A Framework for Green/Eco-Innovation Through Use of a Novel Measure: E/R

Liliya Hogaboam, Alptekin Durmusoglu, Turkay Dereli and Tugrul Daim

Abstract Eco-innovation has been a recent idea used to describe development of products, services and processes that contribute to sustainable development (SD) through commercial application of knowledge considering ecological facts. This chapter introduces a green/eco-innovation framework incorporating the uncertainties and acquisitions together. A measure is used to indicate the ratio between "possible risks" and "values added". This measure is named as "E/R" ratio, where E represents "eco-innovative acquisitions provided by the proposed novelty" and R denotes the "risks which arise as the consequence of novelty". A simple evaluation structure has been developed to calculate the value of E/R ratio for a certain novelty. Proposed framework is tested through the case of green buildings providing an insight into the risks associated with them.

1 Introduction

Water scarcity has emerged as one of the most pressing problems in the twenty first century [1]. It is estimated that 2.7 billion people will face water scarcity by 2025 [2] and several wars could explode. It is obvious that, for today's highly

L. Hogaboam
Nascentia Corporation, Portland, USA
e-mail: liliya@nascentia.com

A. Durmusoglu · T. Dereli
Gaziantep University, Gaziantep, Turkey
e-mail: alptekindurmusoglu@gmail.com

T. Dereli
e-mail: dereli@gantep.edu.tr

T. Daim (✉)
Portland State University, Portland, USA
e-mail: tugrul@etm.pdx.edu

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populated habitat, "scarcity problem" (not just water scarcity) signifies a much more hazardous situation for the world. Scarcity has been a problem which threatens today's community with a higher potential to affect the living standards of future generation. "Scarcity" term, points out to the inequality of the desires/needs of human and the resources available to match them. The solution to the scarcity problem, which human-being is engaged with, is supposed to be found within equilibrium where the needs are satisfied without abolishing the resources. There have been several studies which are focused on finding such an equilibrium point. Objective of these efforts has been to analyze scarcity problem and its link to environmental/ecological change and to identify options for a more sustainable planet. Therefore, it is claimed that, the concept of sustainability- has emerged as the consequence of equilibrium search to scarcity problem. Sustainability concept dates back to studies performed by Malthus [3] on population growth in the late eighteenth century. Thomas Malthus, who published an essay on the "Principle of Population" in 1798, warns society about the fact that population increases exponentially and food production increases only incrementally.

Approximately 200 years later, an official definition for sustainability was declared by the Brundtland Commission Report in 1987 [4]. It was: "meeting the needs of the present generation without compromising the ability of future generations to meet their needs". After the summit, a series of subsequent meetings were held and "Agenda 21" report was published. The report was a comprehensive global strategy towards sustainable development. It is worth mentioning that almost all parties were impressed with Brundtland's definition of sustainability. However, the phrases used in the definition were not clear and these phrases have introduced discussions about the real meaning of sustainability. What was the word "need" referring to? Was the definition indicating lowering of living standards and luxury? It should be expressed that these questions still have value and they are still discussed.

After a five year gap, Rio Earth Summit had been held in Brazil. 172 governments participated, with 108 sending their heads of state or government [5]. As an important outcome of the summit, some essential documents for sustainable management/development have been discussed and declared to the public. At the same summit, "*C*ommission for *S*ustainable *D*evelopment" (CSD) has been founded by the United Nations General Assembly. CSD was also employed with follow-up implementations regarding the Rio Summit.

Millennium Summit has been another milestone for sustainable development. Summit's final declaration was signed by 189 countries. International community promised to apply a specific agenda to reduce global poverty and starvation problem. In parallel to these milestones, the concept of sustainable development (SD) has become a leading goal of policy makers and scientific researchers [6]. It has been a widely acknowledged concept used by organizations representing all scales of governance: local, regional, national and international [7]. On the other hand, philosophical arguments have been issued in scientific journals, to develop a deeper understanding of the real meaning of sustainability. Sustainability has been regarded as both an important but unfocused concept like "liberty" or "justice" [8, 9] and as a feel-good buzzword with little meaning or substance [10, 11]. The views on sustainability were not surprising since the concept was comparatively young, complex and abstract [12]. As a consequence of these debates, scientists have all agreed that "sustainability" is a multidimensional concept and it encompasses economic, social, and ecological perspectives of conservation and change. Therefore, several stakeholders and scientists from different disciplines, including engineers, have been all involved in sustainability and sustainable development.

2 Literature Review

Relationship between resources and the demand for these resources has been subject of economics science. Economics as being 'the study of the most favorable conditions for giving society the greatest amount of useful products with the least waste of human energy' [13] has its roots on the reality of limited resources against the unlimited wants and needs. However, the "sustainability" has been a multidimensional concept and the role of engineers in sustainable development cannot be disregarded. Engineers have been stakeholders of the scarcity problem and sustainability since they are responsible to design machines, tools, devices, processes, systems and employ materials to these designs. They are the providers of the mechanisms for the transfer of technical skills and comprehensive planning techniques to implement "sustainable development" at an individual, corporate, and institutional levels in developing and developed countries. Engineers are involved in sustainability from all aspects such as; resource use, from resource extraction through to technology/product/process design, manufacture, operation and management of wasted resources and products. For an engineer, creating sustainable systems involves making engineering and New Product Development (NPD) decisions based on multiple dimensions: technological, ecological, economical, and socio-cultural, including ethical [14]. Furthermore, creating sustainable systems involves making use of an "integrated systems approach" (holistic approach) which considers all stakeholders and the possible consequences on the environment once attempting to solve problems. They should focus on an overall synchronized solution rather than solely on the technology aspects, and solving one problem at the expense of another.

It is certain that much more items/tasks could be listed to define the role of engineering in sustainable development. However there is a certain need for a well-defined guideline describing these roles. Even though the role of engineering for sustainable development has been discussed in many platforms, as well in this chapter, there has not been a well-defined guideline describing these roles. Canadian Council of Professional Engineers (CCPE) has been one of the institutes which proposed a "well intentioned guide" for the key roles of engineers. CCPE declared a report [15, 16] stating that "professional engineers have an obligation to be mindful of the effect that their decisions will have on the environment and the well-being of society" and "shall hold paramount the safety, health and welfare of the public, and the protection of the environment". One other effort has been the organization of a high-level workshop on centralization of engineering for the sustainable development policy, research and delivery, by Royal Academy of Engineers and Defra [17].

Technology is one of the most important ways for human being to interact with their environment. People use technologies for various purposes such as to extract natural resources, to modify them for human purposes and to adapt our man-made living space [18]. It is required to be conscious and thoughtful in employment of technology in order to cover distance towards sustainability. Since there is a need for a certain awareness to use technologies, engineer's role in developing technology is very important to keep the sustainability.

Even though it is important to develop sustainable products, processes and systems, it would not make sense to do so for the entrepreneurs and customers, if they cannot be commercialized. Therefore it is more rewarding to develop "sustainable and worth-trying" products for customers. "Eco-innovation" is the right term defining the development of sustainable products which has certain commercial value. Sustainable innovation/eco-innovation is an emerging and fundamental force for change in business and society [19]. James [20] defines: "eco-innovation is one of several approaches towards sustainable product design, which aims to provide customer and business value whilst significantly decreasing environmental impact". These two objectives can be obtained through design of products and processes which maximize resource and energy efficiency, minimize (or preferably eliminate) waste and reduced harm to the environment [21]. However, achieving these objectives may not be as easy as it is considered. A framework defining the path through eco-innovation in a stepwise manner is expected to be beneficial for eco-innovation.

Although several definitions, objectives and techniques have been provided for "eco-innovation", the effort to present a general framework for "eco-innovation" has been limited. One of the earliest efforts for a design of such a framework has been performed by Brügeman [22]. She considered Roozenburg and Eekels's [23] product innovation model (PIM) and took "possible merits of sustainable function of innovation" into account to present an eco-innovation framework for service design. She added two steps to Roozenburg's PIM. The model was based on collaboration of possible utilities which can be obtained considering *E*co-efficient *S*ervices (ES). The model initialized with exploration phase where decisions on establishment of a right collaboration are made (such as determination of partners and the divided responsibilities). In the last part of the model, an evaluation phase is performed through the use of indicators of "Design for Eco-Efficient Services" (DES). DES indicators measure the possible environmental improvements which can be turned out by the novel service. Hallenga-Brick and Brezet [24] considered the weaknesses of DES model developed by Brügeman's [22] and proposed a novel framework (Sustainable Innovation Design Diamond Model) to support design of efficient sustainable innovation strategies. They have determined six fundamental diamonds which describe milestones of a design project. One well-structured framework for eco-innovation (interchangeable with "Green Engineering") was published by Anastas and Zimmerman [25]. They have announced 12 Principles for Green Engineering, which has been a design protocol for engineers to utilize in moving towards sustainability. The principles listed by Anastas and Zimmerman [25] have been used as a framework by designers to consider them as fundamental factors at the earliest stages of design.

The application of principles across scales and across disciplines has been documented with case studies from a variety of sectors [26, 27]. Fundamental approaches and instructions in moving towards sustainability have been common for different industries. These implementations also provided guidelines for improving sustainability through the design and development of technologies. Rocha et al. [28] have also proposed a sustainable development management framework which integrates seven key factors: stake-holders, resources, leadership, processes, values, objectives and results. The proposed framework enables the introduction of sustainable development principles in each of these seven factors. It also takes, the interrelationship and trade-offs between them at the macro level, into account. This allows managing the overall strategy according to a whole system perspective that considers short- and long-term impacts. Recently, Flores et al. [29] proposed a framework to be used as a reference guideline for organizations to define a roadmap, specific actions and projects to achieve sustainable innovation, integrating four key enablers: mass customization, sustainable development, value network and complete product and service life cycle. Mass customization (MC) targets the identification and compliance with specific needs and requirements of customers in order to achieve customer-driven design. At the same time, the sustainable development (SD) paradigm is taken into consideration, where, for any new product or service companies analyze the benefits, risks and impacts of not only economic factors, but also social and environmental implications. The third enabler is linked to the value network (VN), where innovations happen owing to the active collaboration and distributed knowledge of partners inside and outside the company. Finally, the fourth and last considers the complete product and service life cycle (PSLC), where the above mentioned three sustainable elements are identified and analyzed in each single business process.

3 Methodology

There have been several efforts to measure eco-innovation. Some of these measures are developed to draw a macro level figure for eco-innovation (surveys, patent analysis etc.) however, some other measures are developed to create a benchmark for eco-innovators to measure how much they reduce environmental burden (ex: [30]). However there has been a serious gap in development of a measure considering the risks due to new product development.

As indicated by James [20], there are two main objectives of eco-innovation: (i) providing customer and business value; (ii) decreasing environmental impact. It is important to consider both of these objectives and follow a systematic path during the New Product Development (NPD) process. However, risks arising from NPD should not be ignored. Because of NPD's inherent features, NPD decisions inevitably encounter a considerable amount of uncertainties which may result in negative consequences of the targeted performance [31, 32]. Therefore, it is apparent that it is important to consider "possible risks" and "values added" by eco-innovation prior to initialization of NPD process.

A measure or ratio can be defined to indicate the relationship between "possible risks" and "values added". Therefore, a ratio is proposed in this work. This ratio has also been employed in the proposed framework. This ratio is named as "E/R" ratio, where E represents "eco-innovative acquisitions provided by the proposed novelty" and R denotes the "risks which arise as the consequence of novelty". Possible acquisitions and risks of eco-innovation need to be defined first to prepare E/R ratio. Seven major eco-efficiency elements defined by World Business Council for Sustainable Development (WBCSD) are used to describe the benefits of novel eco-friendly products or processes [33]. Chin et al. [34] recent study has been considered to outline the risks of NPD since they have scanned literature and prepared a well-structured risk map for NPD.

A "7 × 8 matrix" is build up and presented in Fig. 1, where rows indicate the "acquisitions provided by the proposed novelty" (E) and columns indicating "risks which arise as the consequence of novelty" (R).

A simple evaluation structure has been developed to the calculate value of E/R ratio for a certain novelty. If the novelty added to product has ecological value, it should satisfy at least one of the items listed in rows (E), however the indicated novelty can also create the risks given in columns (R). Then the E/R value of the novelty is:

E \ ***R***	CPD	SEP	RDC	PES	CPP	SES	SPP	PRC
E_1: Reduce the material intensity of goods and services (material reduction).								
E_2: Reduce the energy intensity of goods and services (energy reduction).								
E_3: Reduce the dispersion of any toxic materials (toxicity reduction).								
E_4: Enhance the recyclability of materials (material retrieval).								
E_5: Maximize the sustainable use of renewable resources (resource sustainable).								
E_6: Extend the durability of products (product durability).								
E_7: Increase the service intensity of goods and services (product service).								

Fig. 1 E/R Evaluation Matrix

$$E/R = \frac{\sum_{i=1}^{i=7} \#\text{ of risk factors provided by the proposed novelty by acquisition } E_i}{7}$$

As an exemplification, think of a novel eco-innovative product proposal adding value to an existing one by reducing material intensity of goods. However, in case of realization, it will be very similar to an existing product in the market (SEP) and company's potential to articulate successful R&D activities on this novelty is very difficult (RDC). At the same time, company requires many new machines and equipment to realize production. However the other risks are not expected to occur. At this time, we have three risks and one "eco-innovative single acquisition provided by the proposed novelty", then E/R value for E1 is, 1/3 and we need to calculate the other acquisitions in the same manner and add them up.

Innovation is typically an iterative and interactive process [35]. Like the other iterative processes, innovation requires a base product/process or service to iterate. Majority of patents are related to improvements to existing patented inventions and they form a base for innovation processes. NPD as being a sub process of innovation [36] can utilize patents to search for gaps in the relevant technologies [37] and thereby patents are known to be one very useful source for stimulating innovations.

In this chapter, a novel "*eco-innovative-new product development*" framework has been introduced to support companies in their decisions to add/remove a novelty of an existing product. The proposed framework is initialized with the selection of a significant patent to focus on/iterate. Subsequently, the selected patent is evaluated using "E/R ratio" which is also introduced in this work (previous section). The patented technology/product or service is then could be improved using several "creativity management" tools like "Theory of Inventive Problem Solving" (TRIZ), "Quality Function Deployment" (QFD) and "Cased Based Reasoning" (CBR). The possible improvements are re-evaluated using "E/R ratio" and then a new value of "E/R ratio" is benchmarked with the patented one. A final decision is made upon this benchmarking. Figure 2 illustrates the steps of the proposed framework for developing eco-innovative product. The remainder of this section describes steps in detail.

3.1 Step 1: Selection of a Significant Patent

Patents are seen as a rich, but often insufficiently utilized source of technical information. Much effort have been undertaken to popularize and promote the use of patent information. A central element of these activities has been the launch of freely-accessible databases on the Internet [38, 39]. Although it is possible to access all granted patents, it is still difficult for a company to find a significant patent through millions of patent documents. Patent Alert System (PAS) recently developed by Dereli and Durmuşoğlu [40] presents a practical solution for

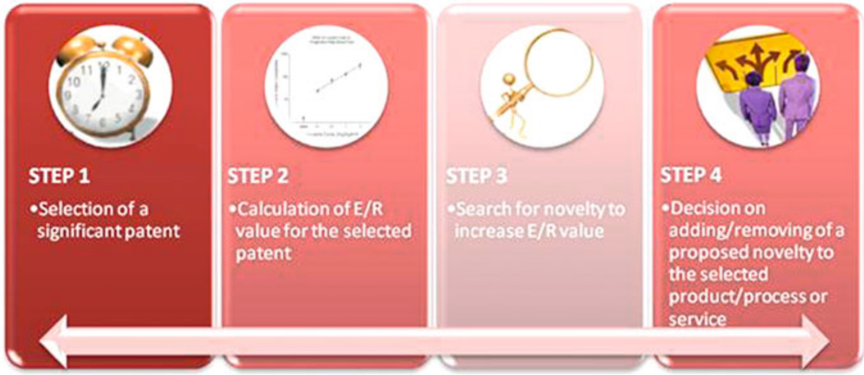

Fig. 2 Steps of the proposed framework

selection problem. PAS is an extended mark-up language (XML) based expert-system which watches the related patents continuously from patent databases and then, *if present*, forwards the trend changes (alerts) along with corresponding patent documents, which create these trends to the user, who configures and requests the patent alert. PAS has a software application created for the "Patent Watch Departments" of the companies, which track the patent information for several purposes. The application currently serves as "desktop software" and it is easy to configure and use. It may be worthy to use PAS, for selecting a significant patent to iterate.

3.2 Step 2: Calculation of E/R Value for the Selected Patent

In this step, E/R value of the selected patent is calculated considering the novelty or novelties proposed by technology. For this purpose, the evaluation structure described in Sect. 4 is employed by the use of E/R matrix.

3.3 Step 3: Search for Novelty to Increase E/R Value

There is a variety of techniques used as creativity management tools for new product development process. These techniques are quite similar with special pros and cons of each [41]. Several creativity management techniques like "Theory of Inventive Problem Solving" (TRIZ), "Quality Function Deployment" (QFD) and "Cased Based Reasoning" (CBR) can be used to add value to the selected patent. However, it should be remarked that eco-innovation is different from general innovation and requires additional attributes of innovation towards sustainability. The goal of eco-innovation is to reduce environmental burden or achieve specific environmental performance objectives. Therefore, seven factors, which were presented as “acquisitions provided by the proposed novelty” in Sect. 4, should be considered and addressed during the idea generation.

3.4 Step 4: Decision on Adding/Removing of a Proposed Novelty to the Selected Product/Process or Service

Decision about adding/removing of a novelty is performed by a simple benchmark among the E/R values of patented product and the proposed novelty. If the value for E/R is increased by the added proposed novelty, then it can be added, otherwise Step 3 can be repeated. It should also be noted that, even if a novelty is valuable to add to the existing product, it could be previously patented. Therefore a functional change of the existing product (towards a new patent) can be required [42].

4 Case Analysis: Green Buildings

Green building has been a developing market especially in the last 10 years. While research continues to define the costs and benefits of green buildings and some strategies to evaluate and achieve the highest benefits at the lowest costs, some questions stay in the center of those research directions. What is green building? How is it different? Is it better? What are the risks? How can we evaluate and analyze them? We will try to discuss these questions in this study based on some case studies.

After some research, there are at least 12 different definitions of green buildings catalogued on the internet, let’s look at some [43]. According to the U.S. Environmental Protection Agency, “green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building life-cycle from siting to design construction, operation, maintenance, renovation and deconstruction” [44]. Another definition is a short one that capitalizes on some main principles of green building: “building that is aimed at energy conservation, saving natural resources, and preserving the environment” [45] comes from Global Green Building, LLC. Some other definitions include characteristics of green buildings as promotion of energy conservation, creation of a healthy place to live, creation of environmentally sound construction [46], usage of internal recycling, renewable energy resources, recyclable or biodegradable construction materials, blending in the local environment [47]. Sometimes green buildings are referred to as “sustainable building” or “environmental building” [48].

The overall impact of the green building on human health and natural environment is reduced by:

- Efficient energy, water and other resources usage.
- Protection of occupant's health and improvement in productivity.
- Reduction of waste, pollution and environmental degradation.

"Green building" is a broad synergetic and multifaceted concept. The roots of green building in the United States arose from the needs and wants of more energy efficient and environmentally friendly construction [49]. The idea for sustainable development can be traced from the environmental pollution concerns and energy crisis of the 1970s. Green buildings combine lots of practices and techniques to ultimately reduce the impact on the environment. The emphasis is on using the renewable resources, better usage of sunlight (active solar, passive solar, photovoltaic techniques), rain gardens, rainwater utilization, green roofs, green concrete, etc.

The technologies in green building are constantly emerging and evolving and are focused in the areas of:

- Siting and structure design efficiency.
- Energy efficiency.
- Water efficiency.
- Materials efficiency.
- Indoor environmental quality enhancement.
- Operations and maintenance optimization.
- Waste and toxins reduction [49].

According to Statistical Summary on Buildings and their Impact on the Environment, buildings account for 38.9 % of total U.S. energy consumption in 2005, buildings account for 72 % of total U.S. electricity consumption in 2006 and this number is projected to rise by 75 % by 2025 [50]. In the United States, buildings contribute 38.9 % of nation's total carbon dioxide emissions [50]. On average, Americans spend about 90 % or more of their time indoors [50]. Some other striking examples of energy use, water use, land use, and other environmental and population facts are published in the above-mentioned summary. The need for improving sustainability of our environments, including buildings is evident.

With this emerging sustainability movement, the questions of how and why build green, as well as valuation and risk management, became some of the most serious questions among engineers, builders, economists, marketing and supply management, appraisers and technology management professionals.

Several grading systems worldwide exist in green building. They range from simple to chronologically complex, from prescriptive to performance based, even from design guidelines to EIAs (environmental impact assessments) [51]. They are usually classified as:

- First generation: nominal (pass/fail type): Those are usually prescriptive certification programs that judge against codes, standards, bylaws with limited focus on energy and indoor environmental quality.

- Second generation: (additive) (LEED, USA): Simple additive systems have appeared due to support from various government agencies with little scope for user-modification to reflect regional differences or individual preferences.
- Third generation (weighted additive): Those systems are inherently complex and lack objective basis. Weights are mostly judgmental or conscious-based and involve expert opinion to rank parameters and allocation based on analytic hierarchy process, statistical correlation and artificial neural networks [51].
- Others: More detailed representation of the grading systems for green buildings could be found in Table 1 [51].

In general, the rating systems for green buildings use some methodologies that allot credits for design features to improve sustainability [52]. Reductions in energy use, improvements in indoor air quality, etc. are the credits. Most of those rating systems are based on a measure of expected performance at design time, so the questions emerge, are those certified buildings living up to their expectations? According to the data by the New Buildings Institute and its analysis by Newscham [52], LEED buildings used statistically less energy than Commercial Building Energy Consumption Survey (CBECS) buildings: average savings ranged from 18 to 39 %, depending on parameters, but at the same time 28–35 % of individual LEED buildings used more energy per floor area then their matched CBECS counterparts.

Also, the grading systems don't include risks analysis, and if green buildings are here to stay, than all the project participants (architects, engineers, builders, marketers) need to be able to manage those process and project risks [53]. Factors like R&D capability, complexity of the product design and production process can have a huge impact on the whole green building construction. To avoid breakdowns, risks need to be managed; materials need to be well selected and application processes need to be chosen very carefully. Any neglect in choosing the right material can cause the whole project to fail. Recycled materials are highly needed, but because these materials are usually expensive, while mixing them with cheaper, weaker or overall inadequate resources may jeopardize the project. Moreover, design and good supervision play an important role when constructing a green building. So, green buildings have to be well designed, properly supervised, and have materials that meet the standards. Since the eco-innovations in green building could bring additional risks, we will analyze two case studies with the novel E/R measure proposed in this chapter.

4.1 Selection of the Cases

The selection of the cases was based on testing of the E/R methodology in two types of green buildings, which had different after-design outcomes despite their LEED certification. We focused on finding one building or building complex as an exemplary green building that continues to excel in green building standards and

Table 1 Most popular grading systems for buildings

Type	Years	Grading system	Developed by	Country
First generation	1981	R-2000	Canadian Home Builders' Association (CHBA, Natural Resources Canada (NRC)	Canada
	1989	P-mark	Swedish National Testing and Research Institute (SP)	Sweden
	1997	ELO & EM scheme	Danish energy authority	Denmark
	2001	Energy Star	Environmental Protection Agency (EPA), and Department of Energy (DOE)	USA
Second generation	2000	Leadership in Energy and Environmental Design (LEED)	U.S. Green Building Council (USGBC)	USA
Third generation	1990	Building Research Establishment Environmental Assessment Method (BREEAM)	Building Research Establishment (BRE) Ltd	UK
	1993	Building Environment Performance Assessment Criteria (BEPAC)	Environmental research group, University of British Columbia	Canada
	1996	Hong Kong Building Environmental	HK-BEAM Society	Hong Kong
	2001	Housing Quality Assurance Law (HQAL)	Japanese Government	Japan
	2002	Green Building Tool (GBTool)	Sustainable Built Environment (iiSBC)	International
	2002	Global Environmental Method (GEM)	Global Alliance for Building Sustainability (GABS)	UK
	2003	Green Star	Green Building Council of Australia (GBCA)	Australia
	2004	Green Globes	The Green Building Initiative (GBI)	USA
	2004	Go Green, Go Green Plus	Building Owners and Manufactureres Association (BOMA)	Canada
	2004	Maintainability Scoring System (MSS)	Dapartment of Building, National University of Singapore (NUS)	Singapore
	2005	National Australian Built Environment Rating System (NABERS)	Department of the Environment and Heritage (DEH), commercialized by Department of Energy, Utilities and Sustainability (DEUS)	Australia
Others	2004	Comprehensive Assessment System for Building Environmental Efficiency (CASBEF)	Japan Sustainable Building Consortium (JSBC)	Japan

the other one that failed to perform even though it passed the certification program. Knowledge of the outcomes may produce bias in our analysis, but it allows us to analyze whether E/R measure could capture the risks in those cases appropriately and be a reflective measure for the known after-design life of each building.

4.2 Green building—Case 1: The AMD Lone Star Campus in Oak Hill, Austin, Texas

AMD lone star campus in Austin is a successful example of a green building. It was built in 2008 and achieved LEED® (Leadership in Energy and Environmental Design) Gold certification by the U.S. Green Building Council in January 2009 [54]. AMD now is considered the largest gold certified LEED® commercial building in Texas [55]. Its management succeeded in increasing efficiency, reducing energy, and water consumption. Moreover, AMD encourages its employees to adapt recycling habits by offering recycling stations at every building. Also, AMD encourages carpooling and usage of public transportation, which led to huge savings. Annual saving percentages reported by AMD usually exceed their original goals [56–59]. AMD conducted intensive and creative sessions with a team of ecological, architectural, engineering, and environmental building experts—known as a "charrette" process—to analyze the special and unique characteristics of the site in Oak Hill and identify specific methods to protect the environment, natural resources, and employees' health [56] (Table 2).

AMD Lone Star main focus was in the following areas:

4.2.1 Sustainable Sites

AMD worked closely with the Lady Bird Johnson Wildflower Center to restore disturbed areas to with 100 % native plants and protect existing habitats. Moreover they decreased the building area 20 % of the land allowable by zoning [56, 58]. In regard to light pollution, AMD worked to minimize the light coming from the building. This helped reduce the site's influence on nocturnal animal habitats [56, 58].

Table 2 AMD Lone Star Project Information [59]

Site area	2,560,892 sq. ft.
Gross conditioned building (excluding garages)	860,000 sq. ft.
Total impervious footprint (including garages, paved walkways, and drives)	737,000 sq. ft.
Surface parking spaces	None
Structured parking spaces	2,35
Project cost (excluding site work, furnishing, and equipment)	$210,000,000
Project completion	April 2008

4.2.2 Materials and Resources

Every building in AMD Lone Star has a recycling station. Also, the cafeteria separates food's waste so it can be used for fertilization [58]. AMD used about 20 % of recycled substances in their construction, 20 % of which were locally sourced [56]. More than 50 % of wood used was certified by Stewardship Council, which encourages responsible forest management [56, 58].

4.2.3 Water Efficiency

AMD used native plants for landscaping that require little watering. Also, applied low-flow water fixture could decrease the usage of water by the average office worker by 30 % [56].

4.2.4 Indoor Environmental Quality

Materials used in construction were eco-friendly, so the indoor environment would be as close to nature as possible. They used low-emitting adhesives and paints, eco-friendly carpets, wood, and agrifiber products. Also, ventilation systems used in AMD were set to meet or even exceed the outdoor air ventilation rates [56].

The building was designed so employees would have maximum outdoor views. Also, AMD installed a light reflector outside the building so it would bounce back more natural light. This helped improve indoor environment and decrease energy consumed by the lighting [56].

4.2.5 Energy and Atmosphere

AMD energy-efficient design helped reduce energy consumption by 15–20 % (compared to building with similar size) through many procedures such as proper building orientation, efficient HVAC equipment, automated switching and dimming, R-30 roofs, and glazing and shading devices [56]. AMD used the most technology available in energy-efficient air conditioning, providing about 10 % of the water in evaporation cooling through the rainwater collection [56]. Moreover, AMD is powered by 100 % by Austin Energy's Green Choice® electricity, which generates its electricity from clean, renewable energy sources [58].

4.2.6 Innovation in Design

AMD rainwater collection system is considered one of the largest in the world. It has a capacity of more than 1.2 million gallons. The water collected by this method is used for cooling towers and irrigation [56].

Summary of main AMD Lone Star green building accomplishments:

- Decreased water usage—rain system through an innovative collection and redistribution methods used; consumption of water decreased 30 % compared to traditional building [56, 59].
- Efficient Recycling—used 20 % recycled materials in their construction, which reduced the use of raw materials; recycled 75 % of construction waste; provided recycling stations in every building (for paper, cardboard, glass, plastic, and metal), and recycling food waste for composting [56].
- Reduced energy consumption—reduced energy consumed by lightning system through proper orientation and maximizing natural light coming from windows, leading to reduction in CO_2 emissions by 15–20 % compared to a traditional building [56].

4.3 Green building—Case 2: The Courthouse Square

The Court Square Transit Mall is a green construction that shows issues, problems, and failure in green building standards. This mall was built in 2000, in downtown Salem, Oregon, and failed in 2010. [60] The five-story building consists of county offices, a transit station, retail stores, and a north part for future expansion. Courthouse Square cost 34 million dollars including 9.8 million dollars from a federal grant [60–62]. Significant amount of concrete has been used for construction of this building, which is approximately 160,000 square feet plus the underground parking. There is 90 miles of telephone and data cable in the building and enough concrete in Courthouse Square for a sidewalk from Salem to Portland [60–62].

The Courthouse building had received U.S Green Building Council's Leadership in Energy and Environmental certification in 2000 [63]. The first problems started to appear in 2008, on the first floor when the tiles started to pop up [61]. Two years later, in 2010, engineers asked the occupants to evacuate the building, since it was too dangerous to stay in it. Some experts estimated that it will take more money to repair Courthouse Square than it cost to build the building in the first place [61].

When architects and engineers went through an investigation, they found several problems:

4.3.1 Design Issues

The building in general was poorly designed, full of errors, and shoddily constructed [62].

Inappropriate materials have been used in the construction. In the Courthouse Square, the risks of new materials impacting the design and strength of materials were not accounted for. Later on, further inspections of the building revealed that 35 of the construction columns were supporting more weight than they could tolerate and the code allows, which ultimately led to building evacuation [63].

As we mentioned earlier, some problems, identified in the building in 2008, appeared not significant enough to engineers. Furthermore, later in 2010, problems got more serious, when a loud noise resembling explosion, as a result of a ruptured cable, was heard in the building, causing floor vibrations [62]. There were several steel cables in the concrete slabs in the floor. These cables were used for back-up supports, and also to make the slabs stronger. However, breaking one of them was a big threat to the building [62, 63].

4.3.2 Problems with Support Structures

One big threat that made engineers move people out of the building was the "punching shear" [64]. This problem will cause the construction's columns to punch through slabs, and then force the whole building to collapse. Because most of the cracks appeared in the floor and the ceiling, it was more likely that punching sheer would happen. The weight of the floor slab could punch through the supporting column, which means the floor could fall over the supporting base at any time [65]. Finally, after an extensive check of 19 columns, the engineers found one column that was going through the punching shear problem [64].

4.3.3 Problems with the Concrete

One of the materials used in Courthouse Square was concrete. After some tests on the concrete, engineers found out that the concrete in the building was not strong enough, and did not meet the requirements. One test showed that the concrete in the building could handle an average of 4,151 pound per square inch (PSI) while it needed to handle 5,000 PSI [64].

Sub-standard concrete was used on the third floor, where there was a slab that could handle just 3,500 PSI [64]. So, the concrete did not meet the standards. In all types of buildings, deflection sometimes can be considered normal, unless it exceeded the deflection code. However, the Courthouse had a higher deflection than the allowed code in the floor [64]. The deflection for concrete slabs in this building was 4 inch while just 1.9 inch was allowed [64]. Also, the tests on the concrete showed that some garbage was used in the creation process whether for the purpose of reusing/recycling or reduction in costs [60].

The type of concrete caused another problem and it was one of the main issues in the construction. For example, the engineers detected air pockets and found out that this kind of concrete should have not been used for Courthouse building because it is usually used for outdoor constructions, such as sidewalks. And it is not suitable for indoor and internal building constructions [64].

4.3.4 Poor Supervision

After the Courthouse's failure, engineers believed that the building had poor supervision during its construction process [66]. Overall organizational and performance issues on top of the design issues could have contributed to the overall failure.

4.3.5 Additional Structural and Non-Structural Problems

Failures accrued in different parts of the building, such as leaking in windows and cracks in interior walls, bending frames and deformations of steel landings [64].

4.4 Calculation of E/R Value for Case 1: The AMD Lone Star Campus in Oak Hill, Austin, Texas

To measure the benefits or the processes of any novel eco-friendly products, we use seven eco-efficiency elements have been defined by the World Business Council for Sustainable Development (WBCSD) [33] and 8 NPD risks described in this chapter by applying the following equations [34], which are implemented into the created Excel spreadsheet matrix (Fig. 3):

E\R	CPD	SEP	RDC	PES	CPP	SES	SPP	PRC	E
E1 (Material reduction)	1								1
E2 (Energy reduction)					1				1
E3 (Toxicity reduction)					1				1
E4 (Material retrieval)				1		1			0.5
E5 (Resource sustainable)				1		1	1	1	0.25
E6 (Product durability)	1								1
E7 (Product service)		1			1		1		0.333333333
								E/R Value	0.726190476

Fig. 3 AMD Lone Star – E/R Evaluation Matrix

$$E/R = \frac{\sum_{i=1}^{i=7} \#\text{ of risk factors provided by the proposed novelty by acquisition } E_i}{7}$$

OR:

$$E/R = \frac{\sum_{i=1}^{7} E/R_i}{7} = \frac{\sum_{i=1}^{7} \frac{1}{\sum_{j=1}^{k} R_j}}{7}$$

where:

$$E/R_i = \frac{1}{\sum_{j=1}^{k} R_j},\ i = \overline{1\ldots7},\ j = \overline{1\ldots8},\ 1 \le k \le j$$

The eco-innovation elements (or benefits) that have been found through our analysis of the AMD building were in:

1. Sustainable sites (used: E5, E7).
2. Materials and resources (E1 maybe E5).
3. Water efficiency (E3, E4, E7).
4. Indoor environmental quality (E2, E5).
5. Energy and atmosphere (E2, E7).
6. Innovation in design (E6, E7).

As we saw from the results and from that successful model, the AMD building didn't have that many risks that can affect the eco-innovation benefits. For example, R&D didn't have any difficulties for reduction of toxicity and decrease of energy usage.

The reduction of impact on local water ecology represented one of the main parts to reduce toxicity. Also the reduction of use in raw materials and construction waste were some of the key elements of retrieval and recyclability.

1. Complexity of the Product Design (CPD): We believed that the risks of the complexity of AMD green building could have impacted material reduction and product durability.
2. Similarity of the Existing Product (SEP): Some of the elements like the material reduction didn't have that many problems for the engineers, who designed the building. The engineers and architects were not especially limited by costs or cheaper materials. We didn't consider large impacts of this risk on the benefits. We considered new product designs impacting product service.
3. R&D Capability (RDC): Didn't have risks especially with a successful model and highly experienced R&D engineers, architects and designers. "Charrette" method of getting feedback was used in the design and production process.

4. Supplier Performance (PES): We didn't have much information about the suppliers in the project and believe that since the project was successful, the risks could have had impact in two places: resource sustainability and material retrieval.
5. Complexity of the Production Process (CPP): The production process is more complex than in the regular buildings, the impact of this risk is considered in the following categories: energy reduction, toxicity reduction and product service.
6. Similarity of the Existing Supply (SES): The risk would impact mostly in material retrieval and resources sustainability since the materials and equipment used could have been completely different than the ones used in common buildings.
7. Similarity of the Production Process (SPP): The production process would be different, so the risk might be present in product service and resource sustainability.
8. Production Capability (PRC): AMD hired qualified and capable production resources (engineers, architects, builders etc.) and companies, so the risk in production capability would impact just resource sustainability.

4.5 Calculation of E/R Value for Case 1: The Courthouse Square

The eco-innovation elements (or benefits) that have been found through our analysis of the AMD building were in:

1. Sustainable sites (n/a).
2. Materials and resources (n/a).
3. Water efficiency (used: E3, E4, E7).
4. Indoor environmental quality (n/a).
5. Energy and atmosphere (used: E2).
6. Innovation in design (n/a).

The Complexity of the Equipment and their design took a big effect on all of the Elements. For example, to reduce the building's energy use, the engineers had to install and design new equipment and tools for that specific reason, so they can save power. The same thing happened to the rest of the elements (Material retrieval, Resource sustainable … etc.).

The failure of the building and then shutdown can be considered as examples of the consequences of the risks volume. The non-sustainable site and the building's poor innovation in design were the results that made a huge impact on the estimated numbers that we had used and then got implemented on the E/R evaluation matrix (Fig. 4).

1. Complexity of the Product Design (CPD): This risk has been found in all of the seven elements. The Courthouse Square a complex with a bus mall and a

E\R	CPD	SEP	RDC	PES	CPP	SES	SPP	PRC	E
E1 (Material reduction)	1			1	1	1		1	0.2
E2 (Energy reduction)	1		1						0.5
E3 (Toxicity reduction)	1		1	1					0.333333333
E4 (Material retrieval)	1		1	1	1		1	1	0.166666667
E5 (Resource sustainable)	1	1	1	1	1			1	0.166666667
E6 (Product durability)	1	1	1	1	1	1	1	1	0.125
E7 (Product service)	1	1	1	1	1	1	1	1	0.125
								E/R Value	0.230952381

Fig. 4 Salem Courthouse Square—E/R Evaluation Matrix

parking structure underground. For example, in reduction of energy, toxicity of the material, complexity can be considered as one of the main obstacles.
2. Similarity of the Existing Product (SEP): Some of the elements, like the material reduction, didn't have that much of problems for the engineers who designed the building. The building had low to medium similarity to the existing building since it was a new green building.
3. R&D Capability (RDC): From the R&D perspective, building a new green construction from scratch can definitely be accompanied with a lot of issues in creating benefits.
4. Supplier Performance (PES): Some new supplied materials and their applications (concrete) as well as equipment brought more risks to the process.
5. Complexity of the Production Process (CPP): The production process seemed to be more complex than the regular platforms, therefore the above indicated risks have been considered.
6. Similarity of the Existing Supply (SES): Issues were found mostly in material reduction, product durability and product service.
7. Similarity of the Production Process (SPP): Since the production process was different in a new green building construction, this item should be considered as a risk in attaining some of the benefits like material retrieval, product durability and product service.
8. Production Capability (PRC): This risk category impacts the benefits from green building directly. The huge failure of the building is a clear example of the constructors' incapability. Material reduction and retrieval as well as resource sustainability, product durability and product service are impacted by the production capability. The companies involved were not capable of building a successful structure.

4.6 Results of E/R Values in Two Green Building Cases

From the E/R matrix calculation results, the values for the AMD case study and the Courthouse were different. To reach the ideal situation, the E/R value needs to be ~ 1. The closest the value to 1, the better and the more benefits we can get out of the project and the less risks associated with each eco-innovation are.

From the E/R matrix calculations:

The AMD E/R value = $\underline{0.726}$ is closer to the ideal situation compared to the Courthouse E/R value = $\underline{0.231}$.

According to the formulas, the largest E/R value means less risk and more benefit. The Courthouse's failed because its risks greatly exceeded the benefits, on the other hand the AMD building had more benefits/less risks.

We have used various assumptions while calculating risks, since we didn't have enough data and expertize available, and our judgment of risks could be biased and perceived on the research that we did. More rigorous testing of the methodology with the right expertise and knowledge of the subject could be applied. However, we believe that E/R measure could be applied to green buildings, especially prior to the initialization of NPD process. In our case we tested this novel E/R measure post-design with known outcomes, so our selection of risk could be impacted by the post-mortem knowledge. It would be best to apply E/R during the fuzzy front end of the project and apply risk mitigation or risk management to lower the risks associated with eco-innovations.

4.7 Future Research

We examined the proposed novel E/R measure for two cases of green buildings. One of them is based on a successful building, another one—on a failed building. For future studies we would recommend applying E/R methodology to more green buildings, possibly a sample of green buildings before their construction, and then analyzing them after.

It would be good to see the usage of E/R methodology in some grading/certification systems in the future at least as a test system in addition to their grading framework. Measures of risk for eco-innovations should be encouraged in evaluating green building design.

Below we propose various measures of risks as well as E/R measure based on severity and probability of risk. Future testing and implementation of those formulas in real cases is encouraged. By adding additional dimensions of risk as severity and probability, we believe in the added benefit to the E/R methodology. It could be a very useful tool if such data could be obtained or calculated before the design of the building. Convenient tool in Excel is also proposed for an easy calculation of those measures.

Ri ratio (7.4), (7.5) measures the ratio of risk to the total possible risk for each acquisition and total.

1-R ratio (7.6), (7.7) measures the non-risk ratio.

E/R [P, S] (7.8), (7.9) measures the E/R ratio, based on the probability and severity of risk (sum of product of P and S for each risk).

$$R_i \text{ ratio} = \frac{\sum_{j=1}^{k} R_j}{8}$$

$$R \text{ ratio} = \frac{\%R_i}{7} = \frac{\sum_{j=1}^{k} R_j}{56}$$

$$1 - R_i \text{ ratio} = 1 - \frac{\sum_{j=1}^{k} R_j}{8}$$

$$1 - R \text{ ratio} = \frac{\sum_{i=1}^{7} \left[1 - \frac{\sum_{j=1}^{k} R_j}{8} \right]}{7}$$

$$E/R[P,S] = \frac{\sum_{i=1}^{7} \left[\frac{1}{\sum_{j=1}^{k} P_{Rj} S_{Rj}} \right]}{7}$$

$$E/R[P,S]_i = \frac{1}{\sum_{j=1}^{k} P_{Rj} S_{Rj}}$$

Our new expanded E/R calculator (Fig. 5) will handle all proposed measures of E/R and will calculate correctly, whether the numbers that will be added represent probabilities or just risks (1 s) as a measure of E/R. For E/R (based on expert evaluations of risks versus every eco-benefit), the model assumes that at least one risk value (1) is present at each "acquisition of the proposed novelty". One is entered if the risk is anticipated. (Numbers go into columns with 7 green three-letter risk abbreviations). There are future possibilities to further improve the calculator, making it a stand-alone application, assigning macros in VBA etc.

All the calculations and assumptions are based on 8 types of risk and 7 types of eco-innovation acquisitions or values. Future research could be done to personalize the methodology by having particular applicable risks and values, or even specific weight assigned to them.

	CPD		SEP		RDC		PES		CPP		SES		SPP		PRC					
E\R	P_{CPD}	S_{CPD}	P_{SEP}	S_{SEP}	P_{RDC}	S_{RDC}	P_{PES}	S_{PES}	P_{CPP}	S_{CPP}	P_{SES}	S_{SES}	P_{SPP}	S_{SPP}	P_{PRC}	S_{PRC}	E/R_i	R ratio	(1-R ratio)	$E/R_{(P,S)}$
E1 (Material reduction)	0.5	0.5															1	0.13	0.88	4
E2 (Energy reduction)	0.5	1															1	0.13	0.88	2
E3 (Toxicity reduction)	0.5	1			0.2	0.5											0.5	0.25	0.75	1.667
E4 (Material retrieval)	0.5	1			1	0.8											0.5	0.25	0.75	0.769
E5 (Resource sustainable	0.5	1									1	1					0.5	0.25	0.75	0.667
E6 (Product durability)	0.5	1															1	0.13	0.88	2
E7 (Product service)	0.5	1															1	0.13	0.88	2
															E/R Value=		0.79	0.18	0.82	1.872

Fig. 5 Expanded E/R calculator

It would be valuable to testing E/R and E/R with probabilities and severities against other risk/benefits methodologies with the reference to green buildings.

5 Conclusions

"Sustainability" has been an emerging concept of today's exhausting world. It has been at the core of governments and industries policy. Since sustainability has a long-term focus, beyond the commercialism of projects, products, processes or systems, a holistic approach has been searched for developing desirable and technically, institutionally, politically and culturally significant product/processes and services. Uncertainty in eco-innovation process has made it difficult to find a holistic approach ensuring all constraints and expectations. Therefore, policy makers preferred developing very conservative policies since they cannot handle the uncertainty. On the other hand, engineers who are involved in developing new technologies are also faced with an ethical dilemma. The dilemma has arisen due to the conflict between responsibility of an engineer to an employer and a responsibility to the welfare of the wider community.

In this chapter, an overview of the state-of-the-art of concepts and frameworks used for assuring the "Sustainable Development" through green/eco-innovation has been presented. Subsequently, a green/eco-innovation framework incorporating the uncertainties and acquisitions has been proposed. The proposed framework presents a practical and useful guideline for eco-innovation through new product development. On the other hand, it is well worth to point out that the proposed framework still in its infancy and it requires further improving and extending. As a future study, various tools, techniques and methodologies can also be integrated into the framework which can hopefully create better solutions for NPD process. In addition to these expectations, the proposed framework should be tested via employing it to some cases.

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