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# Energy Efficiency and Universal Design in Home Renovations - A Comparative Review

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**Abstract.** Policy and societal objectives indicate a large need for housing renovations that both accommodate lifelong living and significantly increase energy efficiency. However, these two areas of research are not yet examined in conjunction and this paper hypothesizes this as a missed opportunity to create better renovation concepts. The paper outlines a comparative review on research in Energy Efficiency and Universal Design in order to find the similarities and differences in both depth and breadth of knowledge. Scientific literature in the two fields reveals a disparate depth of knowledge in areas of theory, research approach, and degree of implementation in society. Universal Design and Energy Efficiency are part of a trajectory of expanding scope towards greater sustainability and, although social urgency has been a driver of the research intensity and approach in both fields, in energy efficiency there is an engineering, problem solving approach while Universal Design has a more sociological, user-focused one. These different approaches are reflected in the way home owners in Energy Efficiency research are viewed as consumers and decision makers whose drivers are studied, while Universal Design treats home owners as informants in the design process and studies their needs. There is an inherent difficulty in directly merging Universal Design and Energy Efficiency at a conceptual level because Energy Efficiency is understood as a set of measures, i.e. a product, while Universal Design is part of a (design) process. The conceptual difference is apparent in their implementation as well. Internationally energy efficiency in housing has been largely imposed through legislation, while legislation directly mandating Universal Design is either non-existent or it has an explicit focus on accessibility. However, Energy Efficiency and Universal Design can be complementary concepts and, even though it is more complex than expected, the combination offers possibilities to advance knowledge in both fields.

**Keywords.** universal design, energy efficiency, home renovation, housing

## 1. Introduction

Demographic shifts and lifestyle changes have created demand for housing renovations to accommodate lifelong living, while environmental concerns and policy goals on energy efficiency drive a need for deep energy renovations. Reviewing scientific

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literature on Energy Efficiency (EE) and Universal Design (UD) reveals that there is no comparative scientific work directly addressing the combination of these domains. Our hypothesis contends that this separation is a missed opportunity to create better renovation concepts and to produce important reductions in time, money, and inconvenience through the simultaneous execution of EE and UD renovations.

As a first step towards studying this hypothesis, the paper reviews and compares scientific research on EE and UD in order to identify the similarities and differences in both depth and breadth of knowledge. Understanding the differences and similarities between these disciplines is necessary to discover a synergetic way of theoretically and practically combining them in order to advance the adoption of both UD and EE . Literature reviewed for this paper is within the scope of private home renovations. Home renovations belong within the domain of the built environment, as opposed to product design or ICT, but are different from public buildings or multifamily housing construction in the number and role of stakeholders involved. In other words, in private single family home renovations the user is often also the one that sets the project vision, finances it, and is the final decision maker . In public buildings and mass housing projects these roles are often dispersed over several, often professional, stakeholders.

This study reveals a different approach and research focus for both fields, which has resulted in a disparate depth of knowledge in areas of theory, research approach and degree of implementation in society. The paper is structured under these three headings. Each one is further elaborated and discusses the nature of the two concepts in terms of product and process, their expanding scope from their origins in the 1970s, their different focus and approach, the societal drivers behind the direction and impetus of research in both fields, methods of implementation of each concept, and finally the study and success of adoption by society of energy efficiency and universal design in housing.

## 2. Theory

### *2.1. Process vs. Product*

One of the first things that becomes apparent from literature is the different nature of EE and UD concepts. EE in housing is mostly understood as a product, a set of physical measures applied to a building in order to achieve more efficient use of energy. The broad definition of energy efficiency is the simple ratio of “useful output of a process” divided by the “energy input into a process”[1]. In precisely defining the useful output and input Patterson [1] identifies four types of indicators used to measure energy efficiency: thermodynamic, physical-thermodynamic, economic-thermodynamic, and economic. The physical-thermodynamic indicators are hybrid indicators which measure energy input in thermodynamic units while the output is measured in physical units which reflect the end-use service required [1]. Since the environment characteristics in buildings, such as temperature, humidity and air quality, are a physical output of energy input, one often used indicator of energy efficiency in housing is energy input/square meter.

The physical nature of the indicators allows for the creation of energy performance standards for building elements (such as U value for windows or walls) or for whole houses (such as Nearly-zero-energy-building (nZEB), passive house, and E-level). Although the standards are subject to change and upgrading, they remain as indicators of a physical product. In order for a house to be labeled nZEB in Flanders it must comply with a checklist of performance criteria set out by the Flemish government such as a Umax of 0.24 $W/m^2K$, an energy performance level of E30, and maximum of 70 $kWh/m^2$ for net heating demand [2].

UD on the other hand is usually defined as a process, guided by principles and aiming to achieve certain goals. The term was coined by Mace in 1985 as “The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design”[3]. Iwarsson & Stahl [3] offer another definition of UD as “…the best approximation of an environmental facet to the needs of the maximum possible number of users”. They continue to elaborate that Universal Design is “uttermost about changing attitudes throughout society” and that it “denotes more a process than a definite result” [3].

The Center for Universal Design, based on the input of ten experts, in 1997 determined seven principles which embody the spirit of Universal Design in order to move away from the practice of simply going through a checklist [4] which is seen as negative in UD research but encounters less resistance in EE. Steinfeld [5] acknowledges these principles and attempts to make the concept more practical and easier to adopt by breaking it into 8 goals. Preiser [6] developed the habitability framework in order to cast Universal Design principles into a framework for evaluation while still trying to avoid a simple checklist approach.

Since Energy Efficiency and Universal Design are two concepts of different type – one being a product and the other a process – directly merging the two is logically impossible. The conceptual difference becomes apparent in the grammatical use of the terms – EE as a noun or adjective, UD as a verb. According to the generally accepted definitions, the phrase “An Energy Efficient house” makes sense while “A Universal Design house” less so. However when UD is used as a verb, the phrase “A Universal Design-ed house” is more appropriate.

One way to merge EE and UD would be by either breaking them down and adding the sub-components, or by abstracting them to higher levels and combine those. For example, it would be possible to combine EE measures with Lifelong-Living (LLL) measures (also called Lifetime Homes in UK). Although most LLL measures focus on usability and accessibility, “Livable Homes” in Australia and “Lifemark Homescore” in New Zealand attempt to make such a combination of EE and LLL with a wider aim of sustainability. These projects also affirm the place of EE and UD under the framework of environmental and social sustainability respectively.

### *2.2. Expanding Scope*

Apart from their conceptual level, EE and UD are part of a trajectory of expanding scope in research that moves towards the broader framework of sustainability. Both fields are born out of the activist movements in the 1960-70s. EE stems from the environmental movement and the oil shocks of the 70s [7], whereas UD developed as a result of a civil rights and equality movement which had a focus on accessibility for people with disabilities, otherwise called “barrier-free design”[8].

Although motivated by higher ideals such as human rights and environmental sustainability, initially UD and EE were focused on providing direct technical solutions. They addressed issues such as efficient energy consumption at home (e.g. by electrical appliances) and accessibility in public buildings for wheelchairs and other disabilities. In the US this led to the first regulations for energy efficiency and accessibility in buildings with the Energy Policy and Conservation Act (EPCA) in 1975 (updated 1979) which established energy efficiency standards for consumer products [7, 9], and with the Architectural Barriers Act in 1968 where the US Congress required that all federal buildings be accessible for people with disabilities [10, 11].

In the EU, energy policy was initially left up to member states, however following the 1992 Maastricht treaty and then the Lisbon treaty in 2007 the EU has produced an increasing number of energy-related directives. The first push towards integration of energy policy was made in response to the 1973 oil crisis and the "Council resolution concerning a new energy policy for the community" was passed in 1974 and then strengthened in 1985 to include both energy production and energy demand [12]. In 1992 the first voluntary directive on energy efficiency was issued on Energy Labeling of Domestic appliances (ELD). It was followed by the Energy Performance of Buildings Directive (EPBD) in 2002, Ecodesign in 2005, and Ecolabel in 2010 among many others. In 2007 the Commission's "An Energy Policy for Europe" strategy was endorsed by member states. The strategy had three challenges, sustainability, security of supply, and competitiveness, which the Commission planned to achieve with its 20/20/20 plan published in 2009 [12]. One of the three goals was to reduce energy demand by 20% from projected levels through increases in energy efficiency. As part of this larger strategy the EPBD was recast in 2010 mandating that all new buildings (and some renovations) in EU must be near-zero-energy (nZEB) [13]. A new recast of the EPBD is to be expected by the end of 2016[14].

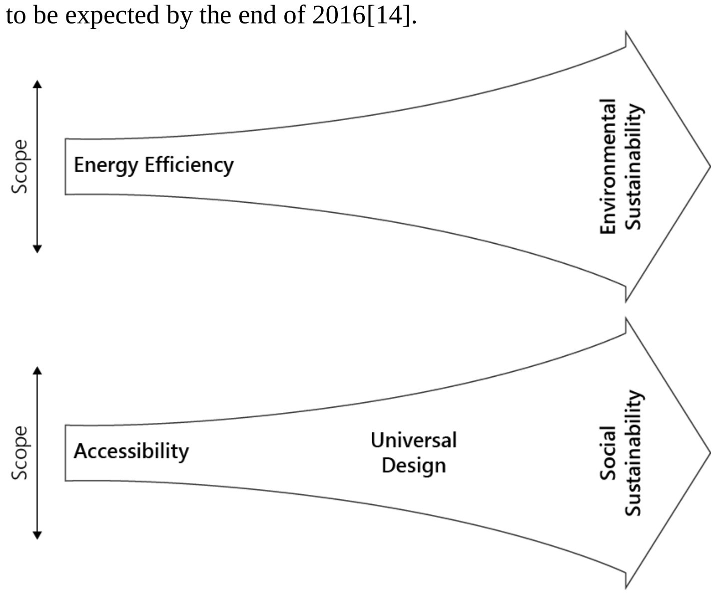


**Figure 1**. Expanding scopes of energy efficiency and universal design towards sustainability.

Unlike in the US, early developments in the fields of disability in the EU were driven more by design and rehabilitation needs, which is why disability legislation in Europe comes later than in the US but is now farther ahead [8, 15]. While most legislation on accessibility in buildings is at a state level, in November 2015 the EU proposed an "Accessibility Act" that would specify the accessibility requirements for products and services [16]. Bendixen and Benktzon [15] argue that in Scandinavia it was the 1993 UN "Standard Rules on the Equalization of Opportunities for persons with Disabilities" that placed accessibility on the agenda. By 2009 Norway published its action plan "Norway universally designed by 2025"[17] which aims to reduce discrimination and "bring both the equality policy and sustainability policy an important step further". Vavik and Keitsch [18] discuss the role and common goals of UD and Socially Sustainable Development.

UD has a wide scope including not only technical aspects like accessibility and usability aspects but also ideas like equity, diversity, and wellbeing [11, 19, 20] and fits well within the social sustainability framework. In contrast, although Energy Efficiency now can be seen as part of the wider environmental sustainability framework (among other subjects such as materials, waste, ecology, resources etc.), it is still a field working mainly at the technical solutions level. This difference of focus is discussed in the next section.

## 3. Research Approach

### *3.1. Driven by urgency*

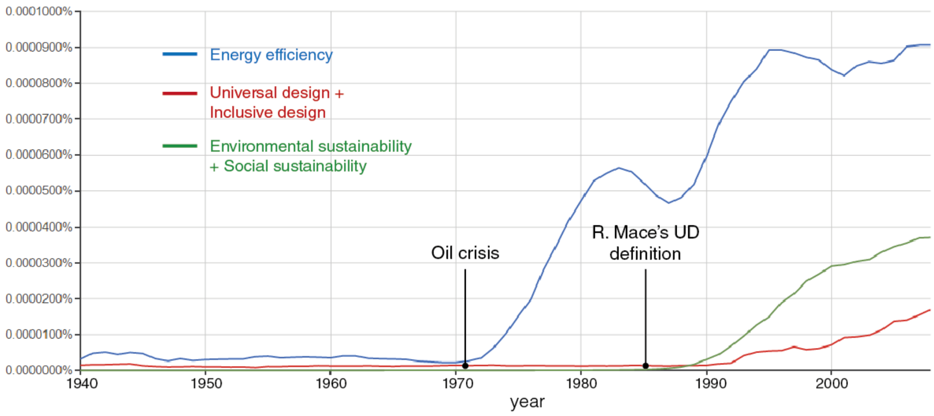


**Figure 2**. Google N-gram charts the frequency of occurrences of the words "energy efficiency", "universal design" with its UK equivalent "inclusive design", as well as "environment sustainability" and "social sustainability" in English literature from 1940 to 2008.

Scientific research is inextricably linked to the society that funds and then makes use of the knowledge produced. Google's N-gram Viewer[2], which can be used as a tool for investigating cultural trends [21], helps to demonstrate the timing and gravity of the rise of the terms "energy efficiency" and "universal design" in English literature (Figure 2). While the graph cannot be interpreted in terms of absolute values, the trends are quite clear. Energy efficiency exploded into the social consciousness in the early 70s and has continued increasing its cultural reach after the late 80s recession. While UD, predictably, started to become part of the conversation in the late 80s after Ron Mace's coining of the term in 1985. By comparison, "accessible design" and "barrier-

[2] The Google N-gram Viewer charts the frequency of occurrence of words in a literary corpus comprising 4% of all works, over 5 million of them, published until 2008 which have been scanned by Google. It includes fiction, non-fiction as well as scientific publications.

free design” were not visible on the graph while the popularity of the terms “social sustainability” and “environmental sustainability” kicks off in the mid-80s coinciding with the Bruntland report in 1987 [22] (Figure 2).

The oil crisis of the 70s was an immediate crisis felt directly (through energy bills) and indirectly (in economic and political impacts) by large portions of society in the western world. The high impact and visibility of the crisis meant that there were political and economic incentives to intervene and search for solutions. The series of legislative measures that mandated more energy efficient consumer products, eventually expanding to buildings and energy consuming sectors of the economy, and the spike in research on energy efficient products and buildings, were a direct response to the need for more efficient use of energy [7, 23]. The International Energy Agency (IEA) created the Energy in Buildings and Communities Programme (EBC) in 1976 with the intention to direct international research projects towards energy saving technologies and activities that support application in practice [24]. IEA-EBC has been bringing researchers together in international research projects on EE in buildings and communities and continues to steadily increase the number of projects from 13 in 1976-1985 to 21 projects in the 2006-2015 decade [25]. Concerns about energy cost and security coupled to environmental concerns have increased and maintained the focus on developing solutions for energy efficiency in buildings.

Universal design has evolved from the concept of accessibility which, while important, it did not have as high an impact on as wide a margin of society as the energy crisis. As such it came into the wider social conscience later than energy efficiency. Only recently, when the economic and political effects of demographic and lifestyle shifts are beginning to be felt, has UD garnered a strong political backing, with the notable approval of UN Convention on the Rights of Persons with Disabilities in 2006 [10]. The current trends in developed countries towards rapidly ageing societies is bringing urgency to the field [3, 10, 26]. Besides discussions on theory and definitions, there will be a demand to come up with practical and measurable solutions that satisfy societal needs.

The European Commission’s *Horizons 2020* program [27], which funds innovative research across the EU, names “Health, Demographic change, and Wellbeing” and “Secure, Clean and Efficient Energy” as two key societal challenges for the future. By 2017 it will spend €2 billion on the first challenge and over €5.9 billion on the second challenge [27]. The funding parallels the relative importance of UD and EE in societal consciousness as shown by the N-gram in Figure 2.

### *3.2. Engineering vs. sociological approach*

The sense of urgency has had an effect not only on the amount (funding) of research allocated, but it also has guided the focus and approach of research in EE and UD. Energy efficiency research is therefore approached mostly from the problem solving perspective of an engineer who leverages knowledge in science and technology to address a specific problem. UD related research has a more designerly and sociological approach where tailoring the built environment to people’s needs is at the focus.

EE’s engineering problem solving approach relies mainly on measurements and calculations. This has the advantage of providing direct, clear and comparable answers, but does not consider whether the question being answered is the right one to ask. Questions like ‘Is energy efficiency necessary if all energy produced is renewable?’ or

‘Are the EE systems compatible with the way people use and perceive energy?’ can hardly be answered by calculations based on an “average user” approach, which has been the trend. An issue often discussed in EE research is thermal comfort, which is usually measured and tested based on an average male wearing a suit in North-America for whom the state of comfort can be found only within a precisely limited range of temperature and humidity levels [28]. This is an obviously over-simplified condition that does not take into account cultural and individual preferences and expectations or the fact that people can adapt their clothing to the environmental conditions. Recognizing this, the field has recently shifted towards a greater focus on people and taking into consideration users’ diversity and ability to adapt [28-31].

A direct focus on people and accommodating their diversity is the approach taken in UD research places. Ongoing discussions about the definition of UD [3-5, 8, 11, 32] are an indication that figuring out what is the right question is an important part of the work of researchers in the field. However these discussions also reveal the difficulty of operationalization of UD. In trying to account for user diversity in buildings, UD ends up either with vague and subjective guidelines or with an unwieldy number of indicators and a wide variety of disciplines involved in its evaluation. There is room for a research approach that balances considerations of user diversity during design with more practical ways of applying and measuring UD success.

Besides the theoretical and methodological discussions, work on advancing technical knowledge, i.e. “what works”, still continues strong today in both EE and UD research. In EE new technologies, construction methods, and their integration and effects on building occupation are continually being developed and tested. From a technological point of view, achieving a net zero house is possible and relatively straight forward (when not considering cost) as exemplified by the many pilot and showcase energy efficiency homes and the passive house movement.

UD theory aims to create more inclusive environments for all and towards that goal knowledge about the specific needs of “non-average” users is constantly being advanced. For example we know more and more precisely about the housing needs of people in wheelchairs [33], who have visual or hearing impairments [34], who suffer from dementia or autism [35], or simply the usability needs of people who have reduced mobility and dexterity [36]. Real world best practice cases are also well documented.

## 4. Implementation

### *4.1. Legislation*

The actual implementation in buildings of EE and UD can be viewed from two perspectives: 1. legislation, where authorities impose or incentivize certain choices on people and 2. adoption, which relies on people’s willingness to choose for UD and EE. Implementation of EE in housing has been largely imposed through legislation such as the EPBD (first in 2002 [37] then updated in 2010 [38]) which places minimum requirements for building elements. This is more difficult for renovations since they must deal with existing conditions and many renovations are too small to require building permits which would enforce EE requirements. For public buildings, new housing and large renovations that require permits, the clear and measurable criteria of EE have made legislation both possible and useful as it forces even skeptics to increase efficiency of new buildings under verification by municipalities or other legal authorities.

E. Ostroff [11] points out that legislative measures have been instrumental in advancing the UD paradigm in larger-scale built environment., There are legislative requirements for some UD goals such as accessibility, safety and signage laws to accommodate persons with disabilities which largely apply to public buildings and in more limited form to multi-unit residential projects. However there is no legislation that mandates a UD process [32]. Norway has passed legislation in 2009 with the aim of becoming “Universally Designed by 2025” but in this case UD is simply equated with accessibility [17]. This is an expected result since it is much more difficult to legislate a process that has goals which are vague and difficult to measure, unlike the simple and clear accessibility criteria. Mace [32] suggests that, particularly in housing, it is probably not possible to mandate UD. Market-driven implementation research is present both in UD and EE research, but in UD it is primarily related to products and (IT) services, rather than housing [10, 11].

### *4.2. Adoption*

More recently EE research has started spending considerable effort on studies of barriers and incentives that affect the adoption of EE measures by home owners [39-44]. Initially research on the topic, particularly the quantitative type, has tended to treat the home owner as a rational consumer with the results showing that the key adoption factors have to do with economic/financial calculations. However, a recent trend is using behavioral and sociological insights to discover the deeper meanings and drivers behind adoption of energy efficiency measures [45-52]. This indicates that in EE research home owners are more and more recognized as core decision makers and the factors that could affect the decisions are becoming an important part of EE research.

In UD research attention is paid to user needs and there is a lot of user involvement and testing, however their role often remains as “informants” for the design process rather than decision makers. They are meant to help the designer (along with other professionals) create the best design possible. The implication is twofold. First, users have no decision making power and second, that a good design is all that is needed to increase adoption of UD. The result is that users’ incentives and barriers to UD adoption are rarely studied. It may be true in the case of public buildings and mass housing that the final users have little or no decision making power, but in custom single family homes and home renovations the inhabitants are not only the final decision makers but are also the ones that often set the initial vision and ambition of the project. As such, their perspectives, perceptions, incentives and barriers towards UD are important factors for its adoption in housing.

## 5. Conclusive summary

At a conceptual level directly merging UD and EE is not possible because EE is defined as a product while UD is a process. The concepts need to be analyzed at the same level, as processes or products, in order to be combined either by breaking them down into sub-components or by abstracting them to a higher level.

Both EE and UD are part of a trajectory of expanding scope, concerns about EE have expanded into general concerns about environmental sustainability, and issues of accessibility have expanded towards universal design and can be seen even further into social sustainability.

Social urgency has been a driver of the research in both fields. Oil shocks and environmental concerns created the conditions for faster and more applied research in EE field. While for UD the sense of urgency is only just beginning to be felt due to the demographic shifts and ageing societies in western countries.

EE has an engineering problem solving approach which relies on calculations and clear criteria. It has the advantage of providing clear answers but it is only recently acknowledging user diversity. UD has a sociological approach that focuses on user diversity but lacks clear criteria for operationalization.

Implementation of EE in housing has been largely forced through legislation which is made possible by the clear and measurable criteria used in EE. While accessibility in buildings has been similarly implemented through legislation, which only partially apply to private housing, there is no legislation mandating a UD process. Implementation through legislation may be impossible due to UD's nature as a process with some goals that are difficult or impossible to measure.

Finally, EE considers home owners as decision makers and has spent considerable efforts lately studying the factors that affect their decision to adopt or not EE measures. UD treats home owners as informants that participate in a UD process but the decision making power is implicitly assigned designers and other professionals. There is an opportunity for UD to recognize the power of homeowners as decision makers whose perspectives, perceptions, incentives and barriers towards UD are crucial for its adoption.

## 6. Discussion

Based on the literature reviewed it is clear that the difference in the evolution of approach between EE and UD fields explains the current disparate status of research. These differences point out the unexpected difficulty in merging the two concepts, but also that UD and EE are complementary and their combination would offer great possibilities for advancing knowledge in both fields.

The results presented here also bring forth a series of questions and areas for further research. One of the more significant blind spots in UD research is the lack of adoption studies. What are the advantages and disadvantages of UD from the perspective of home owners and clients? What would be the levers and brakes on its wider adoption by society? How can the concept be reworked or elaborated in order to make it more appealing to people?

Another area for further research is in exploring ways of making UD principles and goals more clear, measurable, and easier to work with, perhaps by learning from EE methods, while still maintaining its focus on enabling diversity. Energy efficiency research can be expanded by using research methods common in UD, such as research by design and using more nuanced indicators, in order to account of the imperfect human element that is part of every EE technology, and the very wide variety of personal preferences, abilities, and cultural differences which can directly affect the adoption, use, and efficiency of EE measures.

Finally, new and fertile ground for further research is created when EE and UD are studied in conjunction, if the obstacles can be overcome. What concepts may be employed to represent such a merger? What would be the framework and the internal and external relationships of EE and UD when merged? What would be the advantages and disadvantages and how could it be implemented? These questions will also help guide our own research in the future.

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