 2008: 2; Rees 2001). Pioneer of the field Robert Costanza (1989: 1) specifically critiques the "…assumption of continuing and unlimited economic growth" for ignoring the laws of thermodynamics. He classifies this assumption as *technological optimism*, and argues that it has the potential to cause disaster if proven false (Figure 6).

		Real State of the World	
		Optimists Correct	Pessimists Correct
Current Policy	Technological Optimist Policy	*High*	*Disaster*
	Technological Pessimist Policy	*Moderate*	*Tolerable*

Figure 6 - Payoff Matrix for Technological Optimism vs. Pessimism (Costanza 1989: 4)

Another widely cited explanation for environmental degradation is NCE's inability to assign nature an accurate market value. *Natural capital*, a term coined by Schumacher (1973: 17), accepts that natural environments and non-renewable resources are *stocks* capable of generating "… a flow of valuable goods or services into the future" (Costanza and Daly 1992: 38). Goulder and Kennedy (1997: 23) assert that these flows, comprised of ecosystem services and social benefits, are routinely undervalued; resulting in sub-optimal economic outcomes. In an attempt to remedy the problem, a number of different *passive-use* valuation methods based on *stated preferences* have been developed (Kramer et al. 2003: 303). Stated preferences are measured using contingent valuation methods (CVM) which include: *option value*, *bequest value*, and *existence value* (Skonhoft 2007: 4). Passive use valuation methods are well established; they were first used to determine the value of damages caused by the Exxon Valdez oil spill 22 years ago (Turner and Bateman 2003).

A third explanation for environmental degradation is attributed to the NCE principle of *perfect substitutability* between manmade capital and natural resources (Daly 1990: 2). Padilla (2002: 74) and Rees (2001) use the idea of *critical natural capital* to criticize this assumption; stating that "…while market economics can usually price the scarce material inputs to manufacturing, [*they are*] virtually silent on the value of biosphere processes. Not surprisingly, it is these more critical resources that are becoming increasingly scarce and [*for which*] there are no substitutes" (ibid). Hawken et al. (1999: 4) also reject the concept of substitutability; arguing that the four subcategories of capital presented in Table 5 are *all necessary* for the proper functioning of the economy. This concept is also known as *complementarity* (Perrings 1987: 126).

Table 5 – The Four Types of Capital (Hawken et al. 1999: 4)

Type of Capital	*Description*
Human Capital	labor, intelligence, culture, organization
Financial Capital	cash, investments, monetary instruments
Manufactured Capital	infrastructure, machines, tools, factories
Natural Capital	resources, living systems, ecosystem services

Lastly, ecological economists critique NCE for its use of *discounting*. A practice used in cost benefit analysis, discounting is designed to ensure that capital is spent efficiently according to the *potential Pareto optimality* (PPO) criterion (Goulder and Stavins 2002). Invented by Nicholas Kaldor (1939) and John Hicks (1940), the PPO criterion can be fulfilled if "…gainers can fully compensate the losers for their losses and still be better off themselves" (Stavins et al. 2003: 342). Put simply, the profits from a project must be greater than the initial sum borrowed plus the accrued interest.

Discounting, applied via a discount rate, is rationalized using the *positive time preference* argument which states: when comparing identical goods, people always place a higher value on the more immediately available one (Böhm-Bawerk 1959: 265). The same is true for money. The *miracle of compound interest* allows an original sum to grow exponentially; with doubling periods roughly determined by *the rule of 72* presented in Figure 7. Thus, a dollar earned and invested today will *always* be worth more than a dollar earned in the distant future. In essence, discounting is the process of translating future costs and benefits into present-day values by "… [*adjusting for*] the effects of compound interest" (Goulder and Stavins 2002: 673).

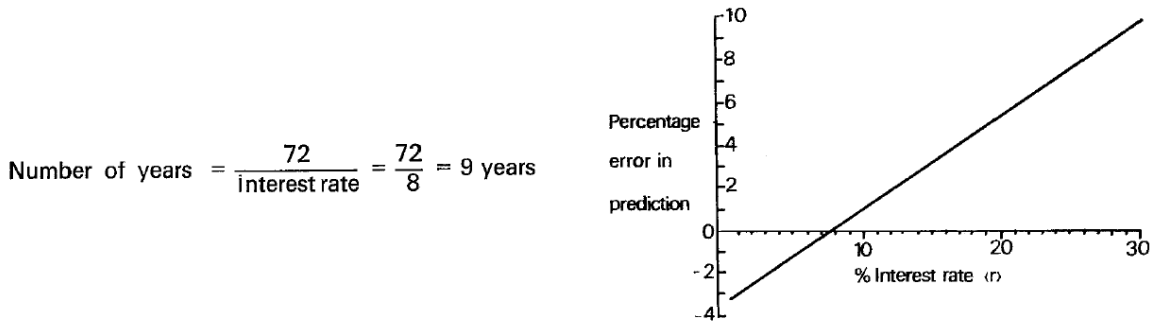

Figure 7 – The Rule of 72 and % Prediction Error (Sandler 1974: 34)

3.3.1 Contingent Valuation

Contingent valuation (CVM) is a survey based methodology based on stated preferences that aims to value non-market goods and services. Whitehead (2003: 67) identifies three methods for surveying which can be used; these include mail, telephone, and in-person surveys. Each of these methods have associated costs ranging from $5-10 USD per mail respondent to upwards of $50 USD per person surveyed in-person; this five-to-tenfold increase is attributable to labor outsourcing which becomes necessary (ibid). Given that large sample sizes are required, the cost of utilizing each of the above-stated methods must be considered and weighted against potential improvements to data quality.

Qualitatively stated preferences, i.e. statements like "I feel that protecting the environment is important", are not useful to contingent valuation practitioners. Rather, "…hypothetical questions about future behavior… constructed around $t and the delivery of Δq_1' (where $t is a tax price and Δq_1 is the resource change)" are used to elicit responses which can be subjected to quantitative analysis (Whitehead and Blomquist 2003: 94-8). These questions can take either the *willingness to pay* (WTP) or *willingness to accept* (WTA) form; WTP assumes that a payment of $t will result in a benefit in the delivery of Δq_1 while WTA assumes that receiving $t is sufficient compensation for a decrease in the delivery Δq_1. In the *Report of the NOAA Panel on Contingent Valuation* (Arrow et al. 1993), the expert panel concluded that WTP is preferable to WTA because it produces more realistic and "conservative" valuations. This conclusion was highly relevant as CVM techniques had previously been criticized for generating over-valuations of the phenomena they investigated (Seip and Strand 1992).

Risk is another important variable related to Δq_1; people's preferences and willingness to pay change depending on likelihood of realizing a benefit. Similarly, the communication of risk in relation to $t must be effective in order for respondents to answer appropriately. Proposed methods include "...graph paper containing 100,000 squares with the appropriate number blacked out [*see Figure 8*] … 'risk ladders' which present the numerical probabilities of dying from various causes on a visual scale, … pie charts, … and verbal 'probability analogies' " (Corso et al. 2001: 166).

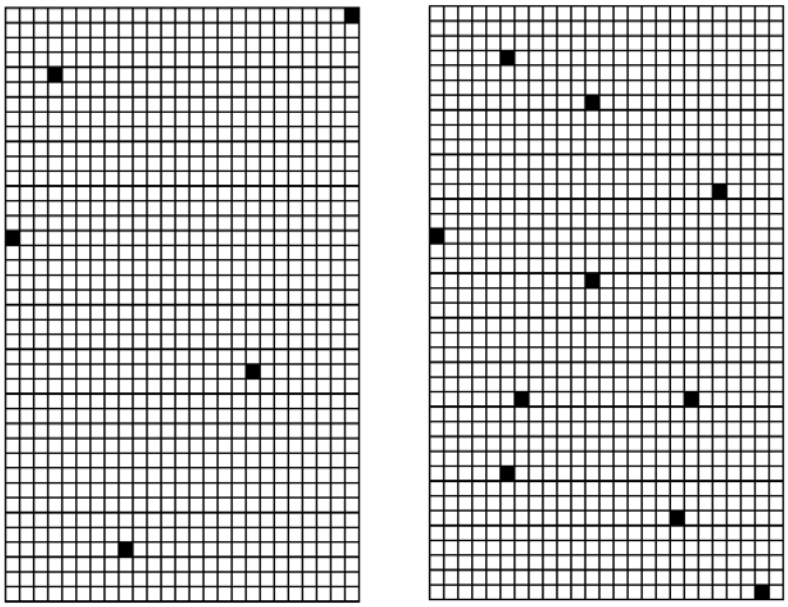

Figure 8 – Grid-Based Visual Communication of Risk Changes (Krupnick et al. 2000: 14)

3.3.2 Multigenerational Discounting

> "To think about the distant future in terms of standard discounting is to have an uneasy intuitive feeling that something is wrong, somewhere" (Weitzman 1998: 201)

While discounting is standard practice in economics and finance, it is not without controversy. Padilla (2002: 72) asserts that discount rates cause *intergenerational externalities* by "… [*strongly favoring*] projects with distant costs and prompt benefits, while [*discriminating against those with*] distant benefits" (ibid: 69). The problems caused by discounting become amplified when considering non-traditional, intergenerational timescales. At a 7% discount rate, "…$1000 of damages [*today*] will be valued at only $1.15 in 100 years and at $0.0013 in 200 years" (Nordhaus 1999: 145). Daly (1990: 2) concurs and clearly distinguishes between attempts to maximizing sustainable annual profit and those which maximize NPV through discounting. Sumaila and Walters (2005: 138) use a similar argument; critiquing standard discounting practices for failing to "…adequately capture human proclivity" in adjoining generations.

> "Viewed as any other investment, the education of children generally yields a negative net present value at most practical rate of discount, making alternative investments more attractive. Yet parents and society seemingly disregard conventional financial wisdom, educating their children with little promise of return save the confidence that they have equipped them with the tools needed for survival" (ibid).

A number of intergenerational discount factors have been proposed in the academic literature. One such attempt to resolve the dilemma focuses on *uncertainty* in the rate of return as a justification for the use of *near-zero* discount rates (Newell and Pizer 2003). When discount rates are assumed to be constant, and applied to a steady flow of income, net present value will be significantly smaller than when the entire range is taken into account. Using the two formulae presented below in Figure 9, $1000 of expected income 200 years in the future would produce a NPV of 34 cents at a certain rate of 4%; the same expected income produces a NPV of $68 with an uncertainty range between 1% and 7% (ibid). When conducting long term NPV calculations which incorporate standard uncertainty ranges, the corresponding *certain* discount rate is always near-zero. Weitzman (1998) argues that uncertainty increases as timescale are extended into the future; thus, near-zero discount rates should be used for the far-distant future.

$$NPV_{certain} = \$FV_{e}^{-r\_const \times time}$$

$$NPV_{uncertain} = (0.5(\$FV_{e}^{-r\_\min \times time}) + 0.5(\$FV_{e}^{-r\_\max \times time})$$

Figure 9 – Formula for Incorporating Uncertainty in Net Present Value Calculations (Newell and Pizer 2003)

Another attempt, *hyperbolic discounting*, uses "… 'normal' discount rates for the near future [*and*] 'low' discount rates for the far future" (Weitzman 1998: 201). The rationale behind this form of discounting is based on experimental observations that "…almost invariably show that [*respondents*] discount the distant future at lower rates than they discount the near future" (Azfar 1999: 251). Academics use the term *empathetic distance* when referring to this phenomenon; expressed another way, people don't differentiate between a hypothetical event that occurs three centuries in the future versus the same event four centuries away (Weitzman 1998). The first mathematical description of this phenomenon, presented below in Figure 10, was formulated by Mazur (1987). Since then, a number of variations on this basic approach have been formulated. More recently, HM Treasury (2003) mandated the use of declining discount rates following a hyperbolic discount factor for all long-term planning projects 30 years in length or longer.

$$f_H(D) = \frac{1}{1 + kD}$$

Figure 10 – Formulae for Hyperbolic Discounting (Mazur 1987)

While hyperbolic discounting is well-defined in the academic literature, it has also been criticized for containing a *time inconsistency problem*. Identified by Strotz (1955), if time-preference is not constant then currently optimal decisions can become sub-optimal at a point in the future. This presents a problem because continuing "… to obey a fixed consumption plan just because it was optimal when viewed at an earlier date is not rational if that plan is not the optimal one at the present date" (ibid: 170). Another aspect of the time inconsistency problem relates to "… when the baseline year is in the future"; net present values will vary depending on this baseline (Settle and Shogren 2004: 269). This complicates the process of deciding upon an optimal policy path to pursue.

Another approach to discounting proposed by Sumaila and Walters (2005) expressly attempts to include future generations in the calculation; their equations are presented below in Figure 11. Their approach is unique in that it views "… benefits as accruing to the current generation (at standard discount rates) plus to each of the annual 1/(generation time) increments of new stakeholders who will have entered the stakeholder population by that future year" (ibid: 138). This discount factor creates an initial period where the discount rate is zero; this is followed by a near-linear, downward trending slope in the subsequent period.

$$d_{fg} = \frac{1}{1+r_{fg}} \qquad W_{i,t} = d^{t} + \frac{d_{fg} d^{t-1} t}{G}$$

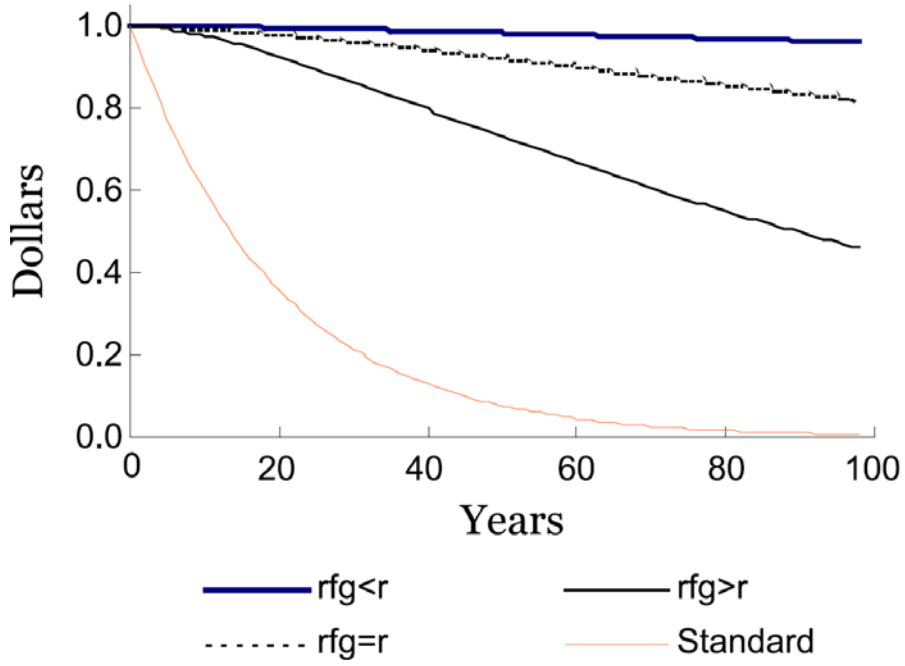

Figure 11 – Proposed Intergenerational Discount Factor Formulae and Value Retention Comparison to Standard Discounting (Sumaila and Walters 2005)

3.4 Sustainable Housing Discourse

Environmentalism's rise to prominence in the 1970s laid the foundations for the first sustainable housing discourse. Based on radical green ideological beliefs, community reorganization and small-scale governance were framed as the solutions to environmental problems (Dobson 2000: 91). The central canons of the discourse led advocates of sustainable housing to divorce themselves from government based solutions; i.e. effecting policy changes (Lovell 2004: 36). As Keenan (1995: 41) observed, the deliberate lack of involvement allowed housing policy to stagnate; as a result, the principles of environmentalism were still absent from UK housing policy in 1995.

Inspired by the reformulation of environmental issues in *"Our Common Future"* (WCED, 1987) and prompted by the publication of *"Innovative Policies for Sustainable Urban Development: the Ecological City"* (OECD 1996), the field of *urban sustainability* evolved from the sustainable housing discourse in the mid-1990s. Urban sustainability is related to *city*

planning and includes a focus on green building, urban ecology restoration, local economic development, land use, transportation, environmental justice and social equity (Wheeler and Beatley 2009). While sustainable housing and urban sustainability are often used interchangeably in the academic literature, sustainable housing refers specifically to the *housing sector* (Choguill 2007: 147). Observing this confusion between terms, Priemus (2005: 5) remarks: "[*in*] the broad literature on sustainable housing, 'sustainable' seems to mean everything".

Focusing on site specific, rather than city or neighborhood scale projects, the IEA (2010: 9) defines sustainable houses as those "…with a substantially better performance in the field of energy use and the use of renewable materials than one built to the standard building requirements. As a rule of thumb, performance is at least 50 percent better". Strangely, Figure 12 presented in the same report includes social, community, and health concerns which remain absent from the definition provided. These additional concerns are also included in the policy areas relevant to sustainable housing identified by Choguill (2007) (see Table 6).

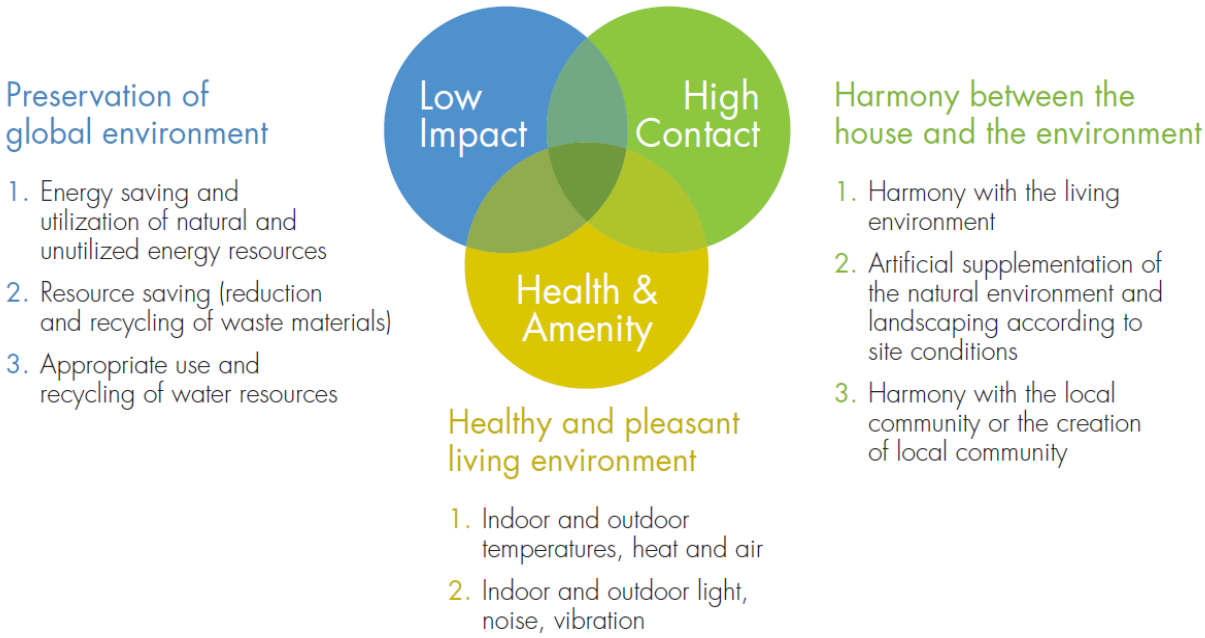

Figure 12 - Three Main Aspects of Sustainable Housing identified by Daiwa House Industry Central Research Laboratory, Nara City Japan (IEA 2010: 11).

Table 6 – Five Key Policy Areas for Achieving Sustainable Housing (Adapted from Choguill 2007: 147-8)

Policy Area	*Justification*
Involvement of the Community	• Ensures projects will deliver satisfaction to future inhabitants • Can be used to improve social relations within communities
Supply of Good Quality Building Materials	• The limiting factor in developing countries • Good quality refers to availability, environmental performance, and access
Building Standards	• Typically increase building costs • Required to ensure good health • Impact on environmental performance • Reduces risk of fire
Housing Finance	• Unlikely that conventional sources of funds will be available on the scale required by developing nations • A central policy issue for governments • Demand for new financial products to support housing will continue to grow
Land	• Any transaction concerning transfer, trade or sale of land almost certainly involves government authorities • Governments have ability to make land available at an affordable price for residential construction

3.4.1 Green Building and Architecture

"Contemporary architecture … sees its main task as the interpretation of a way of life valid for our period" – Sigfried Giedion (1997: xxxiii)

Sustainability is arguably the defining challenge facing current generations. Reacting to this new reality, architectural professionals have proposed a number of principles for designing modern green buildings; "[*most*] such manifestos set forth similar themes in slightly different ways" (Wheeler and Beatley 2009: 262). See Appendix C for a summarized selection of relevant ecological and sustainable architecture principles. Common themes include: (i) respect for limits and capacities of natural systems, (ii) maximizing energy and material efficiency, (iii) eliminating waste, (iv) creating safe objects, (v) inclusion of life-cycle and systems perspectives, (vi) closed loop material cycles, (vii) respect for natural landscapes and species, (viii) consideration of local human needs and preferences, (ix) utilization of sunlight and natural energy flow, and (x) making design visible.

3.4.2 Zero Energy Buildings

Zero energy building, hereafter referred to as ZEB, is a concept that has been refined numerous times since it was first developed in the late 1970s. Initially, the concept referred

to buildings capable of maintaining sufficient thermal energy for occupants during the winter without the use of *artificial* energy; "…the main source being solar energy" (Esbensen and Korsgaard 1977: 195). Without substantial academic attention, progress ground to a halt until sustainability concerns reignited interest nearly three decades later.

In 2006, ZEBs were still in their infancy; with no clear definition, three diverse strategies contended for supremacy (Table 7). Complicating matters further, all the subsequently listed variants of zero in the ZEB concept were also in disputation: (i) net zero site energy (delivered energy), (ii) net zero source energy (primary energy), (iii) net zero energy costs, and net zero energy emissions. See Torcellini et al. (2006: 11) for a brief summarization of the differences. Conducting a literature review of the variants used between 1977 and 2008, Marszal et al. (2011: 973) demonstrated that the total primary energy approach was most common. The study also revealed an academic preference for annual energy balancing using the generation versus use approach (ibid). In an attempt to end the debate, *On The Energy Performance of Buildings Directive (Recast)* (European Parliament and Commission 2010: 18) defined nearly zero-energy building as "... a building that has very high energy performance ... and the nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site and nearby". A similar definition was also proposed by Crawley et al. (2009).

Despite attempts at standardization, additional divisions have recently surfaced. These largely stem from Hernandez and Kenny's (2008) critique that standard ZEB approaches excluded embodied energy. Since then, some countries have opted to include embodied energy considerations while others continue to use the energy balance concept. As a result, "… the ZEB concept is not well defined at the national level… [*and there is often*] more than one understanding of ZEBs in each country" (Marszal et al. 2010: 167). The Norwegian approach is unique in three distinct ways: a) it considers embodied energy, b) focuses on *emissions rather than energy*, and c) uses a *life-cycle perspective* as a foundation for quantification (ibid: 174).

Table 7 - ZEB Renewable Energy Supply Option Hierarchy (Torcellini et al. 2006: 3)

Option #	*ZEB Options*	*Examples*
Supply-Side Options		
0	• Reduce site energy use through low-energy building technologies	• Day-lighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On-Site Supply Options		
1	• Use renewable energy sources available within the building's footprint	• PV, solar hot water, and wind located on the building.
2	• Use renewable energy sources available at the site	• PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building.
Off-Site Supply Options		
3	• Use renewable energy sources available off site to generate energy on site	• Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
4	• Purchase off-site renewable energy sources	• Utility-based wind, PV, emissions credits, or other "green" purchasing options. Hydroelectric is sometimes considered.

3.4.3 Building Information Modeling

According to Rist (2011: 52), "…the term Building Information Modeling (BIM) represents a broad concept that does not have a universally accepted meaning across [*the construction*] industry". Despite this, BIMs can be understood as "…the 'process' of generating and managing building information … and domain knowledge through the lifecycle of a building" (Lee et at. 2006: 758). Through computer modeling, BIMs define geometric objects in three dimensional space, their spatial locations, connections, and the constraints between various objects in the system (ibid: 760). BIMs are already used to provide designers with information about energy use, cost, and scheduling (Young et al. 2009). Attempts have also been made to integrate environmental concerns (Nies and Krygiel 2008). The challenge in achieving this integration relates to lifetime prediction of environmental impacts; BIMs were not initially designed to include temporal dimensions (Rist 2011: 135). Recently however, research has been able to demonstrate proof of concept via integration of life-cycle environmental impact assessment (ibid).

3.4.4 Green Building Assessment Systems and Standards

When assessing buildings according to sustainable principles, it is important to define the criteria against which demonstrated effort can be judged (Cole 1997: 187). Without these,

time, budget, and regulatory restrictions can create debate and compromise over which sustainability goals to pursue (ibid). Standardized *assessment systems* identify "…key characteristics and important subsystems" with serious environmental impacts; they create well-defined rewards, via points in a voluntary framework, for solutions which attempt to remedy them (Retzlaff 2009: 7). "Ultimately, a building receives a total score to reflect its sustainability. Often, the scores are used to assign a ranking, such as platinum, gold, or silver" (Retzlaff 2008: 505). Leadership in Energy and Environmental Design (LEED) in the USA and Building Research Establishment Environmental Assessment Method (BREEAM) in the UK are the two most recognizable metrics in use today.

With many assessment systems in existence, there are distinct differences in theme prioritization (Figure 25) point allocation, the mix of mandatory vs. optional elements, non-environmental considerations, and incorporation of life-cycle analysis among competing systems (ibid; Larsson and Cole 2001: 337-8). The wide variance between systems has been criticized for "… [*lacking*] an ecologically derived baseline, or standard of measure, under which sustainable developments can be analyzed and compared on a universal basis"; i.e. environmental impact per square meter (Olgyay and Herdt 2004: 389). Consequently, the point system can distort public perception of sustainability as it relates to buildings; skyscrapers can achieve better ratings than small residential dwellings despite the fact that they cause considerably more environmental impacts (ibid).

In contrast to assessment systems, voluntary green building *standards* "…provide more detailed descriptions than EU directives, national laws and regulations"; they require full compliance and verification via a third party in order to achieve certification (Standard Norge, 2011). Requirements for the residential Passivhaus standard, considered the pinnacle of green construction technology, include: minimum U-values for walls, ceilings, floors, windows and doors as well as annual average temperature efficiencies, normalized thermal bridge values, specific fan power ventilation factors, airflow leakage rates and a 50% renewable energy requirement (Standard Norge 2010: 7). Green building standards can also be changed by governments in order to compensate for regional environmental, latitudinal and climatic differences; as is the case for the Norwegian passive house standard NS 3700. Other notable green building standards include: R-2000 (Canada), CALGreen (California) and MINERGIE-P (Switzerland).

3.4.5 City Planning and the Growth of Suburbs

Organized city planning, in contrast to *ad-hoc* development of the Middle Ages, developed during the Renaissance in Europe. In 1485, Leon Battista Alberti was the first to advocate for: (i) the careful consideration of where to construct cities, (ii) the use of wide straight streets in large cities and (iii) the use of winding streets in small towns to give the impression of larger size (Reps 1969). Military engineers quickly understood the importance of city planning; both gridded and radial street designs were first used in the design of fortified cities during the late 16th and early 17th centuries (see Figure 13 and Figure 14). These state-commissioned, centrally planned cities embodied the Renaissance ideals of humanism; improvement via the imposition of structure and form. Soon after, these designs were transferred to large metropolitan areas and remained the dominant style until the mid 20th century (ibid).

Starting in the early 20th century, government funding of roads and highways in led to widespread public adoption of automotive technology. The resulting increase in personal mobility provided civic planners with the freedom to design new utopian cities modeled after Ebenezer Howard's (1902) *Garden Cities of Tomorrow*; a book which critiqued city planning and gridded street design for a range of societal problems. In 1929, the Stein-Wright partnership built a residential district in Radburn, NJ based on Howard's design (Figure 15). For the first time, "… housing was arranged in large blocks with interior greens; the innovative use of the cul-de-sac created 'superblocks,' each one 14 to 20 hectares (35 to 50 acres) in size. Units [*were*] oriented towards the internal open areas rather than to the streets" (Friedman 2001: 11). The popularity of this concept created a new standard for subsequent suburban development (ibid). Since then, the number of existing single family households has increased steadily; suburbs now "… grow more rapidly than the central cities they surround" (Song and Knapp 2004: 211). Today, the vast majority of urbanites live in medium sized cities smaller than 500,000 and the suburbs of larger cities (UNFPA 2007).

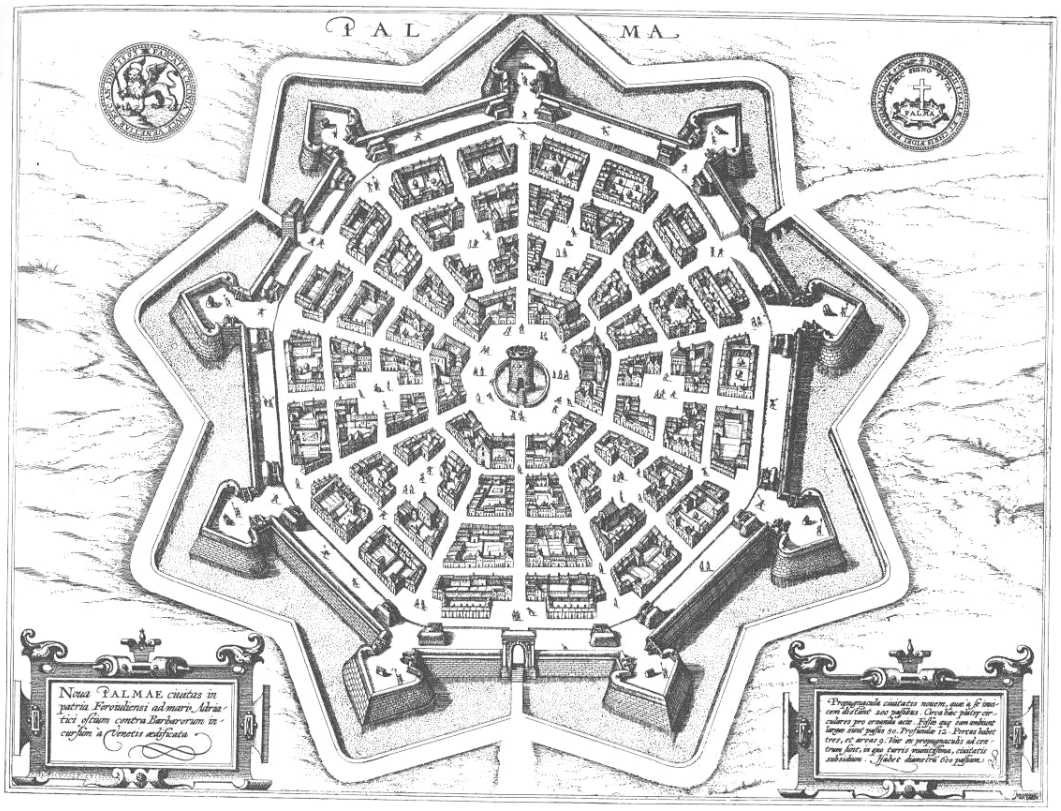

Figure 13 – Radial Street Plan of the Fortified City of Palma Nova, Italy: 1598 (Reps 1969: 11)

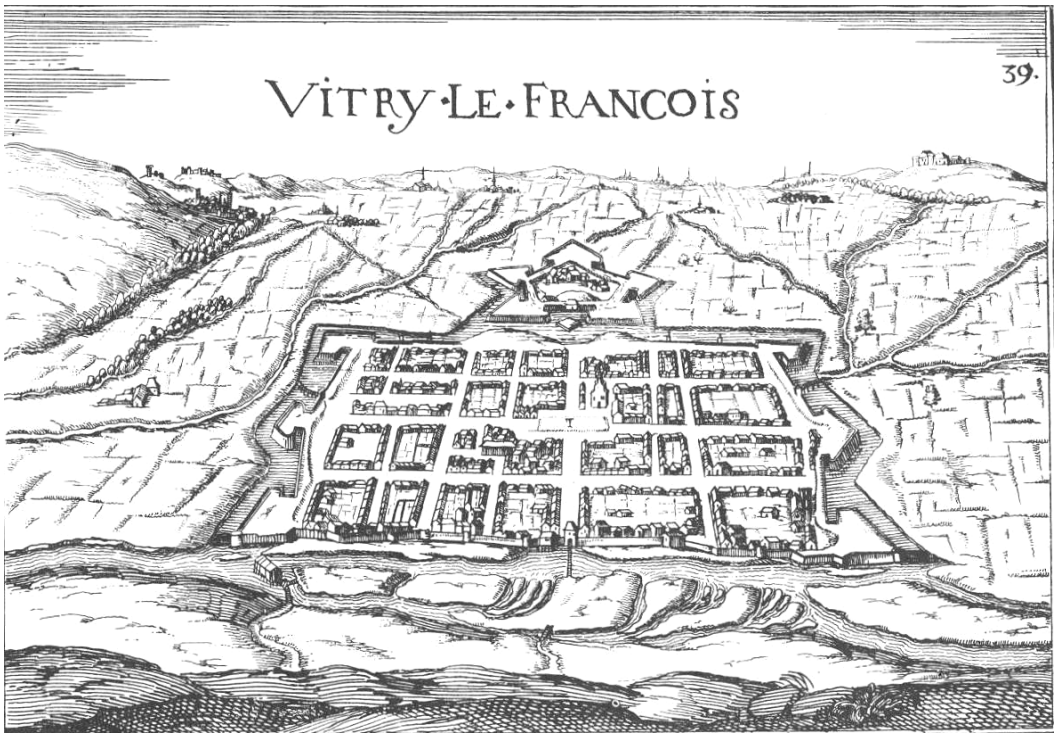

Figure 14 – Gridded Street Plan of the Fortified City of Vitry-le-François, France: 1634 (Reps 1969, p.10)

Figure 15 – Plan for the Northwest and Southwest Residential Districts of Radburn, New Jersey based on the Garden City Concept (Friedman 2001: 11)

3.4.6 Smart Growth and Infill Development

Smart growth is a subset of urban sustainability, and thus, city planning. Also known as infill development, it is a policy which advocates the preservation of open and natural landscapes surrounding urban areas via *urban growth boundaries* (UGB) (Danielsen et al. 1999). Wheeler (2002: 104-5) defines infill development as referring to "…the construction of new housing, workplaces, shops and other facilities within existing urban or suburban areas…[; *it*] represents the opposite of sprawl". A reaction the problems listed in Figure 16, smart growth principles include: increasing urban residential densities, increasing proportion of mixed-use land, pedestrian-friendly layouts, reducing public development costs, creating multi-nucleated urban forms, developing multi-modal transportation systems, and revitalizing older neighborhoods (Downs 2005: 368; Song and Knaap 2004: 211). Infill development has also been suggested as a remedy to gentrification by mandating affordable housing (Steinacker 2003: 493). UGB policies have been implemented in a number of US cities since Portland adopted the first one in 1979 (Figure 24). Benfield et al. (1999:

152) maintain that Portland's UGB has been successful at achieving its goal; "[*the*] results are benefiting both the environment and the region's economy".

- Unlimited outward and "leapfrog" expansion of low-density new development.
- Large-scale conversion of open space and environmentally sensitive lands to urban uses.
- Lack of choice among housing types and neighborhood configurations.
- Worsening traffic congestion and air pollution caused by more intensive use of automotive vehicles for ground travel.
- Costly requirements to expand roads, sewers, water systems, and other infrastructures outward rather than repairing and using those already in place.
- Failure to redevelop existing older neighborhoods.
- Segregation of land uses rather than a mixing of uses that reduces the need for travel.

Figure 16 – The "Undesirable Features" of Urban Development which Prompted the Smart Growth Movement (Downs 2005: 367)

Despite the acclamations, academics investigating the effects of UGBs have warned that they cause housing prices to increase faster than comparable cities with conventional land policies (Voith and Crawford 2004: 89; Staley and Gilroy 2001: 4; Schwartz et al. 1981 and 1984). Others assert that higher housing prices reflect increasing *amenity benefits* that resident experience when *housing services* like access to employment, shopping and entertainment improve (Nelson et al. 2004: 121-140). Finally, a third approach rejects the claim that UGBs cause housing price increases while acknowledging that they cause *land* price increases. Based on the NCE law of supply and demand, Downs (2002: 9) argues that UGBs cannot directly affect price because they "… [*do*] not directly limit the future supply of housing units". Because drastically higher population densities are feasible, builders *should theoretically* react to land price increases as they traditionally have; they build taller buildings capable of accommodating more residents and tailor prices to reflect market demand (ibid).

3.4.7 Community Involvement in Urban Planning

In Trondheim, community involvement in urban planning dates back to the "…successful campaign of direct action to save [*the*] old inner-city working-class area, Svartlamon ... from demolition" in 2001 (Wainwright 2003: xiv). Starting in the early 1990s, squatters took up residence in the area's old, abandoned wooden houses (Smidt-Jensen 2007). After a sustained lobbying effort by the Svartlamon Residents Organization, residents of the area gained government approval to develop the area with their own resources (Wainwright 2003). This

was accomplished via a municipal bylaw that created of the Svartlamon Housing Foundation on November 22nd 2001 (Svartlamon 2001). In order to protect squatters and low-income residents, the Svartlamon Solidarity Fund was established in December 2006 by the Svartlamon Residents Organization (Svartlamon 2006).

Svartlamon is a self described "urban ecology experiment area. The site is organized and operated according to principles of sustainable environmental solutions, flat structure, transparent economy, low standard, affordable rental" (Svartlamon 2011a). The bylaw which created the area states that it "… should be an alternative town with ample room for experimentation, trials and testing. This applies to housing, living arrangements, social interaction, participation, ecology and energy, municipal services, arts, culture and economic development" (Svartlamon 2011b). Evidence of this alternative orientation can be Figure 17; a postcard advertisement produced by resident artists of the area.

In contrast to the Svartlamon area, which was an existing district reclaimed by squatters, Brøset is a *new development* which actively integrates community preferences in the planning process. When completed, the area will contain "…between 1,200 and 2,500 homes [*corresponding*] to 2500 to 5000 inhabitants" (Trondheim Kommune 2010). Initiated in 2007, both the municipality and the local university (NTNU) are involved in the attempt to create a "high-quality carbon-neutral neighborhood"; the inclusion of local facilities is also a focus of the project (Wyckmans 2011: 152). The target is that per-capita emissions in Brøset should "… cause less than 3 tons of CO2 emissions per year [*compared to an average of*] 11.8 tons elsewhere in society" (Trondheim Kommune 2010). If successful, this would correspond to a 75% reduction.

Researchers at NTNU from a variety of disciplines have sought to determine the preferences and social attitudes of potential Brøset residents. This aspect is critical to the success of the project as people "… will need to adapt not only to new kinds of buildings and infrastructure, but also to adjust and adapt their general lifestyle and consumption patterns, user participation" (Löfström 2010: 1). As part of this process, open communication via an online blog has allowed for the diffusion of information to interested parties. A number of breakfast meetings have been announced using this system; these meetings have been used to present proposals to the public and to gauge public opinion via the eliciting of responses (Brozet 2011).

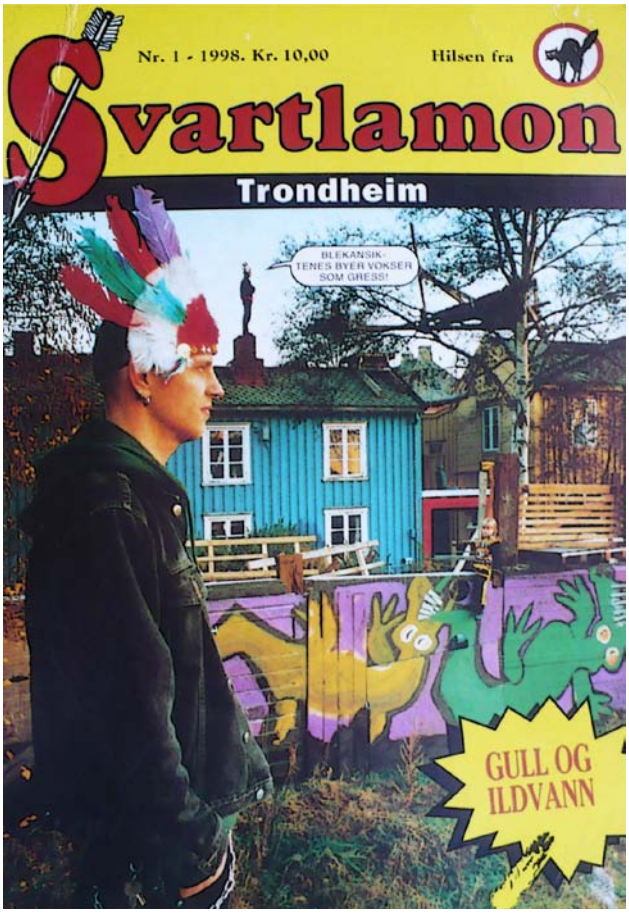

Figure 17 – Svartlamon Postcard Created by Local Resident Artists

3.5 Housing Ownership and Residence Models

Nomad – "a member of a people that travels from place to place to find fresh pasture for its animals, and has no permanent home. Also (in extended use): an itinerant person; a wanderer" (Oxford English Dictionary 2011).

The Neolithic era first witnessed the advent of agricultural practices and permanent settlements; since then, land ownership has been an integral component in the development of society. In nomadic societies "…there was no land-ownership in the capitalist sense" (Khazanov 1994: 159). While the personal possessions required to build temporary structures were recognized as personal property, the ground upon which they stood was not. Land ownership in nomadic societies was a privilege reserved for tribal leaders; it was mainly a symbol of social status. Rather than being traded, lands "…were acquired by way of conquest, seizure and rewards" (ibid).

Land and housing ownership advanced with the development of stratified agrarian societies. In Egypt, the power of the monarch was established via complete ownership of the land; peasants were granted tenancy in exchange for a portion of the harvest or final product

(Manning 2003). Farmers "…were direct tenants of the king, the land was leased year to year with the terms adjusted to take account of fluctuating conditions, tenure could be passed to heirs, or could be leased for the short term"; however, absolute individual ownership was impossible (ibid: 55). Later feudalistic societies were based on similar structural foundations.

Feudalism is a societal system based on "…ties of vassalage [*otherwise known as servitude*], fiefs, service in arms owed to lords, and private administration of justice" (Brown 1974: 1066). Feudal land tenure was predicated on non-hereditary land-use rights which were forfeited at death or when vassals failed to meet the terms of their feudal contracts; ultimately, all land was the property of the monarch (Herlihy 1970). Fiefs were first granted to lords who subsequently granted smaller parcels to knights and peasants. These land use rights were conferred with a ceremony called *investiture*; a "… lord, usually after receiving the homage of the vassal, would hand him a branch or a clod of earth, a symbol of the fief he was granting him for his support" (ibid: 75).

Until 1200 AD, the land-rights of lords were limited to a single lifetime; the *hereditary principle* of land transfer from father to son was not established until after the Norman invasion of England (Thorne 1959). After the legal establishment of hereditary transfer, the regent was still accepted as the legal owner; however, land could be transferred if consent was given by both the lord's son and the king (ibid). A logical inconsistency within the hereditary principle eventually led to the replacement of complex feudalism with *feudum simplex* (also known as *fee-simple absolute*) (ibid). Under fee-simple tenure, debt is assignable to land; in exchange, an individual has "… the right of alienating the lands he holds, either in his life-time or by his will" (Williams 1845: 52). Despite these rights, "tenants in fee [*are not*]…the lords of their own domains"; "all land-owners are merely tenants in the eye of the law" (ibid).

Within the feudal societal structure there also existed vast areas of *common-use* land; a type of land-right that allowed for the equitable distribution of resources between peasants in-lieu of ownership. According to Thirsk (1984: 36), common land was defined by the four essential elements in the following paragraph. By the time the enclosure movement began in the late eighteenth century, common-use land had been a distinctive feature of the English countryside for centuries (Burchardt 2002). During the eighteenth century, population growth contributed to the decline of real income; thereby reducing the surplus available for

taxation (Armstrong 1981). Industrial developments during the same period "… [*reorganized*] production along more efficient, profit-orientated lines" (Beresford 2010: 38). The pursuit of profit created competition between the upper echelons of English society; traditional fixed-lease rent profits quickly became insufficient as inflation entered the new market system (Wordie, 1983). Through the use of private Parliamentary Acts which negated the conditionality of consent required for enclosure, "about about one-fifth of the surface of England [*was*] enclosed … between 1700 and 1844" (Blum 1981: 480).

> "First, the arable and meadow is divided into strips among the cultivators, each of whom may occupy a number of strips scattered about the fields. Secondly, both arable and meadow are thrown open for common pasturing by the [*livestock*] of all the commoners after harvest and in fallow seasons. In the arable fields, this means necessarily that some rules about cropping are observed so that spring and winter-sown crops may be grown in separate fields or furlongs. Thirdly, there is common pasturage and waste, where the cultivators of strips enjoy the right to graze stock and gather timber, peat, and other commodities, when available, such as stone and coal. Fourthly, the ordering of these activities is regulated by an assembly of cultivators—the manorial court, in most places in the Middle Ages, or, when more than one manor was present in a township, a village meeting" (Thirsk 1984: 36).

In contrast to the above mentioned land tenure systems, *Allod* is a type of property ownership where land is "…held in absolute ownership, not in dependence upon any other body or person In whom the proprietary rights were supposedly to reside, or to whom the possessor of land was bound to render service" (Garner 2004: 83). Tracing the roots of allodial land tenure to the Anglo-Saxon colonization of Britian in the 5th century AD, Thomas Jefferson used this as a justification for opposing the feudal structure governing early American colonies (Colbourn 1958). Allodial ownership also briefly existed in the Catalan region of Spain. In an attempt to recapture Spain from Islamic rule, Catholic rulers in the north released peasants from slavery and granted them the right to mobility (Bonnassie 1991: 156). Soon after reconquering Catalonia, these peasants settled and claimed allodial ownership of their new houses and farms. However, this independent form of societal organization was not destined to last; it was replaced by *feudalism* less than a generation later in 1060 AD (ibid).

Modern Land Payment Methods

"Lease - A contract between parties, by which the one conveys lands or tenements to the other for life, for years, or at will, usually in consideration of rent or other periodical compensation" (Oxford English Dictionary 2011).

"Mortgage - The creation of an interest in (originally the conveyance of) real or personal property by a debtor (called the *mortgagor*) to a creditor (called the *mortgagee*) as security for a money debt (esp. one incurred by the purchase of the property), on the condition that the interest shall be extinguished (originally by reconveying the property) on payment of the debt within a certain period" (Oxford English Dictionary 2011).

Today, fee simple is the most common form of land ownership worldwide. Under this system, the two methods defined above can be used to obtain residency. For leases, the renting party is called the *tenant* or *leasee* while the owning party is called a *landlord* or *leaseholder*. Residential leases are available in a number of various configurations; the majority of which are short term. A *year-to-year tenancy* or *periodic tenancy* is a contract that requires renewal at the end of each agreed period (Bruce 1998). In cases where no contract exists, *tenancy-at-will* governs the landlord-tenant relationship; "… the tenant is always vulnerable [*to eviction resulting from*]… a change in the whim of the landlord" (Sparkes 2001: 22). Finally, *fixed-term leases* exist for a set period of time agreed upon by both parties. Fixed-term leases have been used by the Grosvenor family in the Mayfair and Belgravia region of London, England for over 300 years. Available leases "…range from a few years to a century. When the lease is up, the duke (or his heirs) takes back the keys" (Reguly 2011). The company is fully owned by the family and is operated in trust for "…the benefit of current and future members of the Grosvenor family" (Grosvenor Ltd, 2007).

The word mortgage is derived from a French term which roughly translates to *dead pledge* (Blackstone 1770: 157). Mortgages are commonly used to acquire the necessary capital for purchasing property; the risk of foreclosure exists until the principle sum and the accrued interest is paid in full (ibid). Today, mortgagees can choose from a number of variations including: fixed-rate (FRM), adjustable-rate (ARM), and interest only mortgages. For "…FRM the rate is fixed for the term of the loan, whereas on an ARM it is fixed for a shorter period. The period ranges from a month to 10 years" and is based on the market rate set by central banks (Guttentag 2010: 2). Interest only mortgages contain a provision where the minimum monthly payment required "… consists of only interest"; the remaining sum is then due at the end of the contract (ibid: 107). Common mortgage periods range from twenty to fifty years.

3.6 Residential Preferences

"Houses are not just physical shells but also emotional and symbolic places filled with meaning for their occupants… [; *they are*] material *and* social constructions" (Thorns 2004: 5).

While the technological capacity to build 'sustainably' has existed for decades, widespread adoption by consumers has not taken place. As Carlsson (2011) states, psychology based investigations have played an integral role understanding this phenomenon. A number of these studies, aimed at identifying potential barriers, have been done to determine which factors are important to consumers. Based on the results of qualitative interviews, location can be seen as the primary factor guiding residence decisions (Isaksson and Karlsson 2006). While individual preferences vary from person to person, traditional looking houses, closeness to nature, recreation, water-bodies, proximity to large cities and employment opportunities have all been shown to be important considerations for consumers. For examples of typical, traditionally styled Trøndelag residential structures, see Appendix D. Similarly, financial issues considerations are a factor in the decision process related to residence. Hoffman and Henn (2008) demonstrate that consumers reject housing products with higher upfront costs even when cost-benefit calculations prove their cost-saving potential. This is attributable to differences in the payback period and the expected "ownership time frame" of the buyer (ibid). Thus, it is important to design solutions which rectify these different time-scales. Finally, housing characteristics have been identified as important. Table 8 presented below includes a list of factors which families cited as important for fulfilling the condition of *satisfaction*.

Table 8 - Important Factors Related to the Satisfaction of Potential Homebuyers (Saaty 1990: 14-55)

Factor	*Description*
Size of House	- Storage space: size of rooms, number of rooms, total area of house
Location to Bus Routes	- Convenient, close bus service
Neighborhood	- Little traffic, secure, nice, low taxes, good condition of neighborhood
Age of House	- Self-explanatory
Yard Space	- Includes front, back and side, and space from neighbors
Modern Facilities	- Dishwashers, garbage disposals, air conditions, alarm system, and other such items possessed by a house
General Condition	- Repairs needed, walls, carpet, drapes, cleanliness, wiring
Financing Available	- Assumable mortgage; seller financing available, or bank financing

Comparing these results to consumer preferences in the Trøndelag region, Carlsson (2011: 63) found that least important features included "… having a sauna, closeness to water/sea, restaurant, cultural activities, and shopping [*centers*]". This was attributed to cultural preferences for spending time in nature. All of the factors identified by Saaty (1990) were also shown to be important with the exception of *modern facilities* (ibid: 62). The most important factors in Trøndelag were shown to be "… location, e.g. distance to work and city centre, distance to nature, [*and*] a child friendly neighborhood with kindergarten and school nearby. Other important aspects were possible financial benefits from the energy saving potential and indoor characteristics, e.g. number of rooms or possibility to rent out an apartment" (Carlsson 2011: 62). Another key finding from the report indicated that homebuyers considered environmental performance important; however, it was *not determinant* in final purchasing decisions (ibid: 44).

4 Empiri

4.1 Representation of the 4 Aspects of Sustainability in Academic Disciplines Related to Residential Dwellings

Based on the mapping of the four aspects of sustainability presented in Table 9, there is a high degree of variation across the academic disciplines related to sustainable residential dwelling. 58% of the fields included explicit social considerations, 54% included explicit economic considerations, 75% contained an explicit reference or focus on environmental issues and 13% of the fields included explicit intergenerational considerations. Aside from the Brundtland Report, ecological economics was the only discipline which explicitly included a focus on all four sustainability aspects. Four academic disciplines included references to three of the four aspects; of these, only multigenerational discounting included explicit intergenerational concerns. Fields in this category include industrial ecology, green architecture and smart growth and infill development. Ten of the fields included explicit considerations for two of the four aspects. Of these, none contained intergenerational concerns and nine contained environmental concerns; the remainder was equally distributed between the social and economic aspects. Six of the twenty three fields only included explicit considerations for one of the four sustainability aspects; they were distributed evenly among the social, economic and environmental aspects.

Table 9 - Inclusion of 4 Aspects of Sustainability in Academic Disciplines Related to Sustainable Residential Dwellings

	Explicit Social Considerations	Explicit Economic Considerations	Explicit Environmental Considerations	Explicit Intergenerational Considerations
Sustainability / Brundtland Report	X	X	X	X
Cost Benefit Analysis		X		
Life-Cycle Costing		X		
Industrial Ecology	X	X	X	
Life-Cycle Impact Analysis	X		X	
Ecological Economics	X	X	X	X
Contingent Valuation		X	X	
Multigenerational Discounting	X	X		X
Eco Design	X		X	
Design for Diassembly			X	
Reuse without Remelt			X	
Green Architecture	X	X	X	
Zero Energy and Emission Buildings			X	
Smart Growth and Infill Development	X	X	X	
City Planning	X			
Building Information Modeling		X	X	
Green Building Assessment Systems and Standards	X		X	
Community Involvement	X		X	
Sustainable Housing Discourse	X		X	
Life-Cycle Costing		X	X	
Cost Benefit Analysis		X		
Green Building Standards	X		X	
Housing Finance	X	X		

4.2 Interview Results

4.2.1 Defining Sustainable Residential Dwelling

Most responses included at least two of the three aspects of sustainability; however, respondents defined sustainable dwellings in very different ways. All respondents defined dwellings in relation to sustainable principles; however, some only referenced one or two of the three aspects. Only one respondent framed their response in relation to global warming. Another respondent referenced all the sustainable aspects and specifically identified one as being different from the rest in terms of importance. Yet another respondent defined sustainable only in terms of energy and in relation to the passive house standard. Two of the respondents included a lifecycle qualification in their definitions. Another two respondents also extended the system boundary beyond the dwelling itself and included factors that enabled residents to lead more sustainable lives. Others commented on the lack of a standard definition, difficulties in applying the definition of sustainable development, and the tradeoffs which resulted from this. Only one respondent included intergenerational concerns in their definition.

> Respondent #1 – "I would define dwellings and sustainable principles separately. Dwellings that people reside in all year round - in contrast to leisure buildings or part time dwellings - built and operate in line with sustainable principles. Sustainable Principles include systems, buildings, dwellings that maximize the factors that may contribute to a minimized resources consumption, environmental impact, costs and negative social impacts from a life-cycle perspective".

> Respondent #2 – "dwelling that requires little inputs to operate that is not too resource intensive to construct and that doesn't cause and toxicity problems or other problems when you dismantle it. It is clearly a building that sort of enables inhabitants to lead a sustainable life. So aspects that are important are obviously the energy use during operations, the inputs like water and waste-waster treatment"

> Respondent #3 – "I would start from the theoretical separation of environmental-ecologic, social-cultural and economic-financial dimensions. Ideally all three criteria are required for total sustainability, but in practice it is about tradeoffs and a largely elusive knowledge base with non standard definitions".

> Respondent #4 – "…from my perspective it is quite important to look at the environmental and the social issues interplay. So that sustainable residential area needs to be some kind of balance between the social, environmental and economic – but of course I would say that environmental aspects would be sort of the major one… intergenerational equality and the next generations are also important".

> Respondent #5 – "… to combine both the ecological, economic and social sustainability. It's often quite difficult to work with because – well the definition itself is fine of sustainable development – but it is very difficult to operationalize when it comes to architecture or buildings or dwellings".
>
> Respondent #6 – "it should be within the 550 parts per million scenario and of course that's the total allowance of carbon for capitas… In terms of CO2 you would go somewhere around 2 tons of carbon per capita in total … so it should be over the lifetime, lifecycle of dwelling pretty much as good as it can get and currently that is the passive house standard although I'm not convinced that it will be a passive house that will be the sustainable dwelling".
>
> Respondent #7 – "…probably be something like a passive house standard… It can also be low energy buildings. I think it needs to be either one of those categories... we need some certain standards of insulation for instance they need a certain level of insulation to be sustainable".

4.2.2 Sustainability of a Typical Trøndelag Dwelling

Without exception, all of the respondents asserted that typical residential dwellings in the Trøndelag Region were not sustainable; however, the explanations given were highly diverse in their reasoning. Three of the respondents identified the issue of stock and age in buildings. They suggested that most of the dwellings in the Trøndelag Region were built between 1950 and 1980; buildings from these eras were criticized for being inefficient consumers of energy and thus, unsustainable. The respondent who defined sustainable dwelling as a low energy building also used the same logic; they used the lack of passive or low energy houses in the Trøndelag Region as proof positive that dwellings in the Trøndelag Region were unsustainable. High energy use was also cited as a reason by another respondent, however, this was framed in the context of emissions; high energy use could be accepted if it came from renewable sources. In contrast, one respondent also commented on the lack of passive houses, but didn't use this as a justification for classifying typical dwellings as unsustainable. Instead, failure to incorporate all three sustainability aspects in the design of dwellings was cited as the principal reason. Three respondents also commented on the predominance of suburban sprawl as a reason for their answer; two asserted that sprawl was an inherently unsustainable practice while the other commented on its relation to decreased quality of transportation.

> Respondent #1 – "No, they would not. A typical dwelling would does not meet this criteria. Important to distinguish between the entire existing stock, the majority built after the second world war, fairly recent, or new buildings. Typical must be understood as a mix of all these. There will be a type-age matrix in terms of the existing stock. Typical dwellings consume too much energy, and then per unit of floor area. They are not energy efficient… Typical

existing dwelling in Trøndelag is influenced by detached, single family households, which from a resource perspective is much larger than necessary – in terms of floor area per capita…Beyond the dwelling itself – the dwelling neighborhood is normally not planned and developed with the aim to minimize the overall urban efficiency in terms of resource consumption and environmental impacts".

Respondent #2 – "No clearly not. We have not very good energy standards so there is lot of energy use. Most houses, especially houses that are constructed in the 1960s, 70s and 80s and some of the older buildings there is a predominance of single family dwellings and that means that the settlement structures are very dispersed and they don't lend themselves easily to walking, bicycling and public transportation - especially for public transportation the density is too low. I think clearly that the thing that can be fixed is energy use, I see some big needs for improvements".

Respondent #3 – "Intuitively speaking, probably not… As for the location of new developments, in my view the more suburban and peripheral locations suffer from substandard public transport and road networks".

Respondent #4 – "… what is actually a typical residential dwelling in Trøndelag? ... I guess the answer is that none of the dwellings – or very few of the dwellings in Norway today – are really sustainable when it comes to all the aspects that should – all the (*sustainability; researchers note*) criteria – that should be met. We have a very few new buildings that are quite low energy demand…perhaps less than 50…. But we have some old houses, traditional houses that have been used for generations which could be regarded as quite sustainable by many respects because they have a shown ability to adapt to different types of lives and different times and different needs and household functions".

Respondent #5 – "Depending on what you regard as typical there is in Trøndelag there are lots of sprawl which in itself – so even if the house would be fairly well insulated etc, - the transport needed to get to and from the house, the infrastructure needed, even all the local schools and [coughs] sorry all the shops and schools which are needed to sustain people in those sprawling areas - I don't think you can call sustainable".

Respondent #6 - "As they are now, not at all…They are on average way above 100 kHw per square meter per annum and that's not even close. We are going down in the range of at least below 30 I think. So if we are talking energy-wise globally then embodied energy also I don't think they are sustainable if you are talking (*about; researchers note*) new construction. But of course they are already built and then it is a matter of heating and then it's a matter of energy – I mean if every house has its own windmill then any house could be sustainable".

Respondent #7 – "A typical dwelling in Trøndelag or Trondheim area is already built, many of which quite some years ago and it's not very many passive houses and not low energy buildings either. So in that regard there are not very sustainable buildings in the Trøndelag region".

4.2.3 Intergenerational Equality

Four of the respondents asked for clarification on the term or professed a lack of expertise. Two respondents understood this concept as referring to equality between living generations, i.e. children, adults and elderly citizens. One of the two respondents who indicated having this viewpoint suggested that it would be difficult to apply this concept to dwellings. The other one suggested that it would be better suited to applications in neighborhood design. This viewpoint was contradicted by another respondent who said the concept could be applied by designing dwellings capable of being inhabited by all age groups; however it was unclear whether this response was framed using a living generation viewpoint or a future generation viewpoint. Two respondents said that the concept was important in relation to the service life of dwellings; one of the two stated that service lifetimes should be extended to achieve this concept. Only one of the respondents used the future generation frame in their understanding of the concept. Another respondent said that the concept didn't matter and that sustainability via energy efficiency could be achieved without the use of the concept. Three of the respondents said that they were unaware of research related to sustainable residential dwellings which incorporated this concept or had not heard the term used in the related research. Finally, one responded suggested that financial measures and agreements could be applied to achieve this goal.

> Respondent #1 – "I don't know very well the concept of intergenerational equality and I have not been part of reading research literature on this aspect…My understanding is that the concept means that people of all generations could live and flourish – I mean be happy - in the same buildings and neighborhoods not being segregated as much as today… children and old people and workers and people from different social layers and groups could be happy together. I think that is much more related to the qualities of the neighborhood than it is the quality of the dwelling or the building itself … I don't know to what extent this is being done but I don't think it is being done at a large scale … a strong cooperation between researchers from architecture, urban planning, sociology, psychology and geography and they could define (*this; researchers note*)".
>
> Respondent #2 – "Can you explain the concept please?...I think is a very abstract term to apply to building because if you look at the building I think about the kids that grow up there and not about the environment that they will experience later – so if you talk about buildings focus the people who live there whether they are elderly or kids or grown-up or whatever - I think it is a little difficult to relate".
>
> Respondent #3 – "…one should think at least two generations ahead… Some people can and will pay for a premium of a pleasant location, and that premium should now be channeled into good use socially and environmentally too. It is about reinvesting of the extra profits made into future use value. If not voluntarily, then by agreements/covenants".

Respondent #4 – "Buildings and housing should be flexible and be able to meet the different needs and changing use patterns in the future. That is what I understand when you talk about intergenerational equality – that dwellings will last for a long time, they wont only be a kind of a short investment commodity sort of thing … I don't think it has had very – it has not been the issue that has had the most research money and resources put into. Probably because it's quite hard to measure and to assess…I have not heard the concept intergenerational equality used when it comes to architecture and sustainable housing in architecture. It might be, but it is not one which is commonly used".

Respondent #5 – "…people tend to stay in their suburban villas for a long time even if they are only using half of the house due to decreased mobility while lots of younger families have that same dream and that same need so if we want to sustain this dream of suburban villas it would be much better to try to get solutions where different generations could live under the same roof".

Respondent #6 - "You have to clarify what you mean by intergenerational equality…In the way that we are looking into new building more previously is supposed to have longer lifetime and more flexibility in terms of use then it would suggest this quality is of interest. When it comes to the Norwegian residential dwelling stock it's not really been addressed I think… I think that it's an important quality that comes in terms of service life of the building and the flexibility of the building. And so we have to think of the same resilient or robust buildings. I'm not sure if research as such here has been done on that".

Respondent #7 – "I'm not so familiar with this concept …I think that it doesn't really link to the energy efficiency quality of the buildings. So if you can be very energy efficient or say sustainable building – and still not take intergenerational quality into account. So I don't think that it really matters so much about because sustainable buildings in my regard is more about the energy efficiency or the other qualities".

4.2.4 Integration of Community Preferences

All of the respondents indicated awareness of projects which have attempted to integrate community preferences. Five of the respondents mentioned the Brøset project in Trondheim as example; only one of these respondents referenced the Svartlamon area. Two of the respondents talked about the Vauban settlement, one respondent mentioned a settlement in Finland while yet another mentioned one in Sweden. Finally, one of the respondents talked about a research center in the UK and listed a number of individuals involved in research there.

Respondent #1 – "Immediately I think of the Brøset project in Trondheim because this was the first pilot project in Trøndelag where emphasis has been given to not just the design – not just physical design of buildings and infrastructure but also on social activities – in terms of neighborhood qualities with the aim to reduce carbon emissions. If you talk about individuals you could try and approach (*John Doe #1; authors note*). He is from the social sciences and

he is involved in the same Brøset project ... have you met (*John Doe #2; authors note*)? – he is by education a psychologist and he did his PhD in Industrial Ecology from Psychology some years ago and he has been one of the key persons – initiators – for the whole Brøset project".

Respondent #2 – "Yes there has been research and attempts to build this dwellings that have involved user involvement in the planning stage. So, there was for example this project in Freiburg, Vauban, a project in Vienna that I investigated, the car-free settlement there is one of the projects where user involvement has been important. There has also been in Sweden, they have done a lot of research on alternative living firms; sustainable living firms where user involvement has been quite important …user involvement is important and the question is then what does it really mean "how do users participate" – it clearly contributes to creating more of community, more of a sense of identification with the building project, a better knowledge of your neighbors".

Respondent #3 – "(*Royal Institution #1; authors note*) people are the most prominent ones: (*John Doe #6; authors note*), (*John Doe #7; authors note*), (*John Doe #8; authors note*), (*John Doe #9; authors note*), (*John Doe #10; authors note*) and other visionaries involved. I know also others, more individual contributors, mostly from the UK, who have touched on this topic".

Respondent #4 – "…I'm involved in a project that has this part integrated in the research. And I think it's quite – I mean – not common in all projects but its more and more common because it's more and more acknowledged that the users and the user preferences are essential if we want to achieve the objective. So yes, my answer is yes. It is related to urban development project at Brøset … we have a post-doc candidate who works on actually on social-cultural conditions for this development. And she has done several focus group interviews with different groups of people, neighbors, potential future residents, etc. … Vauban in Freiburg; there they have a very strong integration the whole town. People were invited in the very early stages to take part in this project and establish what they call 'Baugruppen' (consisting of 10-15 households) to develop their own housing project … In Norway several more smaller projects, more initiated from the residents themselves; Svartlamon is actually an example".

Respondent #5 – "Yes, we are doing so. Of course there have been a lot of projects in the direction of low carbon neighborhoods. So not just individual dwellings but entire neighborhoods where you look at housing, other kinds of facilities, transport, climate adaptation and so there are lots of international examples as well … We are working for example on this Brøset project where we really try to ask questions with every step in the process – both related to the master planning of the area to the housing itself, the facilities around and the way it which it might be able to influence people's lifestyles. Its architecture, engineering, planning in cooperation with social-cultural studies like product design, artists even. So we are trying to find any kind of overlap between our disciplines that might be able to change or affect peoples' behavior".

Respondent #6 – "I think the Brøset project tries to do that and we are a bunch of people who have been working on that project. So the question is in that regard is yes – whether or not that is a success, I mean it's not completed yet, we don't know the results yet but it has had an impact on the municipality of Trondheim and what they are going to do on that area. It is at least a start and it is somewhere between 1200 and 2500 apartments or dwellings so, ya we are starting. And there are alright examples around the world in Finland and other places – ya it started. And I think it is recognized as an important thing".

Respondent #7 – "Ok I think they are planning this new local community at Brøset. And I think that they have both researchers and possible users involved but I am not so familiar with that project".

4.2.5 Quantitative Tools of Industrial Ecology

Six respondents were able to give examples of how the quantitative tools of industrial ecology have been applied to research related to sustainable residential dwellings. One of these six respondents said that industrial ecology tools had not been used to a large extent in relation to the field of interest. Two of the respondents indicated that there was a connection between the Industrial Ecology Programme at NTNU and the Brøset project. Three respondents mentioned two companies currently using the industrial ecology tools in connection with residential dwellings. Three respondents explicitly referred to material flow analysis (MFA) and three talked about life-cycle analysis (LCA) in connection to research on sustainable residential dwellings. Two respondents connected these tools with the quantification of environmental impact in relation to dwellings; two respondents connected these tools to the quantification of CO2 emissions. Only one respondent commented on the possible combination of LCA with Building Information Models (BIM) to solve one of the limitations of traditional LCA. Scalability was a term that arose twice during the interview process; both times in relation to MFA. Both respondents commented on the need to consider whether a low environmental impact technology was appropriate for large scale implementation. Finally, one respondent was unable to answer the question.

Respondent #1 – "…the quantitative tools that are mainly addressing the flows of resources and emissions and the impacts with respect to economic impact or environmental impact… there has been use of industrial ecology tools in related projects in examining the dwellings stock or examining the individual buildings or examining projects and development areas … the Brøset project that is directly its goal is examining individual dwellings and neighborhoods but mostly focusing on neighborhood areas so they are of course concerned with energy consumption, about energy or fossil energy and greenhouse gas emissions … so you can define it as an MFA or energy assessment linking up to life-cycle analysis methods … Also you have (*Company AS #1; authors note*)– I mean the spinoff company from IndEcol that has been doing this kind of

research. And then it is research activities as (*Research Institute #1; authors note*)".

Respondent #2 – "Well they have been applied to investigate the impact of buildings. So what are the emissions that the person causes living compared to living somewhere else? The tools have been investigated also in connection to some of the design projects. So in Freiburg there is the case where researchers have been involved in the design of the neighborhood and those are quite relevant. I mean there is a lot of research going on – sort of energy performance of buildings that obviously is integrated - building testing and so on".

Respondent #4 – "Ya this is not my field but to return to the Brøset project we also have cooperation with the industrial ecology people… they took part in defining or providing some kind of a basis for the city of Trondheim to define… what carbon neutral would mean or could mean in this context. So with the help from this group – and a consultancy firm called (*Company AS #1; authors note*) – and they supported the City of Trondheim to set a goal of reducing CO2 emissions to 3 tons per person per year in the future".

Respondent #5 – "The most obvious one was CO2 calculator which (*Company AS #1; authors note*) created together with the Industrial Ecology Programme – it was related to all activities and products in Norway. And when the four teams that were in the parallel commissioning process (*for Brøset; researchers note*) that were given the task to develop a master plan they had to fill out this table that (*Company AS #1; authors note*) made and for every design decision they made they had to argue how it was going to affect CO2 emissions … We also had a lot of discussions about MFA for example and especially the scalability …We don't want Brøset to be a unique case but we want to try out solutions that should be transferrable to other areas or even larger regions … LCA we are looking at of course".

Respondent #6 – "…there is obvious LCA to various degrees and various successes. It's not been a complete success due to lack of inventory and then there are several studies who has looked into the MFA of things and have I think the combination of these two tools will make an impact … the construction industry is the Goliath and the LCA is the David I think there has to be changes in how we do the LCA to fit the workflow of the construction industry if it's going to make an impact … the problem with LCA in relation to buildings is it is not complete to what you want to know for the building for instance you will never get indoor air quality from an LCA. So you need other tools… (*using Building Information Models (BIM) is; researcher note*) a route – it's not really been done yet and will take some time. We are trying to make research on this but it's not come very far yet. In principle it would be great".

Respondent #7 – "I do not think that it has been used so much before. But these days when we are talking about zero emission buildings it is being picked up more and more. There are PhD students working on applying these types of tools to analyze various problems related to buildings, e.g. what type of materials are important for the buildings of the future to reduce the carbon emissions … the life-cycle of the building also needs to be considered … Life-cycle analysis is the tool we will use and that is the tool we have used so far".

4.2.6 Economic Cost Models and Finance

Once again, interviewee responses to this question had a high degree of variability. Of the seven respondents, two mentioned life-cycle costing, two mentioned property value studies, three referred to cost-benefit analysis and one mentioned input-output analysis. The same individual who talked about input-output also discussed the importance of discount rates in cost calculations. Another individual touched on this topic indirectly be referring to the influence of mortgage rates in consumers purchase decisions. The previously mentioned respondent also indirectly referred to the financial concept of opportunity cost in their discussion of tradeoffs between energy efficiency and increased comfort via internal amenities. One respondent attributed the limited use of life-cycle costing to the lack of dialogue between producers and purchasers of dwellings. Finally, one respondent asserted that financial models were more common in corporate office buildings and that the practice needed to be transferred to residential dwellings. However, it is of note that two of the respondents were able to provide examples of corporate use of these tools in relation to residential dwellings.

> Respondent #1 – "I have no information on this actually beyond the fact that what I know is that lifecycle costing, which is then one kind of kind of cost benefit – one branch of cost benefit – have been used ... (*Company AS #2; authors note*) in Norway developed a lifecycle costing tool in order to get a quantitative instrument to find out what are the life-cycle costs of different types of buildings …. there is very little – not a very large – dialogue between the planners and the developers and the future owners of the apartments, and therefore of course there is not that strong incentives to include life-cycle costs performance in the project".
>
> Respondent #2 – "…I'm not sure about finance as such. It's clear that people do think about costs and people do trade-off operational costs against the higher costs of building the building. So people have calculated you know starting from simple payback times through some sort of internal rate of return calculations. But those simple – basically investments – calculations that I have seen".
>
> Respondent #3 – "Insofar as 'green' certification of buildings is concerned, there has been some econometric modelling efforts, but any effects of such having price or rent lifts pertains almost exclusively on the office side… My take on this, albeit based on rather qualitative material, is to bring the private sector housing market onto the sustainability agenda, and use the info of property prices to determine economic sustainability, which for me always must come before the other dimensions in the analyses".
>
> Respondent #4 – "…I have been working on (*Research Institute #1; authors note*)– so I have been working together with engineers. They very often do costs-benefit analysis of the technical measures or the – ya or the proposed

specific technical measures – on projects. They also provide some sort of cost models. So when it comes to the low energy or passive houses there is always a discussion about how much extra cost should be used. And when it comes to the energy supply system for example on Brøset it will be assessed on some kind of an optimization of the costs and the environmental issues together".

Respondent #5 – "People don't invest in sustainable housing because it costs more in terms of upfront investment and even if we try to – you know if we give them lifecycle costing models – it often doesn't change the case because people invest everything they have in this new house. So they would rather pay for a larger kitchen than for better insulation … In the context of this Brøset project we would like to cooperate with a bank like (*Company AS #3; authors note*) for example that would be able to provide a loan with better conditions for sustainable housing … In addition we are also, we are planning to look at different kinds of financial models for the housing that is developed at Brøset whether it is different kinds of ownership and tenancy models".

Respondent #6 – "Well there has been a lot of cost analysis and LCC going on but these depend on which interest value you are using because the higher value you use the less impact the future has so it's kind of been a problem that you don't really appreciate the future in economic terms … If there is a conflict between cost and environmental performance I think cost will win – and that's a problem.. I think that maybe through input output or other tools you could use this framework as a way to get to the LCA".

Respondent #7 – "No, I'm not so familiar with that – not in the research. But for zero emissions buildings to be sold in the future they have to be cost effective. It the investment cost is larger than for other buildings, the owner/user need to save money in the operational phase. But, I haven't looked into the research in this".

4.2.7 Building Standards

Answers to question seven took one of several different approaches. Two respondents commented that standards were the result of academic research. One of the two respondents who advocated this viewpoint commented that there was a high degree of cooperation between the research community and the related authorities in Norway. One respondent commented on the possible ways in which building standards could be studied; the two proposed methods included a) studying the link between standards and health and b) studying the influence of historical standards on resource consumption. Another researcher commented on the potential difficulties in studying the effect of building standards. Feedback effects and systemic interactions were cited as examples. Another respondent commented on the limitations of building standards; this individual stated that improvements will diminish and flatten out. Instead, the aforementioned respondent suggested that researchers should start addressing other aspects inside the dwelling where greater improvements could be achieved. Yet another respondent cautioned against linking

standards with specific technology in order to avoid the lock-in effect. However, this respondent also commented on the positive benefits from building standards; they felt that emissions targets could push the industry in the right direction. Finally, one respondent framed their response in relation to cost.

> Respondent #1 – "I think the main research question would be how have building standards influenced in the past resource consumption and residents wellbeing. And for the future the second group of questions is which mechanisms are the potentially strongest in order to influence the priority improvements and how to realize those potentials … there may be contradiction between resource consumption and residents wellbeing in terms of health, for instance if you would like to minimize the consumption of energy, then you would also risk reducing the indoor air quality which may be giving cause to sickness or illness".
>
> Respondent #2 – "… it's just part of the boundary conditions. Actually if you look at today's building standards in Norway. The last revision is pretty close to passive house. So we can bring down the energy we use a little bit more but of course the question is what is sensible – and what we see is that we are sort of flattening out at what we can reduce the heat demand. But there is of course other energy uses in the house that one could start addressing".
>
> Respondent #3 – "Many possibilities for such undertakings, ranging from the simplest dummy/regression approaches towards more holistic methodologies with interaction and feedback effects. The challenge is that sustainability affects many different factors on various spatial levels".
>
> Respondent #4 – "Well building standards are in high degree incorporated in research on sustainable residential houses. That's how many of the researchers work – they work together with authorities in Norway … there is very strong link between the authorities and the research community, specifically when it comes to the low energy and the passive house issue".
>
> Respondent #5 – "People don't invest in sustainable housing because it costs more in terms of upfront investment … they would rather pay for a larger kitchen than for better insulation… better conditions on a loan, for low energy and emission housing that would be a good solution".
>
> Respondent #6 – "… they are making the benchmark line. So in terms of incorporating into research they are a starting point … Standards are ok but they should be given in such a way that they are not locking you into technologies … standards are important, they will force development in the right direction but you will not, should not lock a standard towards technology. They have to be up to – they have to give targets, not technologies".
>
> Respondent #7 – "I think building standards are a result of research, or they should be. Because when you make building standards, like energy calculation standards, you need to base it on some scientific foundation. In that way it is sort of a result of the research. But it is also used when research is being done, e.g. to calculate the energy use of buildings and to analyze various technological solutions".

4.2.8 Land Zoning

Two of the respondents indicated that land zoning was important to traffic studies; one of these respondents said infill development was a good plan as long as public green space was preserved. Another respondent said that it zoning provided a framework which limited the compactness of neighborhoods. This respondent also commented on the difficulty of achieving legislation for mixed use areas due to its divergence from the existing status-quo. Another respondent commented on the historical development of land zones and asserted that mixed zoning was a good idea. Yet another respondent commented that land zoning was overvalued in its ability to achieve sustainability. In contrast to this statement, another respondent discussed how sprawl was logical yet unsustainable from a historical context. This respondent viewed sprawl as the first stage of urban development; infill was viewed as the second development stage. However, this respondent felt that it was not an area of research by itself. Finally, one respondent was unwilling to discuss the subject given their lack of experience with the subject matter.

> Respondent #1 – "I don't think it is very important outside the field of traffic analysis. But in traffic - in the generation of traffic - it is important and it has been quite a lot used, of course. It is central in the whole area of traffic engineering and traffic studies both related to work travels, shopping travels, and leisure travels ... And this is something that I think is very important as part of the field of industrial ecology… (*infill development; authors note*) would influence the issue of demand for infrastructure".
>
> Respondent #2 – "…the spread of living patterns and problems having higher densities clearly is one solution to the addressing some of the traffic issues. Everybody would like to live close to the center – if the only place you can build is on existing lots where there are houses already – you can infill, you can replace single-family buildings with single family residences. It seems to me that infill is a good idea. However, you have to be careful that some green space remains and that kids have places to play and stuff like that".
>
> Respondent #3 – "… urban inequality and disinvestment cannot be solved by design only. The zoning (and planning in general) is somewhat overvalued in this context… Zoning plan can (i) encourage new building, or (ii) just facilitate such, or then (iii) restrict such, for example with growth barriers and density caps, in which case brownfield investment and refurbishment of existing dwellings are the available options".
>
> Respondent #4 – "This is in a way a kind of reaction to the land zoning – which its sort of part of the early modernist planning idea. Where you separate housing from work and from transport and from leisure and all these functionally different zones. And I think part of the compact city idea is to mix these kinds of functions … we need to have short distances to most – as many as possible – of the everyday services that people need: groceries, shops,

kindergartens, schools, offices, workplaces or course, and also leisure, different leisure activities".

Respondent #5 – "Land zoning frames how compact and/or green a particular neighborhood can be developed, it defines whether the housing will be located in a mixed use area and thus have a lot of facilities such as schools, work, shopping available on a daily basis. Accessibility for all user groups is another issue… this type of action can be quite a challenge for municipalities. They are going to get protests from politicians, from industry, from inhabitants and so on, anything and anyone that breaks the standard routines of current practice".

Respondent #6 – "That's already been done in London or other cities they kind of saw that as a city sprawl. For many reasons that's unsustainable - as people moved out in the outer circles – a natural consequence was to build the new city from within almost deserted areas and I think that will happen over and over again. I think a city as such is a valuable thing and you don't want to be in the outskirts because then you will have to move and waste materials along the way. People don't want to do that, they don't want to be in the outskirts … it is a logical consequence rather than an area of research itself".

4.3 Inclusion of 4 Aspects of Sustainability in Responses of Academic Interviewees

Table 10 - Inclusion of 4 Aspects of Sustainability in Responses of Academic Interviewees for Question #1
(Note: [ ] indicates when respondents indicated one of the sustainability aspects was the most important of the four)

	Explicit Social Considerations	Explicit Economic Considerations	Explicit Environmental Considerations	Explicit Intergenerational Considerations
Respondent #1	X	X	X	
Respondent #2	X		X	
Respondent #3	X	X	X	
Respondent #4	X	X	[X]	X
Respondent #5	X	X	X	
Respondent #6			[X]	
Respondent #7			[X]	

4.4 LCC Comparisons of Various Ownership Models

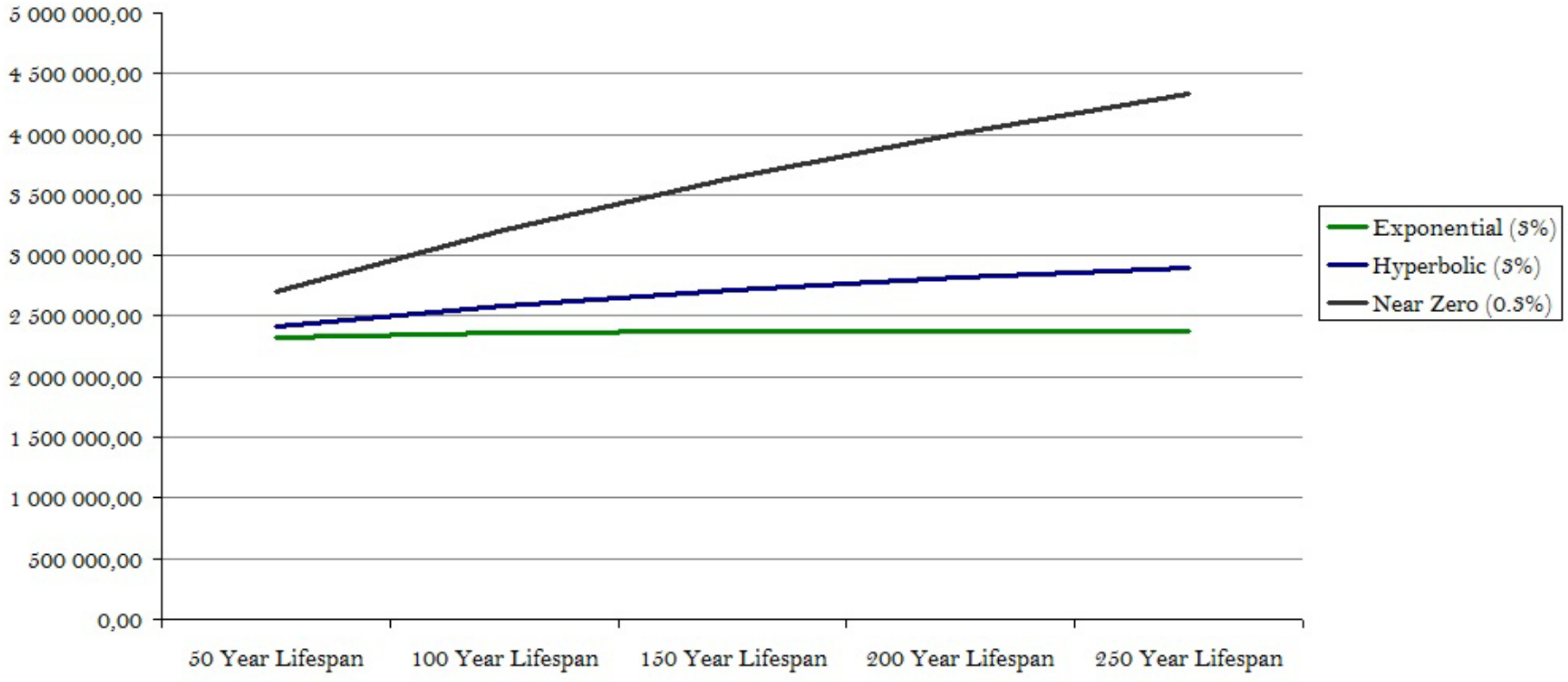

Figure 18 - Net Present Values of Lifetime Costs Using Various Discount Factors and Assumed Life Spans for a Dwelling Built to a Norwegian Passive House Standard (All Values in NOK)

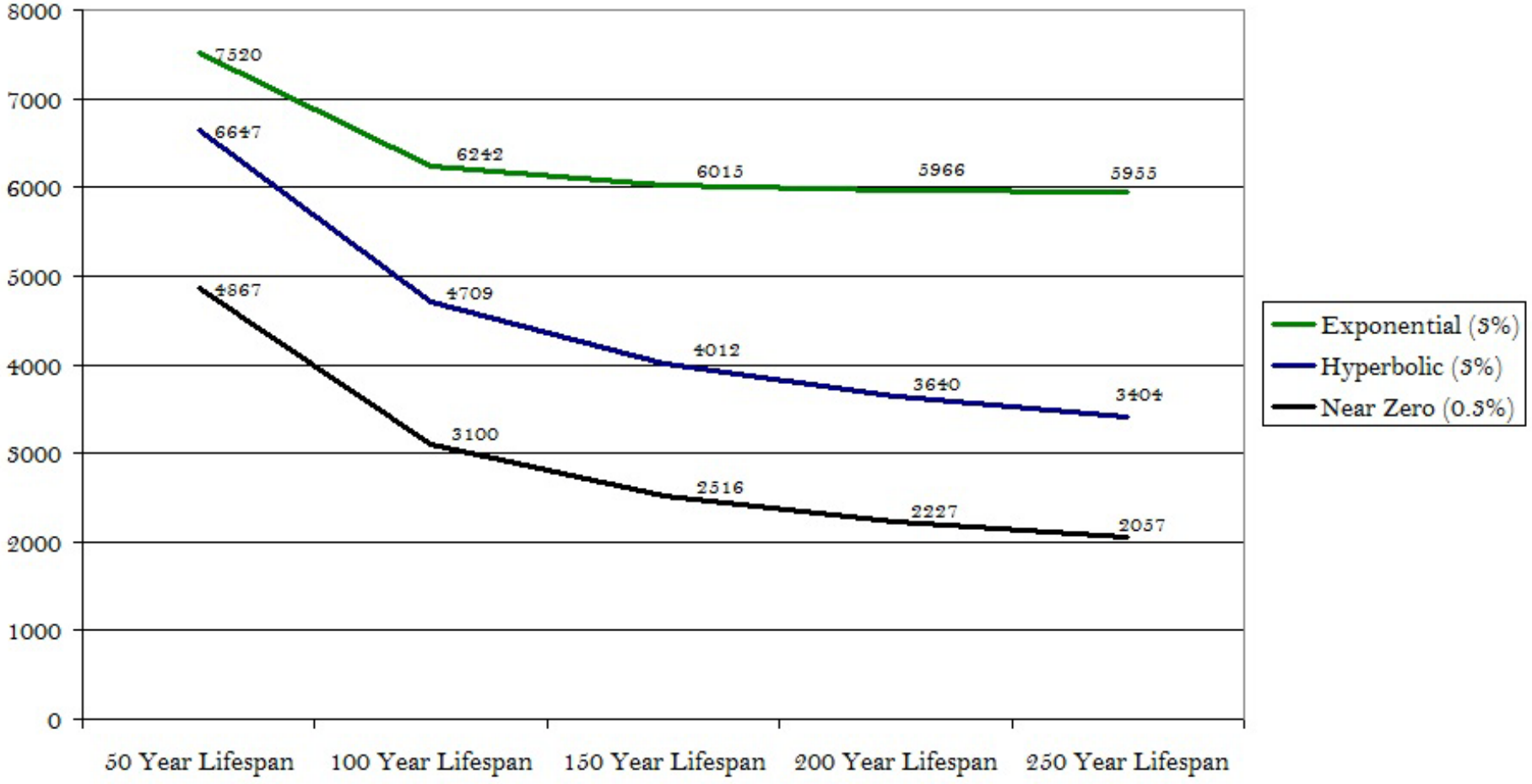

Figure 19 – Minimum Monthly Rent Required for Profitability Using Various Discount Factors and Assumed Life Spans of a Dwelling Built to the Norwegian Passive House Standard (All Values in NOK)

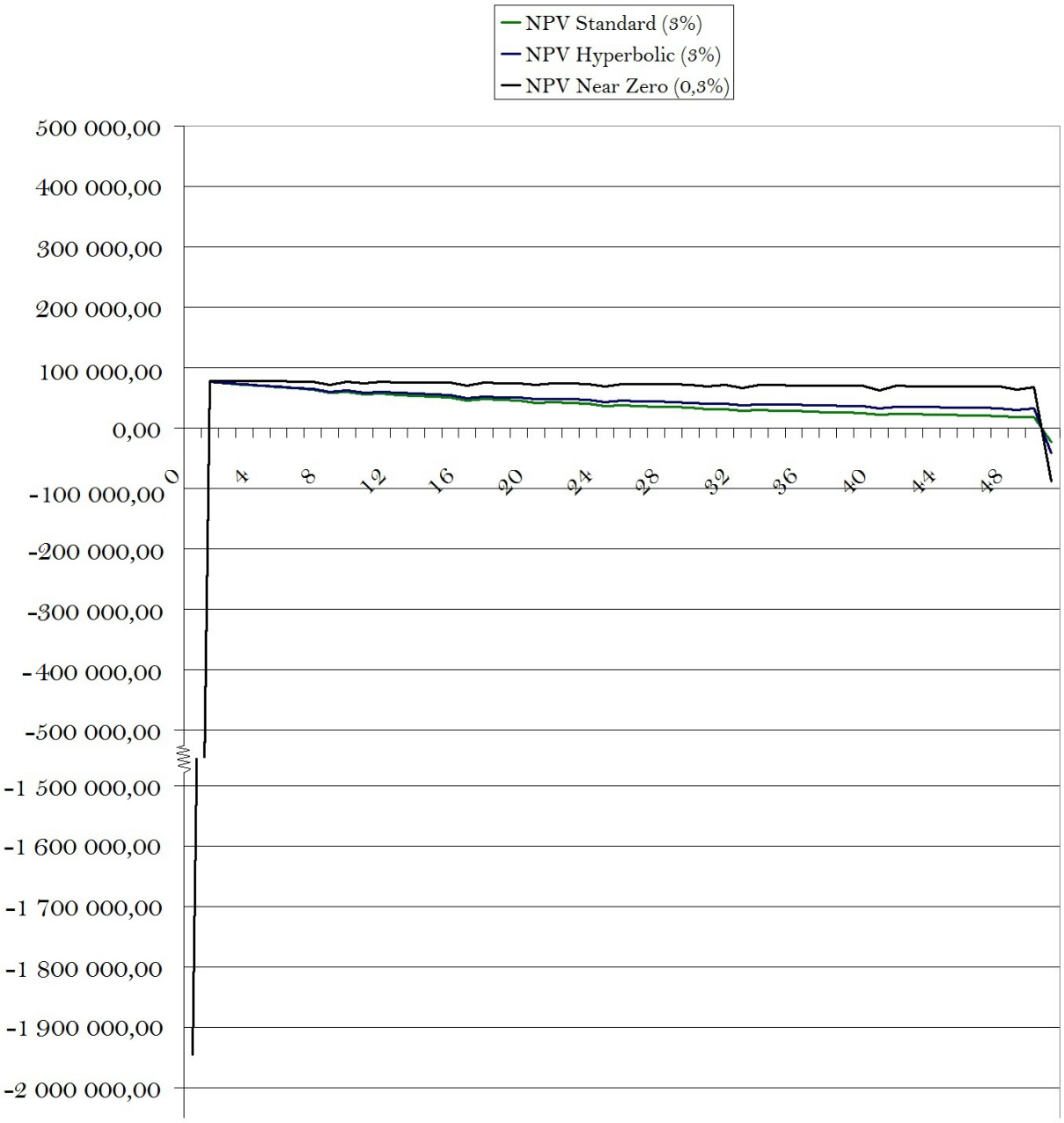

Figure 20 – Comparing Net Present Value Using Various Discount Factors for A Passive House with a 50 Year Assumed Lifecycle and an Income Stream Equivalent to 7550 NOK per Month (Note: All Values are in 2011 NOK)

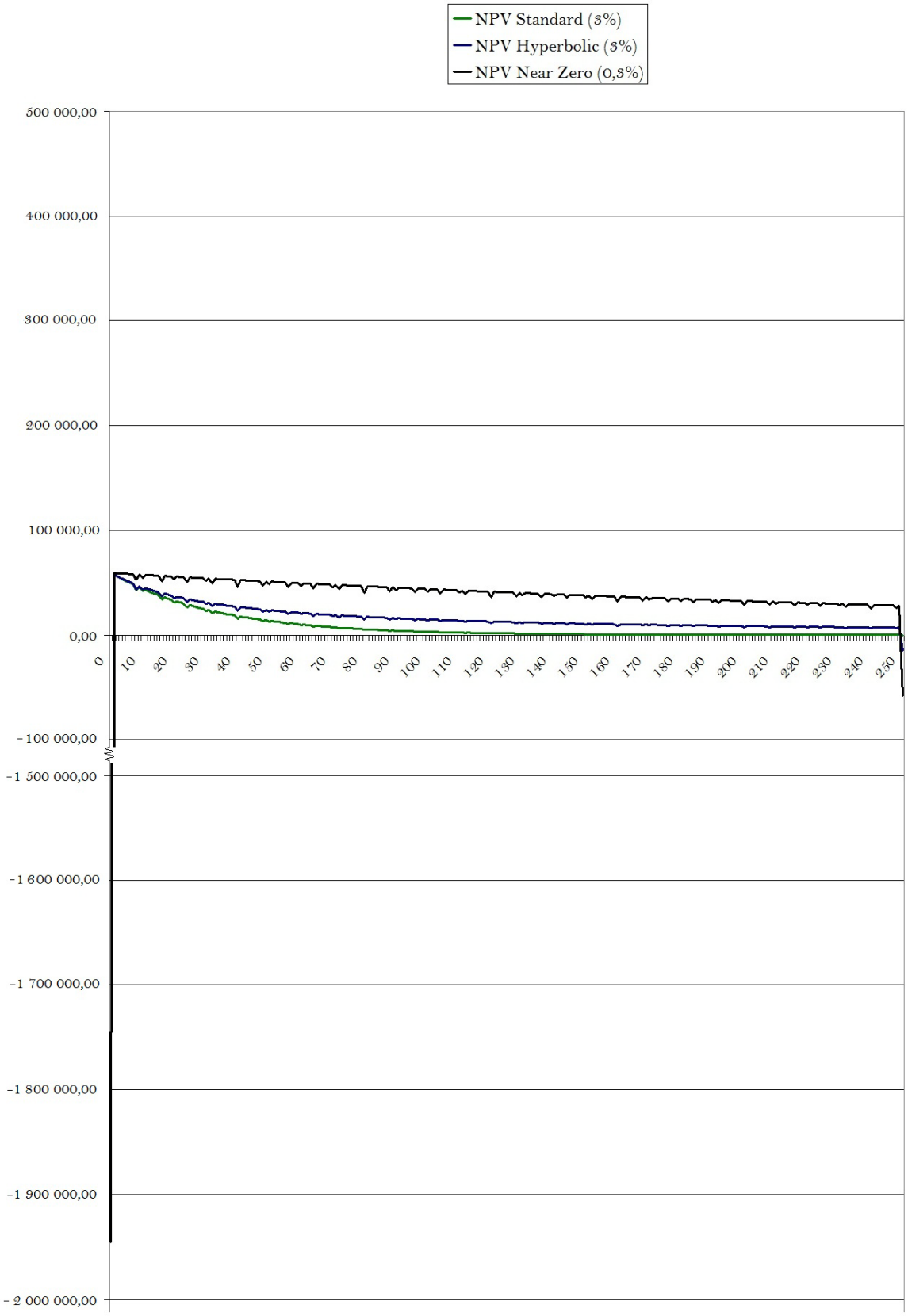

Figure 21 - Comparing Net Present Value Using Various Discount Factors for A Passive House with a 250 Year Assumed Lifecycle and an Income Stream Equivalent to 7550 NOK per Month (Note: All Values are in 2011 NOK)

5 Discussion

5.1 Implications of Life-Cycle Cost-Benefit Analysis Calculations

Looking first at Figure 18, it would appear that using alternative discount rates would lead to unfavorable outcomes. For a lifespan of 250 years, the NPV of costs using a near zero discount rate is 4 336 776 NOK; this is almost double that of the exponential discount factor (2 380 143 NOK). Even at a 50 year assumed lifespan, the alternative discount factors produce higher NPV of costs; albeit only by 400 000 NOK. Given that individuals are assumed to make decisions based on utility maximization, minimization of costs is a rational goal. In a scenario where the owner is unable to generate an income stream from the dwelling, i.e. when the owning party is the only resident, using alternative discount factors in cost calculations would be illogical as they would increase the value of life-cycle costs. However, when the owning party has the prospect of generating income, it no longer becomes beneficial to use the standard, exponential discount factor. This becomes increasingly apparent as the expected time span of the dwelling increases.

Using alternative discount factors allows for value retention further into the future; thus providing a longer time span to recover investment costs and generate profit. A steady income stream of 7550 NOK per month retains value past 120 years using near-zero and hyperbolic discount factors, whereas after this point, the same income stream becomes valueless using standard discount factors (Figure 21). The point at which all value is lost is of critical importance to dwelling lifetimes. Designing dwellings for extended lifetimes may increase initial construction and design costs; no utility maximizing entity can justify the additional expenditure if the associated rent fee increases will lead to prices above the market's equilibrium point, i.e. consumer's willingness to pay. The implications of this can be seen in Figure 19. With only 120 years to recoup investment costs using exponential discount factors, the minimum rent fee required to fulfill the PPO criterion stabilizes around 6000 NOK per month at the 150 year mark. Using hyperbolic and near-zero discount factors this monthly rent fee decreases as the expected lifespan of the dwelling increases. Using a near-zero discount factor and an assumed lifetime of 250 years the minimum monthly rent drops to 2057 NOK; this equates to a 66% reduction in cost compared to the exponential factor with the same expected lifespan. Thus, from a consumer surplus perspective, alternative discount rates have the potential to deliver superior utility benefits from consumption.

5.2 Findings from Triangulation

As discussed in Section 4.2, interviewee responses demonstrated a high degree of variability. Differences in opinion existed in what constituted a sustainable dwelling, the proper system boundary to consider, and the relative importance of various sustainability aspects. This finding was also mirrored in Section 4.3 which demonstrated that the academic disciplines related to sustainable residential dwelling include sustainability aspects to varying degrees. One possible explanation for this finding could be found in a phenomenon known as *fragmentation of knowledge*; a process whereby academics only focus on their areas of expertise.

Evidence of this phenomenon can be seen in the respondent's lack of awareness of the intergenerational equality concept and the lack of discussion related to discount rates or ownership models in the economic question. Although derived from the sustainable development discourse, intergenerational equality is a term primarily used by ecological economists. Fragmentation of knowledge would explain why most of the respondents were unaware of this concept as it has not been traditionally associated with sustainable residential dwelling despite the importance of discount rates to dwelling systems (Section 5.1). Fragmentation of knowledge could also explain why only two of the respondents included discussion of appropriate system boundaries in their definition of sustainable residential dwelling. System boundaries are of critical importance to academic disciplines which emphasize systemic relations; one such field is industrial ecology. All of the respondents who referenced system boundaries were industrial ecologists by training. Similarly, the respondent who indicated that sustainable residential dwellings were defined by energy use was from an academic discipline related to minimizing energy use and greenhouse emissions in dwellings. Continuing this trend, the respondent who defined sustainable dwellings as those which minimized environmental impact worked primarily with environmental impact quantification. Finally, all of the architects framed their answers in relation to the three aspects of sustainability but did not reference specific emission targets, or intergenerational considerations. This is consistent with the fragmentation of knowledge explanation; the principles of green architecture all include social, economic, and ecological considerations but do not contain specific targets or references to intergenerational equality. Thus, it can be said that understanding of sustainability as it relates to dwellings is influenced by each of respondent's respective field of expertise. As a result, there is a demonstrated need to redefine the central aspects of sustainability as they relate to residential dwellings. In line with the author's academic background, a systems

thinking approach will be used to frame the sustainability aspects defined in subsequent sections

It is also noteworthy to discuss respondent awareness of community preferences in relation to sustainable residential dwellings. All of the respondents indicated that they were aware of projects which integrated community preferences; five of them indicated awareness of the Brøset project. This finding is at odds with the fragmentation of knowledge explanation presented in the previous paragraph. One explanation for this is that the Brøset project was connected to NTNU; the university that all respondents worked for. Given that the Brøset project incorporated a wide array of academic disciplines and expertices, a number of respondents either worked directly with the project; others may have known colleagues that were involved or heard about it via word-of-mouth. Thus, it would be logical for this question to display a higher degree of uniformity than the other questions. Similarly, respondents indicated a high level of awareness of the quantitative tools of industrial ecology. Given that the Brøset project was linked to the Industrial Ecology Programme at NTNU, this provides a potential explanation as to why this was the case.

5.3 Redefining Sustainable Residential Dwellings using Systems Thinking

System Boundary - Starting with systems thinking, dwellings should not be viewed as isolated modules. Much of the research related to environmental sustainability in dwellings has attempted to minimize the environmental impact of single units. While this effort is necessary and useful, it is important to remember that dwellings exist within neighborhoods. Historical evidence has shown that the neighborhood design influences the environmental impact caused by residents; i.e. the proliferation of single family villas led to urban sprawl and contributed to the increased reliance on personal transportation vehicles. Thus, it is important for academics studying sustainable residential dwelling academics to adopt a systemic approach to the system boundary; they should consider whether their design approaches reinforce unsustainable development patterns like urban sprawl. Henceforth, the term *sustainable residential dwelling areas* will be used to express the inseparability of these two dwelling scales.

Social - Sustainable residential dwelling areas need to incorporate social sustainability from an intragenerational perspective. Intragenerational equality includes tailoring dwelling areas to a wide array of income brackets and age groups. Doing so could improve social cohesion among different social groups and create a *sense of community* among residents. Common use areas like swimming pools, gyms, dining rooms, guest rooms, etc may also

contribute to the achievement of this goal. Furthermore, the combination of local facilities and amenities with costly and limited parking space could reduce the desire to own personal transportation; common areas could also reduce the amount of floor area residents perceive as being adequate. These systemic interactions would not be traditionally considered, however, they become part of the system definition when the scale is changed. Significant attention should still be given to assuring that dwellings are designed to be safe for inhabitants, comfortable and functional; environmental impact minimization should also remain a priority. In this way, the role of the architect will remain unchanged. Similarly, community preferences will still need to be incorporated in the design of future dwelling areas.

Economic - In relation to dwelling areas, economic sustainability could be defined as the ability of a funding party to justify a project's economic viability via fulfillment of the PPO criterion. The traditional approach to the fulfillment of this criterion has been the use of cost-benefit analysis. From a systems thinking approach it becomes necessary to consider the funding implications of integrating intergenerational equality concerns via alternative discount factors. In doing so, it is necessary to consider possible linkages between social paradigms, monetary systems and the useful life of dwellings (See Section 5.4). Alternative discount factors could change the baseline against which economic sustainability is measured. This could extend the useful economic lifetime of projects; thereby leading to increases in the designed lifetime of dwelling areas. Using alternative discount factors could also increase the relative importance of long term maintenance and demolition costs. One way to reduce these costs could be to industrialize the maintenance of dwellings. If residential dwelling areas were designed for *periodic disassembly and reassembly* they could be transported, repaired or disassembled in a factory setting; thereby reducing cost.

Environmental – In relation to dwelling areas, a systemic definition of environmental sustainability could refer to the minimization of environmental impacts from both inhabitants and dwellings. Impact assessment should be conducted for dwelling areas rather than individual dwelling. In this way, vehicular emissions and changes in emissions related to leisure activity can be included in the system definition. As discussed in Section 3.2.2, there are a variety of environmental impacts that are considered in LCA calculations. Academics studying sustainable dwelling areas should consider a range of major impact substances as well as devoting specific attention to CO2 equivalents. In designing dwelling areas, academics should also consider design solutions capable of preserving structural components for reuse and facilitating material separation at end of life; this could offset

demand for new production and avoid future emissions. Extending the lifetime of structures is another proven strategy for reducing environmental impact. The design for periodic disassembly and reassembly concept introduced in the previous paragraph could provide a method for achieving extended functional lifetimes. It is important to note that any such system will require a data management system capable of tracking building segments over long timeframes; BIMs could become indispensible tools in this process. The application of intergenerational equality concerns in environmental sustainability is related to the desire to protect future generations from substantial irreparable environmental harm. This includes climate mitigation and attempts to protect resources for the use of future generations.

Despite this attempt at creating a systems thinking based definition for sustainable residential dwellings, *standardization* is desperately needed; no individual project or thesis can deliver a consensus on what constitutes a sustainable residential dwelling on its own. As a result, it may be necessary to plan an international symposium with leading members of all the academic disciplines discussed in Section 3. Interdisciplinary breakout groups at such a symposium may also lead to academic collaborations and reduce fragmentation of knowledge in the academic disciplines related to sustainable residential dwelling. Just as sustainability is more than the sum of its four aspects, the creation of a standard sustainable dwelling definition has the potential to deliver synergistic benefits. Academic agreement may serve to quicken the widespread implementation of sustainable residential dwellings.

5.4 On Possible Linkages Between Social Paradigms, Monetary Systems and the Useful Life of Housing

Figure 22 – The Historic City Center of Ghent, Belgium (Jakubec 2008).

As discussed in the previous section, intergenerational equality is a poorly understood concept in the academic disciplines related to sustainable residential dwellings. This is of concern because discount factors may indirectly influence the way in which dwellings are designed.

In Europe, remnants of many medieval societies can still be found. Carcassonne, Rhodes, and Toruń are among those listed by UNESCO as the best preserved medieval towns. When comparing the multi-century life-span of medieval structures with the average fifty year assumed economic lifespan of modern residential buildings, the logical question arises *what is the cause of this apparent decline in life-span?* It would be illogical to infer that the relative decline in modern residential lifetimes is attributable to a decline in construction technology or academic know-how. Similarly, it would be foolhardy to suggest that ancient nomads could not produce structures capable of multi-year life spans. Following this logic, these vast differences in lifespan must be attributable to another source.

Medieval, nomadic, and modern societies were built on vastly different paradigmatic foundations. It can be argued that nomadic societies based their worldview on observations of natural cycles. In their world, nothing had permanence; the only constant was change. Cyclical patterns governed the seasons, migratory patterns of animal herds and the continuum between birth and death. Similarly, their residential structures were built and dismantled on a regular basis. Thus *impermanence* was a central aspect of their existence. It is important to note that barter was the dominant medium of exchange in nomadic societies; currency served little purpose as all members of the community shared the bounty granted freely by nature. In direct contrast, the *complex* feudal society of the middle-ages was based on notions of servitude, allegiance and a social order ordained by deity; it can be argued that *permanence* was an integral part this paradigm. This permanence was also implicit in the dominant gold-based monetary system of the era; gold never tarnishes and the value of gold-based currencies largely remained constant unless deliberately undermined by those in power.

Alternatively, modern western societies are characterized by the principles of progress, scientific advancement, and enlightenment. The religious and traditional sources of knowledge in medieval societies were rejected and replaced by modern scientific methods of inquiry during the Renaissance. Thus, the quest for progress created a societal preference for *novelty*; evidence of this can be seen in the rise of new art styles, clothing and architecture beginning in the 14th century. This preference is also explicit in modern day marketing, sales and advertising practices. To a lesser extent, it is observable in the evolution of the global fiat monetary system. In an attempt to limit the effects of inflation, central banks actively target a rate of inflation that is tolerable to society. In so doing, the purchasing power of money is constantly eroding; thus, old money becomes less valuable unless it is invested at a rate of return higher than that of inflation.

In all the aforementioned cases, the dominant paradigm shares similarities with the medium of exchange and the life span of the residential structures. Despite these similarities, causality between the various factors has not been established; at present, this author can only comment on the observed correlation. However, using a systems-thinking approach it becomes possible to view these discreet factors as potentially interrelated; a change in factor "A" may invariably lead to changes in factors "B" and "C". This line of argumentation will be revisited in the following paragraph.

To begin with, it should be noted that both sustainability and complex feudalism share in common the notion of permanence; albeit, the frameworks by which they apply this concept are dipolar in nature. Complex feudalism, with its stringent social hierarchies, distinctions and obligations, opposed progress for the sake of societal preservation; cynics may contend that this was merely a useful excuse for the perpetuation of existing power structures. Alternatively, sustainability gracefully rectifies permanence with progress; permanence is viewed as the goal and progress is viewed as a means to an end. As discussed in earlier sections, the struggle to achieve sustainability is one of the defining narratives of the twenty first century. Just as the replacement of permanence with progress during the enclosure movement led to profound societal reorganization, it may also be the case if progress is supplanted from its current position as the primary driver of societal efforts; it could lead to a new wave of societal change.

Intergenerational equality is another term for expressing the permanence goal in the sustainability paradigm. Research on the subject is currently limited to the field of ecological economics, and specifically, critiques of standard discounting practice. Given that discount rates are manifestations of the progress principle; these critiques must be extrapolated to be viewed as attacks on modernity. If ecological economists are successful in advocating for the adoption of newly devised intergenerational discount factors, it may be tantamount to *the destruction of 'modern' society.* While this term is often used with negative connotations, herein it is written using a positive meaning-frame; future societal reorganization for sustainability requires this destruction for the transition towards a *post-modern* society. In such a post-modern society, the complimentary goals of permanence and progress may have radical implications for the designed lifetime of residential dwellings.

5.5 On the Limitations of Alternative Discount Factors

Of the proposed intergenerational discount factors and justifications discussed in Section 3.4.2, many can have logical inconsistencies which limit their usefulness; and thus, their application to sustainable residential dwellings. Take for instance the proposed use of near-zero or zero discount rates. In the short term, applying a near-zero discount rate is tantamount to not using a discount rate. Using a discount rate below 0.4%, the PV of earnings 200 years in the future can be worth more than half the amount of a comparable sum earned today. Given that historical inflation trends are not near-zero, using discount rates which are near or at zero becomes problematic. Imagine a project with substantial upfront costs that produces no realizable benefits for the first hundred years; however, in the far distant future the benefits substantially outweigh the costs. This project is assumed to

meet the PPO criterion; beneficiaries have the *financial means* to pay back the initial investors but *restitution is not required*. Despite the PPO criterion having been met, it can be argued that the decision to pursue this project by current authorities would be altruistic in nature. This type of rationalization could be used to place an unfair burden on current generations. Therefore, rather than solving the problem of intergenerational equality, it may contribute to its reversal; generations would be the recipients of positive externalities.

Another proposed discounting method, hyperbolic discounting, has limited use for intergenerational applications for a number of reasons. As stated in previous sections, hyperbolic discounting produces near exponential depreciation factors in the short term; as time progresses, money is assumed to slow its rate of depreciation and eventually stabilizes. In addition to the *time inconsistency problem* discussed in Section 3.4.2, there are other issues which need to be addressed. Using standard discount rates between 3% and 8%, discount rate changes stabilize after 100 years; in this case stabilization refers to discount rate changes occurring no more than once a decade. The stabilization rates for the discount rates listed about are 11% and 24% respectively; they decrease to 6% and 14% after 200 years and fall to 4% and 10% after 300 years. When comparing the change in value between year 100 and 300, value declines 7% and 14%. Thus, the condition of *empathetic distance* is not fulfilled using standard discount rates. This issue becomes more apparent when using near-zero discount rates. Using discount rates of 0.2% and 0.5%, value declines 21% and 27% during the same period.

The intergenerational formula presented by Sumaila and Walters (2005) also suffers from both the issues identified above. In an attempt to solve the time incontinency problem, their factor fails to incorporate empathetic distance via a leveling off of the discount rate. Given that their factor also allows for value retention into the distant future even using standard discount rates, it may also contribute to the reversal of intergenerational externalities discussed previously.

5.6 Towards a Representative Multigenerational Discount Factor

Based on the critiques of the intergenerational discount factors and methods presented in the previous section, it may be necessary to devise an entirely new discount factor to persuade governments to use them in dwelling projects. Given that all intergenerational discount factors are attempts to assign value to future generations, contingent valuation may be a useful tool in this endeavor. Those familiar with CVM may be hesitant to apply this methodology as it has traditionally be used to value priceless costs and benefits;

nowhere has it been applied to the problem of discounting. This author contends that determining the value of future generations is analogous to valuing the priceless. Thus, with a few modifications, CVM may be able to reveal how human beings value their distant progeny i.e. the value of dynasty.

CVM best practice mandates that valuations must be based on willingness to pay for a given probability change. Imagine two questions with identical probability changes and items under consideration but different time horizons. Differences in valuation could logically be said to reveal the time-value preference of the respondents between the two points under consideration. If the same question were asked multiple times, each time with a different timescale, differences in valuation could be said to reveal the way in which time-value preferences change over time. When the highest and lowest values are *normalized*, they can be used to plot the discount function over time. When the normalized results for each generation are averaged, a discount factor based on the results can be formulated. One additional benefit from normalization is that differences in income and wealth become less important to the final result.

People may discount the value of their distant offspring differently than they discount the value of distant environmental changes. Thus, any attempt to value future generations must be based on valuations between subsequent generations. In order to get an accurate representation, future researchers may consider personalizing the question; i.e. questions aimed at valuing respondent's future offspring rather than entire generations. It is conceivable that large differences in valuation will become evident in this process. Grandparents may place a higher value on their grandchildren than their children. The valuation of individuals who do not want children may be relatively stable and low over time. However, if a large enough sample size is taken, it can be said to be representative of the population.

Contained in Appendix D is a sample questionnaire which may be useful for future researchers interested in tackling this problem. Following the seventh generation principle outlined in Section 3.1, questions have been repeated seven times. If a generation rate of 30 years is assumed, a discount curve can be plotted for 210 years. If valuations have not flat-lined, i.e. reached empathetic distance, additional generations can included in subsequent studies by repeating the question additional times.

5.7 On the Parties Capable of Using Alternative Discount Factors

As discussed earlier in Section 3.3, HM Treasury in the UK already uses hyperbolic discount factors in their cost benefit analysis calculations; despite having the seal of approval of a major government, this factor is not used by corporations or private enterprises. One must consider why this is the case. One potential explanation can be found in the inherent difference between producer and consumer surplus. Corporations are legally bound to serve the interests of their shareholders; thus, producer surplus is assumed to be the primary target of business activity. Alternatively, consumer surplus refers to the benefits people derive from consumption. Private enterprise views the creation of consumer surplus as a positive externality; albeit one which is necessary for achieving competitive advantage. Governments actively pursue consumer surplus via cost reduction as a policy goal in its own right.

All of the alternative discount factors mentioned previously attempt to increase the timescales at which value is retained; it is analogous to accepting a lower rate of return on investment. If an individual corporation were to use alternative discount rates in their decision making, they would put themselves at a disadvantage compared to their competitors. In the long run, this could endanger the growth and profitability of the firm. Thus, short term profit-oriented behavior is optimal for the allocation of scarce resources. While this barrier could be overcome by legislation mandating national use of hyperbolic discount factors, it is unlikely that any such bill would receive public support as it could jeopardize the competitiveness of the nation. As a result, it must be concluded that private businesses should avoid alternative discount rates.

In contrast to private corporations, government projects usually are conceived and designed for multi-decade time-periods. There are a number of reasons for this behavior. Firstly, constitutional and parliamentary democracies are historically more stable than corporations. While governing parties are voted in and out at the whim of the public, the system under which laws are enacted remains relatively stable. Large infrastructure projects also deliver unintended positive externalities; i.e. economic development which generates additional tax revenue. Lastly, projects which extend past their expected lifetimes may continue generating social surplus. Therefore, it is logical for governments to engage in projects with longer timescales than private enterprises can consider. Given that alternative discount rates accomplish this in their design, they are logical for use by governments seeking to justify publicly funded sustainable residential dwelling projects.

5.8 Alternative Financial Models for Residence

As identified by Carlsson (2011), the combination of increased upfront costs and low expected residence times has the potential to limit market-penetration of passive houses in the Trøndelag region. One solution could be the creation of new residence assets; specifically, mortgaged long-term leases and loans based on intergenerational discount factors with conditionalities attached.

Long-term leases are already standard tools in real estate, however, mortgages have been historically preferred due to their financial rewards i.e. wealth accumulation. In order to reduce the cost of environmentally ambitious housing projects, long-term leases could be sold in the same way mortgages are sold. Purchasers of these new assets would borrow the necessary capital to pay for the entire duration of the lease upfront; in exchange, tenancy and repairs would be guaranteed for the same period. If these assets were designed to be market-tradable then they could increase or decrease in value depending on the market situation; thus, purchasers of these assets would have the potential to benefit financially in the same way as traditional mortgagees. Using a shorter residence period could reduce the upfront cost compared to a traditional mortgage. If these assets were only provided for low energy and other sustainable dwelling projects, demand could be stimulated.

Similarly, loans based on newly designed intergenerational discount factors could increase the profitability of dwelling projects with longer than traditional life spans. These loans could be created with conditionalities, i.e. developers would need to demonstrate that new residential dwelling projects were designed to last for at least a certain period of time. For neighborhood scale developments, additional intragenerational requirements could be attached. The increased profit potential provided by alternative discount factors demonstrated in Section 4.4 could be used to drive development of sustainable, intergenerational residential dwellings.

5.9 Recommendations for the Brøset Project

The Brøset project is commendable for a number of reasons. In the planning stage, the project has successfully integrated social concerns via the integration of community preferences, environmental concerns by designing safe structures that drastically reduce GHG emissions, and economic concerns by designing developments for a range of income brackets. However, intergenerational equality concerns are notably absent. Researchers connected to the Brøset project should introduce a multigenerational requirement for the construction of residences in order to extend the assumed lifetime of dwellings. These

requirements could drive industry change and contribute to knowledge generation related to low-cost, long-term dwelling maintenance. Finally, researchers connected to the Brøset project should conduct life-cycle cost benefit analyses using an alternative discount factor in order to study potential ways of further reducing costs for residents while still fulfilling the PPO criterion.

5.10 Strengths and Limitations

The strength of this study lies in its highly structured methodology, diverse array of sub-fields investigated, and in the selection of respondents. The final two elements of this list are attributable to the use of systems thinking. This perceived strength may be attributable to the authors self-confessed industrial ecology based worldview and conviction in the usefulness of systems thinking as a framework for understanding complex problems. The results of the interviews are only representative of the state of knowledge in the academic community related to sustainable residential dwellings in the Trøndelag region. The fragmentation of knowledge discovered in responses should not be universalized, i.e. assumed to be true for academics studying sustainable residential dwellings in other locations. Similarly, these results should not be assumed to be representative of industry professionals or public servants connected to the system boundary. It is also possible that intergenerational concerns are understood differently at other academic institutions.

5.11 Reliability and Validity

As discussed in Section 2.6, a number of methods have been used to ensure that the results in this report are valid, reliable and representative. All of the participants were sent transcriptions of their interviews and given the chance to edit, clarify, or amend their transcribed responses. None of the respondents indicated that the transcriptions were unsatisfactory; most of the changes were minor and grammatical in nature. After incorporating these changes, excerpts were selected for inclusion in Section 4.2. These excerpts were sent to respondents to verify that these segments were representative of their opinions. All of the respondents indicated that these selections were representative and acceptable for inclusion if they were presented anonymously. After receiving verification, these excerpts were used to produce Table 10. Alternatively, Table 9 was produced using the findings from Section 3; the data collected for the aforementioned section was governed by the methods for reviewing literature covered in Section 2.3.1.

Contributing to the reliability and validity of this report, the author included a reflexivity essay outlining the attitudes and pre-held notions on the subject of sustainable residential

dwellings in order to minimize the impact of bias. While bias can never be entirely eliminated, the inclusion of this essay in Appendix A and discussion of it in Section 5.9 provides the reader with ability to see the author's bias and see how it affected the results. By transparently and candidly exposing these pre-held notions, the reliability of the report has been improved.

5.12 Transferability of Findings

The subject of residential dwelling is only one of many academic fields in which attempts to integrate sustainability principles have occurred. It is possible that other academic disciplines related to sustainability have sub-fields which incorporate the four aspects of sustainability in similarly varying ways. It is also possible that intergenerational concerns may be less represented in these fields as was the case in this study. The results from the LCC section, i.e. increasing utility benefits from using alternative discount factors, may also be applicable to other infrastructure focused academic disciplines in which assumed lifetime is a factor. Academics studying corporate structures like office buildings and factories may also find it useful to investigate the potential benefits which can result from the use of alternative discount factors in LCC calculations.

6 Conclusions & Future Research

The results of this study indicate that the current state of knowledge in the academic disciplines related to sustainable residential dwellings is fragmented. There is a lack of standardization in relation to the appropriate system boundary; the related sub-fields work separately on both the individual dwelling and the neighborhood scale. These sub-fields also incorporate the four aspects of sustainability to varying degrees. Intergenerational concerns are absent from the majority of sub-fields and the possible systemic implications of using alternative, multigenerational discount factors have not been considered. As a result, alternative ownership and residence finance assets have not been investigated. The interviews done in this study also revealed a similar level of variation in how respondents defined sustainable residential dwellings, the sustainability aspects which were important, as well as the appropriate scale to study. These results were found to correlate with the academic backgrounds of respondents. Thus, fragmentation of knowledge was presented as potential explanation.

Future interview based studies in other geographic locations could be useful in providing a second dataset against which to compare the results in this study. Due to the limitations of current alternative discount factors, future work is also needed to develop the multigenerational discount factor described in Section 5.6. The survey presented in Appendix D would be a useful resource for any such endeavor. Both municipal and national Norwegian governments could benefit from the creation of a new multigenerational discount rate that accurately reflected the declining time-value preference of the population. Finally, future research is needed to establish a standard definition for sustainable residential dwellings. The first attempt presented in Section 5.3 is insufficient if the academic community remains fragmented. A systems thinking based, academic symposium designed to create a standard definition is needed to resolve these internal differences.

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Appendix

A. Author Reflexivity - Short Essay

I grew up in a house, the same house for 20 years. All my earliest memories took place in that house. That house was in a suburb located an hour's drive from the City of Toronto. My neighborhood was a quiet one; located in a maze of streets just off a major road. As a child, this area seemed small; I never ventured more than a couple hundred meters from my house. Everything in my world, even my elementary school, was within walking distance. Every morning before school, I woke up and watched my father put on his suit and tie. By 7:00 he was on the road and driving to downtown office. It was seldom that he returned before 7:00 in the evening. When he got home, his first words were usually related to traffic; over the years, his commute time became longer and longer. Despite these statements, it was hard to really understand what gridlock traffic felt like.

At the age of 8, I began a career as an actor in commercials and television. Part of the job description was the audition process; all of the major casting studios were located in the downtown core. For the first time in my life, I escaped the suburbs which had been my safe haven and caught a glimpse of city life. With my mother at the wheel, I remember looking out the car window and being captivated by sights and sounds of the city. Driving downtown in the mid-afternoon was always fun. There was no traffic and it was clear sailing down the four-lane highways which ran through the city like major arteries. The journey back was an altogether different experience. The very same highways were jammed packed. Traffic moved at a snail's pace. I finally understood in a very real sense what my father had to endure on a daily basis. Continuing my young career, I made regular trips to these casting houses. Over the years, I watched the traffic get worse and commute times increase from an hour to almost two. When I started driving at the age of 17, I started hating this commute; each audition was a three hour commitment.

After graduating from high school, I entered the Faculty of Environmental Studies at York University and turned my back on the acting profession. There I was introduced to concepts including urban sprawl, sustainability and bioregionalism, among others. When I finally looked at a map of the Greater Toronto Area for a project, the vast scale of suburban settlements provided an explanation for the traffic that I experienced. It was at this point that I started feeling confined; my suburb suddenly felt unnatural and artificial. I became aware of the fact that there were no stores or recreational activities within walking distance

and there was a distinctive lack of community connectedness. My friends often voiced similar complaints. The only real activity was a trip to the shopping mall.

Around this time I was introduced to the concept of environmental impact assessment. I quickly became fascinated with the weekly garbage collection day where households discarded vast quantities of waste; people regularly threw out functional electronic equipment, furniture, and artwork. I tried to conduct crude calculations for estimating household waste for the entire city; the resulting figures were too large for me to adequately conceptualize. In the months afterwards, I realized that consumption and waste generation could be explained by this lack of recreational activities; it also struck me that the suburban housing system was unsustainable.

Towards the end of my undergraduate degree I was introduced to the field of ecological economics. I was fascinated by the boldness of the concepts; the direct critiques of neo-classical economics were particularly intriguing. Intergenerational equality, a term I had only heard a few times in my introductory environmental studies course, was discussed at length. In the same way that I had come to believe the suburban dwelling system was unsustainable I realized that the existing economic system was unsustainable. From that point onwards, I began thinking about potential relationship between the economic and dwelling systems. Conducting research on this relationship during a prolonged university strike, I came across the field of Industrial Ecology. The systems thinking foundation of the field immediately caught my attention and provided an alternative to the survivalist worldview advocated by the Faculty of Environmental Studies at York University. It appealed to my desire to investigate relationship between seemingly disparate systems. After reading extensively through the Journal of Industrial Ecology I became convinced of its usefulness and decided to apply for a Masters level degree in the subject.

B. Interview Transcriptions

Semi Structured Interview Questions for Academic Respondents

1) How do you define sustainable residential dwelling?
2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?
3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?
4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?
5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?
6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?
7) In what way should building standards be incorporated in research on sustainable residential dwelling?
8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

Academic Respondents - Interviewee #1

1) How do you define sustainable residential dwelling?

- I would define dwellings and sustainable principles separately. Dwellings that people reside in all year round - in contrast to leisure buildings or part time dwellings - built and operate in line with sustainable principles. Sustainable Principles include systems, buildings, dwellings that maximize the factors that may contribute to a minimized resources consumption, environmental impact, costs and negative social impacts from a life-cycle perspective. Without going into great detail, resource consumption and environmental impacts as part of environmental sustainability, costs as economic sustainability and negative social impacts as social sustainability. The whole lifespan of the building should be taken into account and the whole value chains of important resource consumptions for the construction and operation of the dwelling.

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

- No, they would not. A typical dwelling would not meet this criteria. It is important to distinguish between the entire existing stock, the majority built after the second world war, fairly recent, or new buildings. Typical must be understood as a mix of all these. There will be a type-age matrix in terms of the existing stock. Typical dwellings consume too much energy, and then per unit of floor area. They are not energy efficient. This is due to the fact that Norway and Trøndelag have very low energy prices, during all the decades after the Second World War, even today relatively speaking, with large building activity between 1960s and 1980s in Trøndelag. You can see it also in Trondheim of course. There was not very good motivation for owners or developers to focus on energy efficiency. There is a lot to improve there. A lot of the energy that is consumed is high-quality electricity that could be better used for other applications. We see that now particularly in Trøndelag where there is a limit for transmission of electricity from other parts of the country so there is actually a lack of electricity; in certain seasons of the year - in the winter. Of course this gives higher prices, which is in one part good. A lot of the energy used for heating is not from renewable sources. There is a lot of biomass and wood used outside urban areas – of course this is renewable – but when you look at the cities there is quite a low level of renewable energy. 71% of Norway's total energy demand is electricity and 23% is wood. Looking at Trondheim separately the only renewable source (beyond firewood) is district heating, which is partially a mix of waste and other fuels mainly used in cold days when there is peak demand in excess of what can be generated from waste. Extra high peak load is to a large extent imported electricity which is generated from oil and gas. Sweden as a contrast – much higher use of renewables due to installed district heating. Typical existing dwelling in Trøndelag is influenced by detached, single family households, which from a resource perspective is much larger than necessary – in terms of floor area per capita. Much of future growth is projected to be in urban areas and in Trondheim.

- Beyond energy, materials are important – they should be local, natural – in contrast to synthetic – reusable, recyclable and/or degradable. My gut feeling is that the typical dwelling in Trøndelag is made of local, natural materials because much is wood-based in detached houses – but there are things to improve there – in particular with respect to use of materials and building components that are prepared for being reusable or recyclable or degradable in landfills. There has really not been a large focus on this to date. Beyond the dwelling itself – the dwelling neighborhood is normally not planned and developed with the aim to minimize the overall urban efficiency in terms of resource consumption and environmental impacts – where is the building located? – how is the neighborhood planned in terms of density? – what is the traffic generation? – to what extend is the existing infrastructure utilized by dwellings? Here I am mainly talking about new dwellings and new areas that are being developed. I read something in Adresseavisen – the local newspaper which I am reading on the web – that in the next years, definitely the majority of new dwelling would be in existing high density or higher density urban areas. Exactly these factors of location, density, traffic and infrastructure will be utilized in a better way than previously. I was also thinking about to what extent our typical dwelling reflected the expected future strong growth of demand from single person households – elderly people - there is a change in demography. When you look at population forecasts lots – definitely most – most of the population increase in Norway and in Trøndelag will be in the urban centers. It will be in Trondheim it will be in Stjørdal - I mean the cities. When you combine the population growth with the fact that there will be more and more elderly people and single person households – I think that the typical dwelling does not reflect this situation.

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

- I am not – I don't believe that I am really qualified to have a good response here…umm… because I don't know very well the concept of intergenerational equality and I have not been reading research literature on this aspect. My understanding is that the concept means that people of all generations could live and flourish – I mean be happy - in the same buildings and neighborhoods not being segregated as much as today. I assume that the only way to approach that challenge is to bring in experts and couple experts from other disciplines in larger extent than what is done today. I don't know to what extent this is being done but I don't think it is being done at a large scale. I think particularly then of influencing the research agenda by a strong cooperation between researchers from architecture, urban planning, sociology, psychology and geography, and they would define the research agenda themselves because they have a background which is good enough – if you find the right people – to define what are the important questions here and how that should influence the research. And why I think of architecture, urban planning, sociology, psychology and geography is that I think these are the key disciplines which are important in developing more knowledge about which factors and which issues are important to people if they could live and flourish in the same buildings and neighborhoods. It is about buildings themselves and it is the functions and the

social aspects of being together and living together – not necessarily in one building – it could be – but certainly in a neighborhood so that children and old people and workers and people from different social layers and groups could be happy together. I think that is much more related to the qualities of the neighborhood than it is the quality of the dwelling or the building itself. Of course, the building and the dwelling would have to be fitted to each individual group's or person's needs. There are different needs between an old or a handicapped person or a child or a busy working woman. So buildings have to fulfill those needs, but particularly what is the social mechanisms – the glue in the local society that keep and bring people together so that they thrive together

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

- Community preferences – do you mean what individuals prefer in relation to where they live and how the live, not just in terms of the dwellings but in terms of the areas? Immediately I think of the Brøset project in Trondheim because this was the first pilot project in Trøndelag where emphasis has been given to not just the design – not just physical design of buildings and infrastructure but also on social activities – in terms of neighborhood qualities with the aim to reduce carbon emissions. So I think the Brøset project and the researchers involved there from the social science side and also the architecture side will be a reference. If you talk about individuals you could try and approach (*John Doe #1; authors note*). He is from the social sciences and he is involved in the same Brøset project. He could add aspects beyond what (*Respondent #5; authors note*) is able to give you. And also, have you met (*John Doe #2; authors note*)? He is by education a psychologist and he did his PhD in Industrial Ecology from Psychology some years ago, and he has been one of the key persons – initiators – for the whole Brøset project. So he would also have quite a few potential feedbacks to your project. I can send you the emails of these afterwards. Basically those people I would advise you – there might be others as well – to approach. They also in the Brøset project examined what are the experiences from similar sustainable settlements abroad. So if you don't know about them, you should ask (*Respondent #5; authors note*) in the interview with her addition to the questions here – what are these projects from aboard she would think of, and who are the researchers?

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

- I define it in a way that the quantitative tools that are mainly addressing the flows of resources and emissions and the impacts with respect to economic impact or environmental impact. I don't think there has been very much related to this because the concept of sustainable residential dwelling has not really been defined as this is where we would like to go in our research. So what does it take and how should you do it, if you were to try and analyze sustainable residential dwelling with industrial ecology as a starting point, and then using industrial ecology tools? But of course, there has been use of industrial ecology tools in related projects in examining the

dwellings stock or examining the individual buildings or examining projects and development areas. I guess that – of course the most important part – the part of research where you find most examples – would be energy and greenhouse gas emissions studies. Here there is directly making use of industrial ecology tools; there are 3 projects basically, or 3 activities, outside of the one in our own department. Within our own department, Hydraulic and environmental engineering – this is the Brøset project – the goal is examining individual dwellings and neighborhoods, but mostly focusing on neighborhood areas and the role of infrastructure, so we are of course concerned with energy consumption, fossil energy and greenhouse gas emissions. The methodologies using there is [*incomprehensible*] examining what are the energy consumption and emissions from houses and aggregated building stocks, so you can define it as an MFA or energy assessment linking up to life-cycle analysis methods, where you are defining the greenhouse gas emissions per unit of energy carrier being used. Also you have (*Company AS #1; authors note*) – I mean the spinoff company from IndEcol that has been doing this kind of research. I am not fully aware of all the projects they have been involved with, but they have been involved with different projects. (*John Doe #3; authors note*) would be a central person to contact because he has been both involved in Brøset and other projects from (*Company AS #1; authors note*). They have also been using input-output methods in order to link that up with consumption research at IndEcol and (*Company AS #1; authors note*) from before. And the greenhouse gas emission calculator that was developed for households. And then it is research activities as (*Research Institution #1; authors note*) – in both Oslo and Trondheim – for 20 years more or less on how to improve energy efficiency and how to minimize greenhouse gas emissions and also kind of environmental concerns – I mean toxic materials related to building – different type of building traditions. There are several researchers at (*Research Institution #1; authors note*) who have been involved in this. But few of these studies were initiated from Industrial Ecology - and thereby strictly speaking – using the quantitative tools of Industrial Ecology in the way that an Industrial Ecologist would do it. For instance, developing methods that both have an MFA and LCA background and coupling with scenario work – but of course you find some examples, such as (*John Doe #4; authors note*) work at (*Research Institution #1; authors note*) Oslo. In my department where we have had several projects and masters theses and some PhD studies related to this. But this is more on the aggregated stock of housing than on the single houses or dwellings. And we have been working with dynamic MFA on floor area of resource consumption material flows and waste flows and waste management including the construction and demolition waste flows and how these issues are developing over time. Finally there is one example how industrial ecology tools could be applied where we did a research development of a waste to heat LCA tool for the district heating company in Trondheim – so how could waste energy be used to replace other energy carriers for the heating of buildings. You could find many examples – of course I would basically divide these qualitative tools in 3 groups. The first group could be quantitative tools in order to investigate in more depth the demand and the change in demand over time – I mean demand for buildings and energy in buildings and materials in buildings – but mainly the driver side. So this is partially qualitative

and partially quantitative. But if you would like to work with other aspects – like what is the amount of toxic materials or the how is the composition development of toxic components or materials in buildings – how is the greenhouse gas emissions developing over time you need first to have good quantitative understanding of the drivers. The second group is then the issues related to energy consumption, efficiency and emissions from the energy system – mainly greenhouse gas emissions but also NOx. And the third group would be related to material consumption which would mainly be the large bulk materials including wood, concrete and cement and so on and metals, and it might be toxic materials – particularly related to the challenge of indoor climate in houses – these things – or it could be related to PCB (polychlorinated biphenyls) that were used in quite a lot of building components and equipment in the 60s and 70s - for instance in windows and so on – and it would be related to waste generation. So in all these aspects the quantitative tools of industrial ecology have an important role to play. And they have partially been used, but there is potential for increased use.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

- I have no information on this actually beyond the fact that what I know is that lifecycle costing, which is then one kind of kind of cost benefit – one branch of cost benefit – have been used. Of course there is lots of potentials for use of this, but during well maybe starting 10 years ago, (*Company AS #2; authors note*) in Norway developed a lifecycle costing tool in order to get a quantitative instrument to find out what are the life-cycle costs of different types of buildings they have responsibility for. Of course if you are an owner of an apartment or if you are a tenant of an apartment you have different responsibilities and you bear different costs. And I guess it is very typical that the life-cycle costing issues are to a very little extent actually known. There is little awareness on the life-cycled costing of buildings – there is little awareness of the factors that you should try and influence, improve in order to reduce the costs or increase the cost benefits. But also there is lots of mechanisms in the recent let's say years of practice in the construction sector that is also in favor of using life-cycle costing to a large extent. For instance when you are developing locally area for new construction, this is then by companies who very often would like to of course – they are profit oriented – they are developing and managing the construction, the realizing of this project and then very often they are selling to intermediate persons who again are selling to those who are buying the apartments. So therefore there is very little – not a very large – dialogue between the planners and the developers and the future owners of the apartments, and therefore of course there is not that strong incentives to include life-cycle costs performance in the project. The life-cycle costing will have to be barred by the future owner, whoever that will be, but the project cost is bared immediately by the project developer and influences the price at the point of purchasing. So these things represent a hinder. I also asked one of the bosses from (*Company AS #3; authors note*), a social housing bank in Trondheim, some two, three years ago, to what extend do they make use of life-cycle costing or let's say economic life-cycle cost models when

they are examining, planning and realizing new projects. He said that well I agree that this is important – it is very important and should be important for (*Company AS #3; authors note*) who actually then owns and manages a very large stock of dwellings. But they do not apply life-cycle costing in a daily activity. So I think – I don't have very much information on this – but I think economic life-cycle cost models have been applied to a very little extent. And this initiative by (*Company AS #2; authors note*) – they have even a software LCProfit – that were used for some time and I don't hear much about it the last few years. I don't know what is the current state of this, and in research on sustainable residential dwelling also I don't think that economic life-cycle cost models – finance models have been very much used. I don't *think* so, because I don't really know.

7) In what way should building standards be incorporated in research on sustainable residential dwelling?

   - Since you here clearly state 'incorporate into research on sustainable residential dwelling' I think there are two groups of questions that are important. The first one is the past – relates to the past – how has building standards – so what standards, where and how - actively influence negatively or positively residential dwelling resource consumption and residents wellbeing? I put these questions because there may be contradiction between resource consumption and residents wellbeing in terms of health, for instance if you would like to minimize the consumption of energy, then you would also risk reducing the indoor air quality which may be giving cause to sickness or illness. But that was just one example. So I think the main research question would be how have building standards influenced in the past resource consumption and residents wellbeing. And for the future the second group of questions is which mechanisms are the potentially strongest in order to influence the priority improvements and how to realize those potentials. Let's say that if we for instance conclude that there are two issues that are the most important ones; it is the energy consumption and greenhouse gas emissions and it is the toxic substances involved in building materials. If those two are just examples, the priority improvements in the future then specifically would be which mechanisms are the strongest ones in order to influence on those. And when we know the mechanisms how should we trigger the realization in order to have policies being effectively implemented. So think those are the two questions I would come up with for proposals here.

8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

   - I'm not sure if I get what you try to mean with land zoning. I guess what you may mean is the different land usage in districts of a city or region occur and therefore you have land zoning within a city or region. Is that correct? [*Researcher responds: Yes that is correct*]. The ways in which land zone applies to research today. I don't think it is very important outside the field of traffic analysis. But in traffic - in the generation of traffic - it is important and it has been quite a lot used, of course. It is central in the

whole area of traffic engineering and traffic studies both related to work travels, shopping travels, and leisure travels. Where people live for instance; there is now a work quite recent in Trondheim, a survey – quite new – I think the last survey was back in 2002 – so now there is a recent survey – quite detailed – one of the best in the country on how people travel. And of course then to combine that kind of knowledge with research on resource consumption for fuels and greenhouse gas emissions maybe other sustainability issues related to personal travelling is important. And this is something that I think is very important as part of the field of industrial ecology – urban studies – we also see it from a broad similar kind of problems where you are combining GIS methods with scenarios for planning location of new activities and with econometrics and with travelling data, in order to try to develop more knowledge about the combinations of planning and land use and emissions and resource consumptions related to transportation. There is also internationally an upcoming research activity in this field as part of the Society of Industrial Ecology which in January - or yes, it was in this winter - started a new section – the section of Sustainable Urban Systems. So we see also that these questions are quite important in research abroad. But in general I think there is lots of potential for further research on several issues related to how urban form and land use - both in the urban and the peri-urban areas actually then influence urban metabolism. This may partially be related to the – I mean beyond traffic and transportation it could be related to – resource consumption of the other kinds of urban infrastructure – housing, water, energy, wastes, of course energy. So for instance at NTNU we have not at all been able to be making use of these kinds of research, where we have combed land zoning with metabolism for urban areas, but we are starting to do that. Do you have some follow-up questions related to that?

- [*Researcher: I was wondering how land zoning - specifically an infill or smart growth policy in your perspective would influence the sustainable residential dwelling agenda and the achievement of that?*] I guess immediately it would influence the issue of demand for infrastructure, or let's say – is there an increased demand for infrastructure when you are developing let's say 1000 new dwelling units, or is there a very low demand for new infrastructure because you are utilizing existing infrastructure? So that is one area where there is room for quite a lot of research. I think this is also one of the main motivations in terms of costs, in order to reduce extra costs per unit of dwelling that is developed in a city. But also questions related to traffic generation is quite interesting in these aspects – "fill in" policies – in contrast to the alternative that is to develop residential areas in the peri-urban zones.

Academic Respondents - Interviewee #2

1) How do you define sustainable residential dwelling?

   - Well residential dwelling that requires little inputs to operate that is not too resource intensive to construct and that doesn't cause and toxicity problems or other problems when you dismantle it. It is clearly a building that sort of enables inhabitants to lead a sustainable life. So aspects that are important are obviously the energy use during operations, the inputs like water and waste-water treatment is concerns and then usually there is also talk about sort of aspects of users how do use perceive this, how do they feel does this lead them to lead more sustainable lives, do they want to stay there or do they want to leave at every occasion, what is the kind of transportation that the building triggers – I mean some of us expand the definition beyond the building itself to include the neighborhood and connectivity of the places that you need to reach.

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

   - No. Clearly not. We have not very good energy standards so there is lot of energy use. Most houses, especially houses that are constructed in the 1960s, 70s and 80s and some of the older buildings there is a predominance of single family dwellings and that means that the settlement structures are very dispersed and they don't lend themselves easily to walking, bicycling and public transportation - especially for public transportation the density is too low. I think clearly that the thing that can be fixed is energy use, I see some big needs for improvements.

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

   - Can you explain the concept please? [*Researcher: It refers to equality between successive and multiple generations across long periods of time*]. No, I think is a very abstract term to apply to building because if you look at the building I think about the kids that grow up there and not about the environment that they will experience later – so if you talk about buildings focus the people who live there whether they are elderly or kids or grown-up or whatever - I think it is a little difficult to relate.

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

   - Yes there has been research and attempts to build this dwellings that have involved user involvement in the planning stage. So, there was for example this project in Freiburg, Vauban, a project in Vienna that I investigated, the car-free settlement there is one of the projects where user involvement has been important. There has also been in Sweden, they have done a lot of research on alternative living firms; sustainable living firms where user involvement has been quite important – I don't remember who contacted [*incomprehensible*].

- Well, I mean, it's obvious how the user involvement is important and the question is then what does it really mean "how do users participate" – it clearly contributes to creating more of community, more of a sense of identification with the building project, a better knowledge of your neighbors. So better overall social climate that is definitely one thing that I remember that being observed.

- Well, I mean the question is "do the design solutions function as intended?". So if it contributes to enhancing that function then it is an interesting thing. So it is clear for the car-free housing project that I was investigating in Vienna, users were important and people identified with the theme and were quite adamant about sort of policing each other [*laughs*] in terms of behavior so that definitely had a contribution. Its maybe not the setting that everybody would like to live under [*laughs*] having nosey neighbors looking whether you have a car or not. [*Researcher: different strokes for different folks I guess*]

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

- Well they have been applied to investigate the impact of buildings. So what are the emissions that the person causes living compared to living somewhere else. The tools have been investigated also in connection to some of the design projects. So in Freiburg there is the case where researchers have been involved in the design of the neighborhood and those are quite relevant. I mean there is a lot of research going on – sort of energy performance of buildings that obviously is integrated - building testing and so on. I mean that if you think about the history of the so called passive houses which have a low energy consumption for heating. There was lots of design being done, lots of research being done in Germany but it really took off when some architects decided to build the first house. So I mean you have research but then you really need to go to implementation.

- Ya. I think that is a difficult one because the question is whether they just – the energy flow and the water flow and those things through the house. To what degree do you take into account the things that are more user connected. You know your food consumption is that related to the dwelling or not? – I mean you have to eat anyways and whether you eat now high impact meat-based diet or low-impact vegetarian diet probably has nothing to do with the dwelling as such. It might be influenced by who your neighbors are and what they do. So there is definitely an effect that way but I think that's – but maybe we should really focus on the function of living, of housing when we look at these dwellings and the kinds of impacts that are fulfilled there. I mean it is clear that you need to take a life-cycle perspective so you need to take into account the construction of the houses, and the production of the energy you need to operate. If you watch TV, you use energy and you do it in your house. Is it part of the dwelling or not? And the TV gives off energy which heats up the room so either it contributes to the heating or it increases the cooling need so it clearly has an interaction with the building shell and the energy flow through the building. It is not clear to me what should be then the boundary.

[*Researcher: I never considered that before*]. Ya those large flat-screen TV's need quite a lot of energy.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

   - Ya, I'm not sure about finance as such. It's clear that people do think about costs and people do trade-off operational costs against the higher costs of building the building. So people have calculated you know starting from simple payback times through some sort of internal rate of return calculations. But those simple – basically investments – calculations that I have seen. I haven't seen any finance calculations actually. There's the argument that actually if you do the design right, it doesn't cost much more and I think that's true; however, it seems like you need a lot more attention by the designer or the architect. They need more competence to design sustainable buildings. So that definitely, there must be an additional cost.

   - [*Researcher: How have discount rates been applied to research on sustainable residential dwellings?*] Ya, not in relation to the building research.

7) In what way should building standards be incorporated in research on sustainable residential dwelling?

   - Ya, it's just part of the boundary conditions. Actually if you look at today's building standards in Norway. The last revision is pretty close to passive house. So we can bring down the energy we use a little bit more but of course the question is what is sensible – and what we see is that we are sort of flattening out at what we can reduce the heat demand. But there is of course other energy uses in the house that one could start addressing. Ya, but I don't know building standards – of course you can do research as to what is a sensible building standard. I don't know.

8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

   - As I said, the spread of living patterns and problems having higher densities clearly is one solution to the addressing some of the traffic issues. Everybody would like to live close to the center – if the only place you can build is on existing lots where there are houses already – you can infill, you can replace single-family buildings with single family residences. It seems to me that infill is a good idea. However, you have to be careful that some green space remains and that kids have places to play and stuff like that. And if we are going too much to denser settlements it should be also – we should make sure that the public interests were there to support this and that also includes public green spaces.

   - [*Researcher: What would you say is the average age of the buildings in the Trøndelag region?*]. I don't know so much about that. I think we have – it's probably somewhere between 50 and 70 years but I think there must be a large spread. So some of the older houses we would like to preserve then, some of the houses from the 1970's they

are still around but I think they should be scrapped ⁅*laughs*⁆ because it's probably cheaper to build new solutions today than to try and refurbish those buildings.

Academic Respondents - Interviewee #3

1) How do you define sustainable residential dwelling?

   - It's a combination of a number of elements, some of them related to the actual apartment and building, and the rest to the location and surroundings. My expertise relates to the latter category. Here I would start from the theoretical separation of environmental-ecologic, social-cultural and economic-financial dimensions. Ideally all three criteria are required for total sustainability, but in practice it is about tradeoffs and a largely elusive knowledge base with non standard definitions (as (*Respondent #4; authors note*) has pointed out). For example, an increased building efficiency (i.e. floor-space per land area; density) is sustainable environmentally and economically, but unsustainable socially ((*John Doe #5; authors note*) and colleagues have done empirical work on this in the UK), which then contradicts the conventional wisdom of density also leading to community cohesion. Furthermore, when we look at how to manage these issues (i.e. behavioral aspect), what is referred to as 'good community governance' needs the support of the private sector too. If looked at from a more top down angle (institutional aspect): smart policies, regulations and especially incentives set at the local and regional levels are an imperative to meet the sustainability goals set out in the Rio-1992 agenda. The last thing that come to mind is that one needs to be prepared for catastrophes such as flooding (or as in Trondheim, quick clay landslide) when designing the building and its location. Sustainability is per definition a local issue, e.g. one is encouraged to consume and produce locally as much as possible; however, the problems are global (climate change, urban inequality, financial crisis etc).

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

   - Intuitively speaking, probably not, but I lack professional experience on this point. As a layman, I have heard from colleagues and mates that lots of new buildings have serious moisture and fungus problems. I also don't know what the current theory says about the wooden vs. brick debate. As for the location of new developments, in my view the more suburban and peripheral locations suffer from a substandard public transport and road networks. (I attach a book review for *NGT* of the recent book by Holt-Jensen and Pollock, where I express my thoughts on this.)

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

   - The latest I learnt (from a conversation with (*John Doe #6; authors note*), who is a member of a UK think tank on this) is that one should think at least two generations ahead

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

- (*Royal Institution #1; authors note*) people are the most prominent ones: (*John Doe #6; authors note*), (*John Doe #7; authors note*), (*John Doe #8; authors note*), (*John Doe #9; authors note*), (*John Doe #10; authors note*) and other visionaries involved. I know also others, more individual contributors, mostly from the UK, who have touched on this topic. (See reference list of the attached article) I recommend a simple internet search on this.

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

- No, sorry.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

- Insofar as 'green' certification of buildings is concerned, there has been some econometric modeling efforts, but any effects of such having price or rent lifts pertains almost exclusively on the office side (e.g. Eichholz and colleagues; Fuerst and McAllister). My take on this, albeit based on rather qualitative material, is to bring the private sector housing market onto the sustainability agenda, and use the info of property prices to determine economic sustainability, which for me always must come before the other dimensions in the analyses. (See the attached article for *HTS*.)

7) In what way should building standards be incorporated in research on sustainable residential dwelling?

- Many possibilities for such undertakings, ranging from the simplest dummy/regression approaches towards more holistic methodologies with interaction and feedback effects. The challenge is that sustainability affects many different factors on various spatial levels.

8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

- The starting point is to realize the harsh realities: sustainability poses massive problems (e.g. urban inequality and disinvestment) and these cannot be solved by design only. The zoning (and planning in general) is somewhat overvalued in this context. History here shows a lot too: think for example about late medieval Florence; it did not flourish because of planning, but because of the preconditions for layers of private investments that were created due to innovations in banking! Planning nevertheless comprises a secondary set of factors after the investment related ones. It is entered as a parameter into the market based models in four ways (zoning applies for the first three ways). Zoning plan can (i) encourage new building, or (ii) just facilitate such, or then (iii) restrict such, for example with growth barriers and density caps, in which case brownfield investment and refurbishment of existing dwellings are the available options.

Academic Respondents - Interviewee #4

1) How do you define sustainable residential dwelling?

- Quite broadly. So I think it is difficult to define it in exact way and I think that the definition of sustainable dwellings would have to be depending on the context actually. Where the dwellings are situated at what time and so forth. But from my perspective it is quite important to look at the environmental and the social issues interplay. So that in sustainable residential area there needs to be some kind of balance between the social, environmental and economic – but of course I would say that environmental aspects would be sort of the major ones because that is what gives the limitations and that your issue intergenerational equality and the next generations are also important. That was [*laughs*] I guess quite a vague answer to the question but I am not able to sort of say that it is on a specific level when it comes to emissions or anything like that because I think that it is not a definite result – it is more like some kind of a process

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

- That is a difficult questions – first because what is actually a typical residential dwelling in Trøndelag? So I don't think I'm able to answer that and I guess the answer is that none of the dwellings – or very few of the dwellings in Norway today – are really sustainable when it comes to all the aspects that should – all the criteria – that should be met. We have a very few new buildings that have quite low energy demand. I'm not sure how many in Trøndelag but perhaps less than 50 or something I think. But we have some old houses, traditional houses, that have been used for generations which could be regarded as quite sustainable by many respects because they have a shown ability to adapt to different types of lives and different times and different needs and household functions. So they have some important sustainability aspects to them. They are probably not good enough in technical measures and this is something that is possible to deal with.

- [*Researcher: what are you referring to when you use the term 'technical'?*] I am referring to the environmental aspects or implications of all these things, the heating system, how the construction is done, the installations and everything. They have some sort of impact on environmental issues.

- [*Researcher: As a follow up question, If you had to take an educated guess, what is the average age or the most prevalent period of building construction in the Trøndelag area? From what time period were are most of the current residential dwellings built?*] Iwould say between let's say the late 1950s and 70s. Because then you have large post-war housing developments. Lets say during the late 1960s and 70s you have large estates in the southern part of Trondheim – Heimdal and others. And earlier you had development closer to the city center in the 50s. That is my guess but I don't know the numbers. During that time there were a lot of people moving into the city and a lot of demand for new housing.

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

- Ya, I think that is very interesting because it has been an issue and in my field it would be about flexibility and adaptability in building and the kind of robustness of buildings. But it is also – I don't think it has had very – it has not been the issue that has had the most research money and resources put into. Probably because its quite hard to measure and to assess what you really – or the results - of this kind of quality in the long run. But it is still always part of every sustainable housing development plan. Buildings and housing should be flexible and be able to meet the different needs and changing use patterns in the future. That is what I understand when you talk about intergenerational equality – that dwellings will last for a long time, they wont only be a kind of a short investment commodity sort of thing. [*laughs*] I had to think about what you meant with this one because I don't use this concept as you have used it but that is how I understood it

- [*Researcher: And what about your peers in your field of study. Would you say that they use this concept regularly?*] I have not heard the concept intergenerational equality used when it comes to architecture and sustainable housing in architecture. It might be, but it is not one which is commonly used. The concept of long-term robustness – what is actually the understanding of sustainability. If you know Norwegian, Hållbar is a kind of a synonym to sustainable and is used in Sweden instead of sustainable. It means actually something that is lasting. And ya, but of course intergenerational equality has to do with perhaps some kind of economic, social economic connotations that is not covered in that understanding.

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

- Well ya, I'm involved in a project that has this part integrated in the research. And I think its quite – I mean – not common in all projects but its more and more common because its more and more acknowledged that the users and the user preferences are essential if we want to achieve the objective. So yes, my answer is yes. It is related to urban development project at Brøset. I don't know if you have heard about it. It is south-east of the city center. It is an interdisciplinary project we have cooperation with researchers at Dragvoll in interdisciplinary studies of culture and there we have a post-doc candidate who works on actually on social-cultural conditions for this development. And she has done several focus group interviews with different groups of people, neighbors, potential future residents, etc. And discussed the issues that – and the objectives of this specific area – with them. And this is planned to be followed up by several more participatory events during the future planning process because this is a project still in they very early stages. It won't be built until lets say three of four years in the future.

- [*Researcher: what about outside of Trondheim. Are there any notable examples of projects that have integrated community preferences that you can think of?*] I'm sure you know of Vauban in Freiburg; there they have a very strong integration the whole town.

People were invited in the very early stages to take part in this project and establish what they call 'Baugruppen' (consisting of 10-15 households) to develop their own housing project. So this is a kind of an inspirational project for the Brøset area. In the same way potential residents were invited to participate in the planning stages. In Norway several more smaller projects, more initiated from the residents themselves Svartlamon is actually an example – I don't know if you have heard of that, I don't know how long you have been in Trondheim [*Researcher: I have been in Trondheim for two years now – I know the area, it is near Dora 1*] Yes, that's an area where user participation has been very important and then the community preferences is integrated as it was in this case, the community preferences here are not sort of the average preferences and the problem – the challenge for Brøset is that the City of Trondheim want the area to be an area where everyone would like to live. So it's not to be something for the special interested. And then you have challenge of how to integrate people with who have the preferences for their own large detached house with two cars, etc. So these are some quite difficult challenges to deal with [*laughs*].

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

- Ya this is not my field but to return to the Brøset project we also have cooperation with the industrial ecology people. So they have in this project – they took part in defining or providing some kind of a basis for the city of Trondheim to define the objective for the area when it came to – this was supposed to be the carbon neutral settlement and they helped the City of Trondheim to define what carbon neutral would mean or could mean in this context. So with the help from this group – and a consultancy firm called (*Company AS #1; authors note*) – and they supported the City of Trondheim to set a goal of reducing CO2 emissions to 3 tons per person per year in the future which is very ambitious and which is probably difficult to reach only through technical and material measures. This also requires quite substantial lifestyle changes and also changes in society as a whole. But that is perhaps the objective of this project

- [*Researcher: So what type of analysis did* (*Company AS #1; authors note*) *conduct?*] I am not able to describe this, but I can give you the link to the website where the report is. They also has been parallel commissioning process connected to Brøset where four design teams have made proposals for the urban design of the area and (*Company AS #1; authors note*) has made an assessment of these proposals afterwards so there is also a report on that.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

- Well this is not my field either, but I know that of course, that when it comes to the technical issues - I have been working on (*Research Institute #1; authors note*) – so I have been working together with engineers. They very often do costs benefit analysis of the technical measures or the – ya or the proposed specific technical measures – on projects. They also provide some sort of cost models. So when it

comes to the low energy or passive houses there is always a discussion about how much extra cost should be used. And when it comes to the energy supply system for example on Brøset it will be assessed on some kind of an optimization of the costs and the environmental issues together. I am actually not very into these issues – only observe it more or less because I think this cost question is quite difficult. When it comes to housing there are so many issues that will decide how much a house will cost. It is mostly the market and if the site is good then the developer will get a high price and probably high – what to say provision? – I mean they will earn money on it if the site is attractive.

- [*Researcher: In relation to the cost benefit models that you were referring t earlier, are you aware whether a life-cycle approach is taken?*] Yes, I'm sure it is in many cases it is yes, but again I cannot give you more information about this actually. I know that these are issues that are discussed yes.

7) In what way should building standards be incorporated in research on sustainable residential dwelling?

- Well building standards are in high degree incorporated in research on sustainable residential houses. That's how many of the researchers work – they work together with authorities in Norway – I don't know the English word - there is very strong link between the authorities and the research community, specifically when it comes to the low energy and the passive house issue. So in a way it is – I would say that perhaps it is a – from my perspective a rather limited approach because it is some kind of – it doesn't always help to improve the standards if the actors, residents and everyone who are involved in this project approach it from different perspectives and roles. If they don't understand or have the knowledge or have the values or whatever that is needed to use and to operate these buildings then they are. So there is an issue that - or a knowledge that there is quite a big difference between the calculated energy demand in buildings and the actual energy demand when it is operated. And why these differences are so big? We have several answers to this question. There are many different aspects that influence this.

- [*Researcher: To what extent has the concept of design for disassembly, prefabrication been incorporated into the field of architecture and residential dwelling design?*] It has been an issue among architects and also engineers for a long time I would think. But it is not the topic that most research resources are put into. I think again that this is an issue of flexibility and adaptability that is hard to measure the achievement of these – calculate actually the achievements of these measures. It is much easier to calculate the energy demand so there has been a very one-sided focus on energy when it comes to sustainable dwellings and research on sustainable dwellings. I think because its easy to calculate its also doesn't require very complicated technical innovations perhaps. Ya there are probably many reasons – I think one reason is that it is easy to calculate, it is easy for the research community to sort of point to what is possible to achieve and easy for the ones who fund the research to say that they have funded [*laughs*] a project that has achieve a so and so kilowatt hours reduction. But the

practice in the end when the buildings are in use and operated over some time, the reduction is not as big as calculated to be. But there are people who are very eager on the issues you are asking about

8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

- I'm not quite sure what you mean, could you explain this? [*Researcher: traditionally there are different types of land zones which are designated by municipal authorities. For instance, corporate, industrial, and residential zones. The question refers to how the distribution of where these zones are located influences sustainable residential dwelling*]. For at least two or three decades now, or since the 1990s, there has been this strategy in most western cities I would guess and in Trondheim – Norway as well – on more compact cities and more densification of the already built up land. This is in a way a kind of reaction to the land zoning – which its sort of part of the early modernist planning idea. Where you separate housing from work and from transport and from leisure and all these functionally different zones. And I think part of the compact city idea is to mix these kinds of functions. This is also a discussion in the Brøset case as this is defined by the City of Trondheim as a new urban neighborhood with mainly residential – as part of the discussion on what is a sustainable neighborhood there is a need to reduce transport. This suggests that we need to have short distances to most – as many as possible – of the everyday services that people need: groceries, shops, kindergartens, schools, offices, workplaces or course, and also leisure, different leisure activities. So there is even though they don't want to have they call the industrial work – I don't think they call it industrial work – workplaces that require a lot of transport into this area. There is an idea that it should be as mixed as possible but still with a high share of housing. But with possibilities to work at home or to have a kind of a shared office space and with as much as possible of services – both shops and also public services like schools, homes for elderly, kindergartens, perhaps some cultural institutions as well.

Academic Respondents - Interviewee #5

1) How do you define sustainable residential dwelling?

- Well the traditional definition would be to combine both the ecological, economic and social sustainability. What we find its often quite difficult t work with because – well the definition itself is fine of sustainable development – but it is very difficult to operationalize when it comes to architecture or buildings or dwellings. So we are now working towards – working with – environmental qualities, quality of life, architectural quality, and try to create specific overviews, specific indicators and parameters for each of these qualities and how they can be combined. In some cases there are quantifiable measures available and in others we have to develop them. So it's a combination of statistics, [*coughs*] architectural theory, user participation, focus groups, etc. So there is a lot of new work being done. Because we see often that when a lot of those qualities especially related to use and users – there are often – we don't have any way to quantify them which means that the ones that can be quantified, like costs or energy consumption or even emissions, those tend to dominate the discussion when it comes to sustainable dwellings and the other qualities are [*coughs*] – well – in [*incomprehensible*] these qualities have to be satisfactory but there is no way to measure whether they are true. So anyone can claim that they are satisfactory and they often lose in competitions to quantifiable measures like cost, energy. So we try to develop indicators and parameters that can compete with those – or that can be used in conjunction with the quantifiable ones in order to get more balance results both for evaluation and for planning of sustainable dwellings.

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

- Depending on what you regard as typical there is in Trøndelag there are lots of sprawl which in itself – so even if the house would be fairly well insulated etc, - the transport needed to get to and from the house, the infrastructure needed, even all the local schools and [*coughs*] sorry all the shops and schools which are needed to sustain people in those sprawling areas - I don't think you can call sustainable. In the urban area of Trondheim for example or any other smaller villages around most of them have a policy of building in more compact manor and combining built environment with green spaces and high quality public spaces which is a very good quality. But at the same time it's quite difficult because well Nordic weather, half of the year is difficult to go outside so people tend to stay in their houses. People like fireplaces, open their windows for fresh air etc, so there is a challenge in building low energy low emission houses that can be combined with peoples lifestyle – so adapting the physical dwellings to peoples lifestyles and preference but also trying through the design of the house to influence peoples lifestyles to be more sustainable. At the same time of course – so not everyone can live in cities: you also need people out in the districts, in farming or other activities, but it's mainly sprawl just in suburban areas that is quite a challenge. So if it's possible to have more of the dense compact urban cities then that would be a better solution.

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

- Well in Norway the ideal still seems to be the detached villa, suburban villa which is probably one of the least sustainable forms of buildings you can find. But that seems to be the ideal for - you know students like to live in the city center and then as soon as they start a family and have children then they move out to this villa, they stay there for the rest of their life until they become older and maybe need help or they cant live on several stories anymore, they become less mobile – so then they have to move again. One of the problems related to this is that people tend to stay in their suburban villas for a long time even if they are only using half of the house due to decreased mobility while lots of younger families have that same dream and that same need so if we want to sustain this dream of suburban villas it would be much better to try to get solutions where different generations could live under the same roof. Young families usually don't have that much money either so it might also be an option for them to rent or own part of a house. At the same time if we actually want to decrease this kind of suburban villa we should make housing closer to the city center. Different kinds of user groups, maybe also related to social housing for example, so any kind of user group where as now – with a lot of specially here in Trondheim a lot of urban near to the central dwellings are being developed by contractors which is making standard apartments and they are based on specific user groups or a kind of generic user group which doesn't really fit anyone, just people who absolutely want to live in center and pay a lot of money to get an apartment which is not in itself of a very good quality. It is more the location for which you pay. So to have more research into how people actually live and how they use their dwellings in everyday life, how the dwelling is related to its surroundings, the facilities, the sites, climate, etc. And how you can use these different characteristics to maybe reduce the size of the dwelling. Or create some shared facilities or other kinds of solutions which would make it possible to reduce both the size and the costs of the dwellings while providing say qualities that people are looking for. And this is kind of research that we are doing at the Brøset project.

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

- Yes, we are doing so. Of course there have been a lot of projects in the direction of low carbon neighborhoods. So not just individual dwellings but entire neighborhoods where you look at housing, other kinds of facilities, transport, climate adaptation and so there are lots of international examples as well. And yes, one of the challenges is that a lot of these kinds of projects either focus on the building aspects or the technological physical aspects or on social-cultural studies, so user lifestyles etc, but it is difficult to unite both. That is what we are doing – trying to do at least – but it is a challenge because the disciplines are quite different and there is not that much tradition of cooperation between them – or there have been but they are quite instrumental for example in office buildings how do you get users to behave in a specific way but when it comes to dwellings those are quite private part of people's

lives. So it is difficult to influence both the kind of dwelling that people want to have and how they behave in that dwellings. We are working for example on this Brøset project where we really try to ask question with every step in the process – both related to the master planning of the area to the housing itself, the facilities around and the way it which it might be able to influence people's lifestyles. Its architecture, engineering, planning in cooperation with social-cultural studies like product design, artists even. So we are trying to find any kind of overlap between our disciplines that might be able to change or affect peoples' behavior. There is also a lot of studies – well behavioral psychology on how to nudge people into making specific decision the same as you would have in a supermarket – the shelf you place a product can influence what consumers buy so we try to do the same for architecture. This is a very long term project though – we started planning Brøset in 2006 and now the master plan isn't even ready yet, we just finished a parallel commissioning process where four teams made proposals for master plans so it really takes a long time but at the same time we have opportunity to work closely with the municipality and ask questions with every step - try to change the way in which decisions are made. It brings up very interesting questions for example – if you have this low carbon neighborhood area with low energy use, a lot of blue-green structures to enable climate adaptation for example. If people live in this environment does it make them more happy – would they also start to consume less or would they travel less, would such an environment prevent them from going on shopping sprees to London. We are trying to find an indication of how this environment affects people's lifestyles, this is quite difficult because there are so many factors involved and whether your design is actually affecting people of if is due to something completely different.

- [*Researcher: What are some of the main preferences that people have expressed in the Brøset project? What are the attributes of the structures and neighborhoods, the residences that they have expressed?*] You mean the end users? [*Researcher: Yes*]. We hired a research fellow who works with focus groups and interviews for two years with this project. The end users, one of the challenges is that there are no end users yet in this project – so for the focus groups she used people living in the vicinity of this Brøset area and school children for example in the area. And one of the main problems is that a lot of the housing surrounding the Brøset area is kind of suburban villa type housing so people are very used to a specific lifestyle which is one of the most polluting types of lifestyles. They are most likely not the user group that would be the most likely to move into Brøset. We have been trying to find out what kind of qualities they would appreciate in this area that might convince them to not own their own car for example or be able to park their car in front of their house. And a lot of it is related to accessibility of everyday facilities – we also have people working on non motorized transport – people's everyday walking, cycling for example. And what we saw was that if people have five chores or activities during the day, if they need the car for one of them, they will take the car for all of them. So to make sure that you have kindergarten, school, work, groceries, everything available in walking distance is one of the main things. So people will most likely still want to own a car, but it would be ok to park it at the outskirts of the area for example if they don't need it on a daily basis. That is one of the issues, the other is for example for families with small

children - or any children – we see that in Norway specifically a lot of people tend to move out of the city center to a more quiet place where they can have the garden, not that much traffic to give children a more quiet upbringing and in Brøset area or other projects like those where you focus a lot on climate adaptation and integrating blue and green infrastructure into your neighborhoods to accommodate storm water or reduce air pollution, we see that these types of structures have a very good effect on local neighborhoods so that it does become more attractive for families with children because if you can reduce the local transport, if cars stay on the outskirts and you have more biking and walking facilities and in addition you have green areas you have some water, maybe a small lake or something, it makes it quite attractive. Also for elderly people for example who do like this social contact, everyday contact and local life, they are not so mobile and for them to live in this kind of area is a big advantage.

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

- The most obvious one was CO2 calculator which (*Company AS #1; authors note*) created together with the Industrial Ecology Programme – it was related to all activities and products in Norway. And when the four teams that were in the parallel commissioning process that were given the task to develop a master plan they had to fill out this table that (*Company AS #1; authors note*) made and for every design decision they made they had to argue how it was going to affect CO2 emissions in this area so off course for the housing or building infrastructure that was not straightforward but the most straightforward part but for an influence on lifestyle or on transport they basically had to find argumentation in existing research or other experiences to show how they through design could effect CO2 emissions. And that was a very strange experience for most of them – they are not used to thinking that way. On the other hand it did make them think – you know is there a link for example providing a good neighborhood environment and people consuming less or by facilitating something more straightforward a marketplace for vegetables and fruit can you make people buy those or for organic produce. Can you encourage people to consume those rather than taking a car and going to a shopping center outside of town. So we got feedback that at first they found it very irritating to fill out these issues but actually when they start to think they found that they could influence more than just the building itself. We also had a lot of discussions about MFA for example and especially the scalability – we discussed electric cars, are we going to ask the people if they want to own a car it should be an electric one for example. We don't want Brøset to be a unique case but we want to try out solutions that should be transferrable to other areas or even larger regions. So you have to find solutions that don't just apply to this one thirty five hectare site with a lot of political goodwill and extra funding and then the problem is always well there is a lot of solutions in renewable energy, electric cars other even local organic produce that wouldn't be scalable to such a high degree or at least not in an economic framework. To be conscious of that, so not that is necessarily has influence the design of the neighborhood itself but maybe more of a policy factor. LCA we are looking at of

course – for example so how to design the housing or any building in a way that all the components can be reused, recycled, that the house can be refurbished and that it is worth refurbishing over long periods of time. And if you have some temporary structures that can be taken down again and reused in a different setting. This has been done for single buildings but not on a large scale.

- [*Researcher: Has there been any research or projects which have integrated that design for disassembly concept?*] Well we had a PhD on this topic design for disassembly concept, (*Jane Doe #1; authors note*) working at this faculty, now she works for Industrial Ecology. And of course well basically throughout history a lot of vernacular architecture was designed in this way and then with industrial revolution new materials – we kind of lost that focus. One of the challenges now with for example now there is a huge passive house debate – so whether we are kind of locking ourselves in with all the energy and money and so funding that has gone to Norwegian passive house standards – whether they are too much focused on technology whether they require a lot of materials that are in of themselves not sustainable at all, that have a high embodied energy, that cannot be reused because they are maybe laminated or destroyed when you take apart the layers of the building. And ya, which have fairly short term use so maybe the building you design, or modules are too specific to be used elsewhere. That might be the case here now that we know from other examples in Austria and Germany that it is perfectly possible to design it in a different manner so it is not the concept of passive house in itself that is the problem but the way it is implemented. And maybe also who, because there are a lot of people who copy specific methods or solutions without actually knowing the history behind them. There are in other countries solutions, examples of how this can be dealt with without creating this technological lock in. Actually they built two houses in Trondheim two years ago, identical, but one was made of new materials and one way made of recycled materials. The company said it was an interesting exercise but they wouldn't do it again because they had large problems with ensuring the quality of the reclaimed materials, which I can understand because there are no routines or methodologies for doing it but on the other hand we see that (*Research Institution #2; authors note*), which is one of these environmental centers in the UK, they actually have done a lot of studies where old reclaimed materials are much more robust than newly produced ones, especially when it comes to wood. Again there is the issue of scalability [*laughs*] if everyone is going to use reclaimed materials it is going to be a problem. The construction industry currently is built on new products, technologies, and if you want to use something different it is quite difficult, it costs more just because there are no routines and actually when you do try something like that you have to provide a lot more proof of quality than would in a standard house. More work needs to be done to provide a kind of support framework for anyone who would like to try to work with reclaimed, reused materials or try different design solutions, even maybe different financial models because that is often also the case, either you use more time, or it costs more when you try these solutions that actually could be more sustainable.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

- People don't invest in sustainable housing because it costs more in terms of upfront investment and even if we try to – you know if we give them lifecycle costing models – it often doesn't change the case because people invest everything they have in this new house. So they would rather pay for a larger kitchen than for better insulation. So that is quite difficult – in most cases people don't act rationally in that way – even if you say in 5 to 12 years time you will be saving money, they don't care that much. In the context of this Brøset project we would like to cooperate with a bank like (*Company AS #3; authors note*) for example that would be able to provide a loan with better conditions for sustainable housing. It is done in other countries, not in Norway – well there is a small bank called (*Company AS #4; authors note*) which offers this kind of product, but they are quite small so a lot of people wouldn't dare to take the risk to loan their money there. But (*Company AS #3; authors note*) has had this kind of role before with providing housing for everyone so if they could be persuaded to provide better conditions on a loan, for low energy and emission housing that would be a good solution. In addition we are also, we are planning to look at different kinds of financial models for the housing that is developed at Brøset whether it is different kinds of ownership and tenancy models, well that is something that we intend to do but haven't started to look at yet, also related to what is the shared facilities and what are the private facilities and how can they be funded because of course we also look at how this areas is going to be – who is going to pay for the area for example. Usually, or if we hadn't started this project, the area would have been sold to a developer who would have developed the area with the highest density possible and probably build quite expensive apartments so now we are trying to see whether there is any possible cooperation between municipalities, other site owners and developers, preferably several small developers or several developers taking smaller areas and checking whether they can be made responsible for developing several of the shared infrastructure. Since we want to get different kinds of users into the area we also look at maybe you have some very high end housing and some more towards social housing and how distribution can be made there.

7) In what way should **building standards** be incorporated in research on sustainable residential dwelling?

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8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

- There are quite a lot of perspectives in this question. Land zoning frames how compact and/or green a particular neighborhood can be developed, it defines whether the housing will be located in a mixed use area and thus have a lot of facilities such as schools, work, shopping available on a daily basis. Accessibility for all user groups is another issue. What kind of transportation links are available, by walking, biking, public transport? Is the area designed in a way that it feels private and only for that particular neighborhood, or does it provide a good connection with the surrounding areas? In fact, we've seen case studies where only green businesses were allowed to start their operation in particular neighborhoods: certified materials, organic produce, eco-certified supermarkets, shared facilities for neighbors, such as meeting places, temporary offices, guest rooms and so on. But this type of action can be quite a challenge for municipalities. They are going to get protests from politicians, from industry, from inhabitants and so on, anything and anyone that breaks the standard routines of current practice. At the same time, there are a lot of things with which we have to experiment, where we just don't know the answer yet. If we allow a developer to build apartment blocks of 5 storey's high, for example, does that mean that people living there are going want to leave the area more often during weekends? If we integrate blue and green structures into a neighborhood, is that going to attract more families with children? Are they then going to travel less, when they have such a local neighbourhood available? Land zoning has been discussed extensively during the past 5 years of the Brøset project, and basically the area will become a kind of Living Lab for testing out promising principles. This means we'll have to plan, guide and follow-up the area and the residents continuously

in order to learn more about how it works in practice, before we can recommend some of these principles to other developments. Therefore we are planning to start an environmental centre that can take care of the daily follow-up in the area, both in terms of people, measurements, and maintenance. And of course as a meeting place for various stakeholders such as the municipality, industry, researchers, students, users and so on to discuss how to move further with these principles, in the Brøset project and elsewhere.

Academic Respondents - Interviewee #6

1) How do you define sustainable residential dwelling?

- Sustainable residential dwellings – well we tried that in the Brøset project and we ended up being just saying that the – it should be within the 550 parts per million scenario and of course that's the total allowance of carbon for capitas. And then going to the dwellings part it's you are not allowed to emit a lot of carbon so you would be [*incomprehensible*] In terms of CO2 you would go somewhere around 2 tons of carbon per capita in total and you don't have much room for dwelling so it should be over the lifetime, lifecycle of dwelling pretty much as good as it can get and currently that is the passive house standard although I'm not convinced that it will be a passive house that will be the sustainable dwelling. But that is what we are investigating but it's in the very near to passive house arrangement but it's not all about in use phase energy, you have to also include embodied energy in the materials. So, but anyways, way beyond where we are at average now so it's in the range of very low energy buildings and the interesting thing is then the embodied energy which don't have any fixed design there yet.

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

- As they are now, not at all. At the average now, no they are way above. Well Norway is an exception as the heating is from electricity but. Well in theory they could be if they were self dependent on renewable energy but as we speak worldwide, they are not. They are on average way above 100 kHw per square meter per annum and that's even close. We are going down in the range of at least below 30 I think. So if we are talking energy-wise globally then embodied energy also I don't think they are sustainably if you are talking new construction. But of course they are already built and then it is a matter of heating and then it's a matter of energy – I mean if every house has its own windmill then any house could be sustainable. Ya that's the big question for the future, what to do with the already existing buildings – it's the main headache. The new constructions will be solved in a ten year framework I think.

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

- You have to clarify what you mean by intergenerational equality. [*Researcher: intergenerational equality referring to equality between multiple generations so not just a single generations like children but extended generations into the future*]. How they interact with sustainability? [*Researcher: How has that concept of intergenerational equality been, or how should it influence research on sustainable residential dwelling or how has it been integrated already?*] In the way that we are looking into new building more previously is supposed to have longer lifetime and more flexibility in terms of use then it would suggest this quality is of interest. When it comes to the Norwegian residential dwelling stock it's not really been addressed I think. We have very new building stock that if you look at the buildings built before the Second World War they have in many senses better quality in this regard and its now also a question of whether

we are going to keep buildings of different age types. I think that we want to keep the older buildings because of their qualities. We are not so interested in keeping all buildings from the 50s, 60s, 70s, and perhaps 80s for the same reason. I think that its an important quality that comes in terms of service life of the building and the flexibility f the building. And so we have to think of the same resilient or robust buildings. I'm not sure if research as such here has been done on that – we are looking at the technical building envelope and the structural parts. Here we are dealing with the building physics. So there we are interested of course in the service life.

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

- I think the Brøset project tries to do that and we are a bunch of people who have been working on that project. So the question is in that regard is yes – whether or not that is a success, I mean it's not completed yet, we don't know the results yet but it has had an impact on the municipality of Trondheim and what they are going to do on that area. It is at least a start and it is somewhere between 1200 and 2500 apartments or dwellings so, ya we are starting. And there are alright examples around the world in Finland and other places – ya it started. And I think it is recognized as an important thing.

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

- Well yes, there is obvious LCA to various degrees and various successes. It's not been a complete success due to lack of inventory and then there are several studies who has looked into the MFA of things and have I think the combination of these two tools will make an impact. What I would like to see is the use of LCA on individual building – that will come -but the problem with LCA in relation to buildings is it is not complete to what you want to know for the building for instance you will never get indoor air quality from an LCA. So you need other tools so these sustainable building tools like BREAM, LEED, Greenstar, etc – they are kind of using a more holistic approach. The problem with these is they do not include the scalability issues and they are not also dealing with limits to growth problems so there are several people that say that ok this is all fine but we need to do MFA to look at the embodied energy total, scalability of new technologies and that's not often been done but it is coming. Scalability of urban systems is growing so yes I will say that it is starting and it start with the industrial ecology community and also some outside. And it's slowly being integrated in the sustainable research – yes I think the tools are good in this sense but it will take some time before they are widely used. The problem with these tools is that they are very generic and they are coming from a system of products with kind of short lifetimes. And they don't really fit the workflow of the construction industry. Given that the construction industry is the Goliath and the LCA is the David I think there has to be changes in how we do the LCA to fit the workflow of the construction industry if it's going to make an impact.

- [*Researcher: How can LCA be remedied with this structure. How do Building Information Models relate to this?*] In a nice way – I think that is the route to go. But it's a route – it's not really been done yet and will take some time. We are trying to make research on this but it's not come very far yet. In principle it would be great. You could have a BIM model, you could have geographic information, you have your BIM and then you get all you need in terms of all [*incomprehensible*] the BIM has, environmental information. And you are able to make this 3D drawing and from that you can put that together so you can get the physics the quality of the building, the geographic location, sun, etc. And you could basically get the energy calculations given the sun, weather etc, and you press the button and say have a complete LCA of whatever lifecycle you are talking. But we have been talking BIM for 15 years but nothing much has happened with these tools - I still think are a few years left before we can make this happen. But in principle you need to do so.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

- Well there has been a lot of cost analysis and LCC going on but these depend on which interest value you are using because the higher value you use the less impact the future has so it's kind of been a problem that you don't really appreciate the future in economic terms. But I think using the framework of LCC is a very good start to start harvesting data which can then be used for LCA. So I think that maybe through input output or other tools you could use this framework as a way to get to the LCA. So I think they are important or need to be careful about the interest rate and we have to see how we can deal with this because cost is always a problem. Today it is much more important than tomorrow. If there is a conflict between cost and environmental performance I think cost will win – and that's a problem.

7) In what way should building standards be incorporated in research on sustainable residential dwelling?

- Well they are – the role they have are they are making the benchmark line. So in terms of incorporating into research they are a starting point. So the point is then how much beyond these are we supposed to go? And standards is has such a good thing but they could also be a limit if you have too rigid standards they will kind – there is a danger of then locking you into a side-track that you can't escape in terms of technology - way of doing things that could hinder future development. Standards are ok but they should be given in such a way that they are not locking you into technologies. We have seen that tried before in terms of pulp and paper that you had different approaches in standards in the US and Canada – there the standards locked you into standards where in the rest of the world they were locking into emissions. It was much more – it was developed much more cost efficient technologies outside the US and Canada – it almost broke those industries that were locked into technologies and they achieved less for much more money and they also went out of business. I think that proved that standards are important, they will force development in the

right direction but you will not, should not lock a standard towards technology. They have to be up to – they have to give targets, not technologies.

8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

- It's hard to say, I think ya not currently looking at it. It's probably – there is always a conflict between let's say urban areas and agricultural areas. And it's supposed to be reflected in the LCA in terms of the impact on the land and biological systems. But as such we are not completely discussing it in our research, we are dealing with the building regardless of where it is. And I think we will continue to do so. I also think that as we merging towards what is going on with the buildings – kind of like city ecology – I think that the logical next step will be shrinking cities and rebuilding of cities from within. That's already been done in London or other cities they kind of saw that as a city sprawl. For many reasons that's unsustainable - as people moved out in the outer circles – a natural consequence was to build the new city from within almost deserted areas and I think that will happen over and over again. I think a city as such is a valuable thing and you don't want to be in the outskirts because then you will have to move and waste materials along the way. People don't want to do that, they don't want to be in the outskirts. There will of course be research on how this could best happen but for us I think we have plenty to do with the building itself and then what is going on between the buildings to take into account the land use and I think that problem will more or less be solved by itself since agricultural areas will of more value given the population size. We will also see it with climate change that you need more areas of non-developed land from various sources – so it's on the agenda but it's not spoken as your question – it is a logical consequence rather than an area of research itself. Yes I think it will be handled somewhere. And there is people that are doing research, probably – but we are not and I don't think we will do so – at least not in the near future.

Academic Respondents - Interviewee #7

1) How do you define sustainable residential dwelling?

   - Today a sustainable residential dwelling is not a specific defined building. I think it depends on the context but I think we are getting towards a time and place where it will be defined and it will probably be something like a low energy dwelling, a passive house or a zero emission building - when that is defined. And in Norway we have a standard that defines the former two building categories.

2) Would a typical residential dwelling in the Trøndelag Region meet your criteria?

   - A typical dwelling in Trøndelag or Trondheim area is already built, many of which quite some years ago and it's not very many passive houses and not low energy buildings either. So in that regard there are not a lot of sustainable buildings in the Trøndelag region. But hopefully in time we will have quite some new passive houses and a lot of the existing buildings will also have been upgraded.

3) Can you describe the ways in which the concept of intergenerational equality influences/should research on sustainable residential dwelling?

   - I think – I'm not so familiar with this concept so, but I think that it doesn't really link to the energy efficiency quality of the buildings. So it is possible for the building to be very energy efficient or say sustainable building – and still not take intergenerational quality into account. Currently I think that sustainable buildings are more about the energy efficiency than other qualities. In our research into zero emission buildings we are talking about buildings that will produce energy. And for these buildings we are also including e.g. architectural qualities. Intergenerational equality may therefore also be a part of future buildings.

4) Are you aware of anyone who has integrated community preferences in research on sustainable residential dwelling?

   - Community preferences – Can you elaborate please? [*Researcher: as in the expressed preferences of the community expressed via involvement in planning*]. Ok I think they are planning this new local community at Brøset. And I think that they have both researchers and possible users involved but I am not so familiar with that project.

5) Can you describe the ways in which the quantitative tools of industrial ecology have been applied in research on sustainable residential dwelling?

   - I do not think that it has been used so much before. But these days when we are talking about zero emission buildings it is being picked up more and more. There are PhD students working on applying these types of tools to analyze various problems related to buildings, e.g. what type of materials are important for the buildings of the future to reduce the carbon emissions. I don't think it has been used so much but I think it will pick up as we move toward the future building and define buildings in a different way than we used to. Up till now we have mostly been looking at kWh per

square meters. Now we are sort of switching to carbon emissions – and then the lifecycle of the building also needs to be considered.

- [*Researcher: which tools are the most important to this field?*] Which tools? Do you have examples of these tools [*Researcher: life-cycle costing, life-cycle analysis, material flow analysis, input output analysis*]. Life-cycle analysis is the tool we will use and that is the tool we have used so far.

- [*Researcher: do you think it is possible to achieve absolutely zero carbon emissions in buildings?*] That is what we are aiming for. It's hard – the building needs to produce more energy than it use during operation because we also take into account the carbon emissions related to materials of the building.

- [*Researcher: is your definition of zero emission building based on energy balance – thus allowing for carbon emissions to be negated by surplus production of electricity during another life-cycle phase?*] Yes.

6) Can you describe the ways in which economic cost models/finance have been applied to research on sustainable residential dwelling?

   - No, I'm not so familiar with that – not in the research. But for zero emissions buildings to be sold in the future they have to be cost effective. It the investment cost is larger than for other buildings, the owner/user need to save money in the operational phase. But, I haven't looked into the research in this.

7) In what way should building standards be incorporated in research on sustainable residential dwelling?

   - I think building standards are a result of research, or they should be. Because when you make building standards, like energy calculation standards, you need to base it on some scientific foundation. In that way it is sort of a result of the research. But it is also used when research is being done, e.g. to calculate the energy use of buildings and to analyze various technological solutions.

8) Can you describe the ways in which land zoning applies to research on sustainable residential dwelling?

   - I haven't worked with this.

C. Figures and Tables

Table 11 - Nested Principles of Ecologically Sustainable Building (Graham 2003: 206)

Law	*Principles*
#1 – Consume resources no faster than the rate at which nature can replenish them	• Minimize resource consumption • Maximize use of renewable and used resources • Do more with less – resource efficiency
#2 – Create systems that consume maximum energy-quality	• Use solar income • Use energy in a large number of small steps, not in a small number of large steps • Minimize waste
#3 – Create only byproducts that are nutrients or raw materials for resource production	• Eliminating pollution • Use biodegradable materials before bio-accumulating materials • Reuse, then refurbishing and recycling of materials, components and buildings
#4 – Enhance biological and functional adaptability and diversity	• Apply life-cycle awareness and the precautionary principle • Provide access to fast-cycling materials without destroying slow-cycling materials • Protect and enhance biodiversity

Table 12 – The Six Principles of Green Architecture (Vale and Vale 1991)

Principle	*Short Explanation*
#1 – Conserve Energy	• A building should be constructed as to minimize the need for fossil fuels to run it
#2 – Working With Climate	• Buildings should be designed to work with climate and natural energy sources
#3 – Minimize New Resources	• A building should be designed so as to minimize the use of new resources and, at the end of its useful life, to form the resources for other architecture
#4 – Respect for Users	• A green architecture recognizes the importance of all the people involved with it
#5 – Respect for Site	• A building will "touch this earth lightly"
#6 – Holism	• All the green principles need to be embodied in a holistic approach to the built environment

1. **Insist on rights of humanity and** nature to co-exist in a healthy, supportive, diverse and sustainable condition.

2. **Recognize interdependence.** The elements of human design interact with and depend upon the natural world, with broad and diverse implications at every scale. Expand design considerations to recognizing even distant effects.

3. **Respect relationships between spirit and matter.** Consider all aspects of human settlement including community, dwelling, industry and trade in terms of existing and evolving connections between spiritual and material consciousness.

4. **Accept responsibility for the consequences of design** decisions upon human well-being, the viability of natural systems and their right to co-exist.

5. **Create safe objects of long-term value.** Do not burden future generations with requirements for maintenance or vigilant administration of potential danger due to the careless creation of products, processes or standards.

6. **Eliminate the concept of waste.** Evaluate and optimize the full life-cycle of products and processes, to approach the state of natural systems, in which there is no waste.

7. **Rely on natural energy flows.** Human designs should, like the living world, derive their creative forces from perpetual solar income. Incorporate this energy efficiently and safely for responsible use.

8. **Understand the limitations of design.** No human creation lasts forever and design does not solve all problems. Those who create and plan should practice humility in the face of nature. Treat nature as a model and mentor, not as an inconvenience to be evaded or controlled.

9. **Seek constant improvement by the sharing of knowledge.** Encourage direct and open communication between colleagues, patrons, manufacturers and users to link long term sustainable considerations with ethical responsibility, and re-establish the integral relationship between natural processes and human activity.

Figure 23 – The Hannover Principles (McDonough 2000: 6)

Table 13 – The Five Principles of Ecological Design
(Adapted from Van der Ryn and Cowan 2007)

Principle	*Brief Explanations*
#1 – Solutions Grow from Place	• Build using inspiration gained from the location (culture, climate, materials, landscapes, etc) • If possible, use solutions and strategies employed by local, indigenous communities • Use inspiration from similar biomes/bioregions
#2 – Ecological Accounting Informs Design	• Accurately measure the environmental impacts associated with design • Follow the flows - consider the quantity of energy, water, materials, toxins, wastes, and land used in design over the entire life-cycle
#3 – Design with Nature	• Aspire to designs that are compatible with the living world - nothing should violate the wider integrities of nature • Waste equals food, closed loop material cycles • Utilize self-organizing, self-designing systems • Respect ecotones, biodiversity, and space requirements for maintaining ecosystem health
#4 – Everyone is a Designer	• Employ participatory processes – design as a cultural process rather than an expert one • Utilize community workshops, design competitions and provide environmental education to increase number of possible participants • Ongoing discussion of goals with community
#5 – Make Nature Visible	• Showcase nature to reestablish personal connection with local environment – visual ecology • make complex natural processes visible and understandable • unmask systems and processes that remain hidden from view • emphasize our unrecognized connections to nature

Table 14 - Strategies for Regenerative Design (Adapted from Lyle 1994: 37-45)

Strategies	*Brief Explanations*
Letting Nature Do The Works	• Reject technological solutions when natural ones can be used equally as effectively (predator species vs. pesticides for pest control, trees vs cooling systems for climate control in urban areas, etc) • Natural systems are regenerative, and thus cheaper to maintain – they are also less environmentally damaging than technological system
Considering Nature as Both Model and Context	• When developing natural environments for human use, maintain or reestablish continuity and connections with the larger landscape and ecosystem • (e.g. - investigation of typical native vegetation proportions and structure as a basis for designing ideal agricultural mixes) • Use nature for inspiration - applications can be highly abstract
Aggregating, Not Isolating	• Reject design of parts in isolation – parts are easy to design but cannot be combined easily into an integrated whole • Systemic design of multiple objectives at the same time
Seeking Optimum Levels for Multiple Functions	• Think in terms of a range of values for objectives vs. defining a single value • Accept fuzziness and ambiguity between seemingly conflicting goals • (e.g. - David Hopcraft harvesting surplus antelope to remove risk of depleting natural vegetation in Kenya)
Matching Technology to Need	• Amory Lovins's comparison - nuclear power being used to heat water for generating electricity is like using a chainsaw to cut butter • As multiple goals enter design process and as all the costs of operation become more apparent, the price of overdesign becomes too high • (e.g. – using fossil fuels to ensuring comfortable interior spaces is inefficient when considering multiple objectives like cost and indoor air quality)
Using Information to Replace Power	• In industrial system, response to uncertainty is over-engineering • If the potential situation can be more precisely described, the safety margin can be reduced and the system designed to suit the situation • (e.g. - integrated pest management where farmers watch for signs of pests in combination with traps. When pests become problematic, action can be taken)
Providing Multiple Pathways	• Multiple pathways are more resilient to sudden, unexpected changes • (e.g. - smart grids which allow houses to either contribute or feed from the grid depending on the weather conditions, farms with varied combinations of crops and animals that change from year to year)
Seeking Common Solutions to Disparate Problems	• Solutions must originate from a systemic understanding of system requirements, challenges, etc • (e.g. – using heat from decomposition for aiding plant growth in greenhouses, treated wastewater filtered through soil to aid in agricultural production and wildlife habitats)
Managing Storage as the Key to Sustainability	• All natural systems have associated storage capacities, replenishment and release rates which must be respected • (e.g. – atmospheric and oceanic storage of carbon dioxide vs. geologic storage stocks)
Shaping Form to Guide Flow	• Energy and material flows occur within the physical medium of the environment, and the medium largely determines the pace and direction of flow - by shaping the medium (the environment) we can guide the flow • Build structures to optimize flows, thus reducing environmental impact • (e.g. – charcoal starters which use air-flow to eliminate fossil fuel fire starters)

Table 8 Continued - Strategies for Regenerative Design (Adapted from Lyle 1994: 37-45)

Strategies	*Brief Explanations*
Shaping Form to Manifest Process	• The massive scale and harsh forms of industrial technology have forced it to exist in exile, located where it is seen no more than necessary • Not seeing the real face of industrial technology makes it possible to ignore its presence until its effects become overwhelming • Regenerative technologies are much harder to hide because they are by nature more integral to their context
Prioritizing for Sustainability	• Sustainability must become a high priority, perhaps an overriding priority - it will have to enter into every development decision

Table 15 - Three Images of Architectural Sustainability (Williamson et al. 2003: 25)

Image	*Dominant Concern*	*Dominant Horizon*	*Symbolism/ Aesthetics*	*Approach*
Natural	Environmental place, ecosystems, health, balance	Local	'Touching the earth lightly' with forms echoing nature	Study local natural systems; emphasize sensitivity and humility in relation to nature.
Cultural	Cultural place, people, genius loci, difference, cultural sustainability	Local	Highly contextual with forms, materials and construction methods echoing the local vernacular	Study local culture and building; emphasize local involvement and local expertise
Technical	Technologies, global environmental impacts, cost-benefit analysis, risk management	Global	Leading edge contemporary international systems	Study science, economics and technology; emphasize transnational expertise

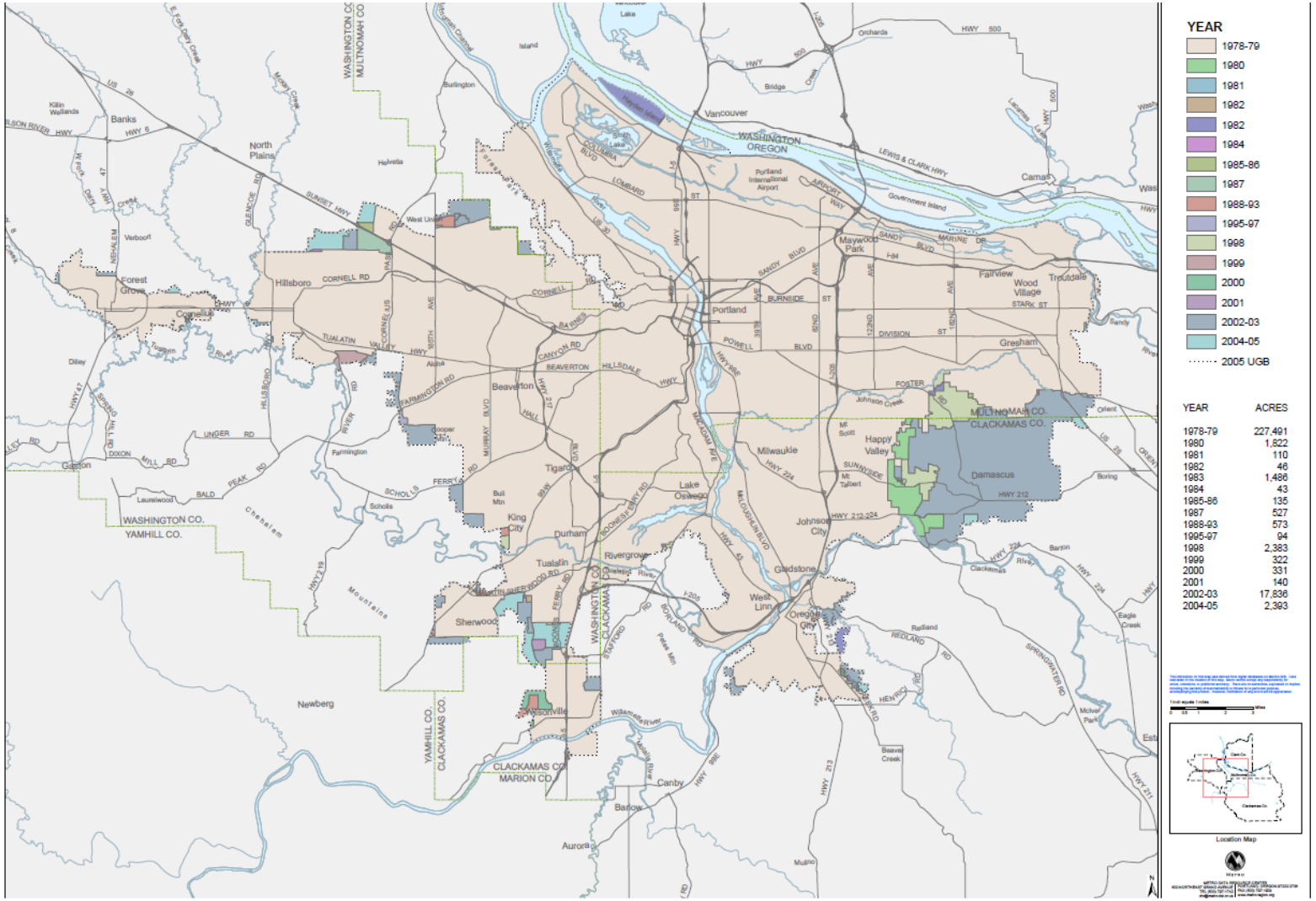
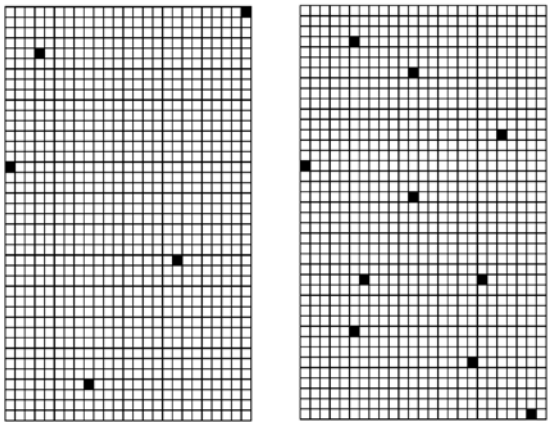


Figure 24 - Urban Growth Boundary Expansion History Map for City of Portland, OR from 1978 to 2005 (Metro Regional Government, 2006)

Themes	EarthCraft Communities	EarthCraft House	Enterprise Communities	Green Globes	Health House	LEED-H	LEED-ND	LEED-NC
Innovation, integration, project management, and design process	1%	6%	2%	6%		14%	10%	7%
Location, linkages, and neighborhood fabric	43%		16%			12%	56%	
Sites	24%	5%	8%	10%	10%	16%		20%
Water	11%	6%	5%	9%		9%		7%
Energy		40%	16%	24%		6%		26%
Building materials and waste management	8%	22%	11%	19%	87%	9%	34%	18%
Indoor environmental quality		18%	36%	23%		30%		22%
Education, maintenance, and communication	12%	2%	5%		3%	5%		
Emissions and global impact				9%				

Figure 25 - Emphasis on Major Themes in Nine U.S. Building Assessment Systems (Retzlaff 2008: 511)

D. Proposed Questionnaire for Deriving a Representative Intergenerational Discount Factor



A B

1) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your CHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

2) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your GRANDCHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

3) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your GREAT-GRANDCHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

4) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your GREAT-GREAT-GRANDCHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

5) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your GREAT-GREAT-GREAT-GRANDCHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

6) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your GREAT-GREAT-GREAT-GREAT-GRANDCHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

7) Please identify the *maximum* amount of money you would be *willing to pay* today for the *increased probability* (represented by the difference between grid A and B) that your GREAT-GREAT-GREAT-GREAT-GREAT-GRANDCHILDREN would experience a quality of life *equal or better* than the current Norwegian average.

☐$0 ☐$50 ☐$100 ☐$150 ☐$200 ☐$250 ☐$300 ☐$350 ☐$400 ☐$450 ☐$500

☐$550 ☐$600 ☐$650 ☐$700 ☐$750 ☐$800 ☐$850 ☐$900 ☐$950 ☐$1000+

E. Images of Typical Residential Dwellings in Trondheim

"Rekkehus" – Two Family Residences near Singsaker, Trondheim
Photo Credit: Deha Örencik

Multi-Resident Apartment Block near Rosenborg, Trondheim
Photo Credit: Deha Örencik

"Enebolig" – Single Family Villa near Tyholt, Trondheim
Photo Credit: Deha Örencik