Prospects for Appearance Wood Products Ecodesign in the Context of Nonresidential Applications

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Abstract

As environmental awareness grows, societal demand for more environmentally friendly products increases. Demand for environmental responsibility also reached the building material and construction sector. Green building has become more widespread over the past decade and can be considered a challenge for specifiers and building products manufacturers. Ecodesign, an application of the sustainable development concept, is one of the available tools to address this challenge. This article aims at proposing an ecodesign pathway for appearance wood products in the nonresidential building sector. Through extrapolating results from a previous interior wood door case study, it has been possible to obtain environmental profiles for the main segments of the appearance wood products family for nonresidential buildings. These profiles have allowed devising ecodesign solutions. Results show that for this whole family of products, raw materials are what cause the most environmental impacts, followed by shipping and end-of-life stages. Product component weight tends also to influence the environmental profile. Ecodesign solutions for composite-based products are strongly related to decreasing the composite component weight by design and remanufacturing. For solid wood–based products, ecodesign can be approached through remanufacturing or reclaiming, using locally certified sustainable wood. The use of hardwood waste may be available for energy purposes, but this may not be as relevant as reuse and recycle in the context of the province of Quebec energy grid mix.

Toward Sustainable Buildings

As in any industry, the construction sector has an environmental footprint. For example, the building sector has a large environmental impact when looking at carbon dioxide emissions, energy consumption, and material extraction (González and García Navarro 2006, Bribián et al. 2011). According to Bribián et al. (2011), building construction and civil works use 60 percent of the raw materials extracted from the lithosphere, and the building sector represents 24 percent of these global extractions. According to Bonda and Sosnowchik (2007), in the United States, an average estimation of building materials waste proportions generated during a construction project shows that half of the waste was from concrete and mixed rubble. Wood represents 20 to 30 percent of generated wastes (Bonda and Sosnowchik 2007). In Canada, residential and nonresidential construction consumes half of the extracted natural resources and a third of the energy (Industry Canada 2013). This sector is also responsible for a quarter of the national landfill wastes. When looking at national air emissions, the building sector emits 10 percent of airborne particulates and 35 percent of greenhouse gases (Industry Canada 2013). Buildings are also subjected to indoor air pollution. Building materials such as composite wood products can be a source of volatile organic compounds (VOCs), including formaldehyde and aldehydes. Because 80 to 90 percent of North Americans spend their time in indoor environments, the issue of indoor air pollution requires attention (Bonda and Sosnowchik 2007, Industry Canada 2013).

However, actions can be taken to help reverse the trend. Thormark (2006) explains that building-embodied energy can vary significantly, depending on materials substitution. Building environmental impacts are indirectly linked to

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their performance and their effects on the performance of adjacent structures (Spiegel and Meadows 2012). Design decisions have potential indirect impacts because they help drive the market. By choosing green building products, Spiegel and Meadows (2012) claim that the consumer makes a philosophical statement as well as an economic choice. As custodians of the built environment, architects and interior designers have an opportunity and an obligation to address these issues. In fact, architects and interior designers can have a significant impact because they are involved in the design process and building design, which affect the people who use it and the market and accepted practices (Spiegel and Meadows 2012).

On a similar note, green building certification programs have been developed over the past two decades (Fullana et al. 2008). The oldest, one of the most globally recognized, and the most comprehensive is the English BRE Environmental Assessment Method, which was launched in 1990 (BRE Global Ltd. 2011). In the United States, the Leadership in Energy and Environmental Design (LEED) is another widely recognized program (US Green Building Council [USGBC] 2011). American programs such as GreenGlobes and the Collaborative for High Performance Schools (CHPS) are also listed as sustainable construction standards (Green Globes 2005, CHPS 2010). In Japan, green building standards have emerged with the Comprehensive Assessment System for Building Environmental Efficiency (Japan GreenBuild Council/Japan Sustainable Building Consortium 2008). In France, the Haute Qualité Environnementale was developed (Certivéa and CSTB 2011).

Sustainable construction is more than a trend and is about to become a norm in the sector. The world green building market was expected to grow by 5 percent in 2013, according to Spiegel and Meadows (2012). Annual growth for the American market alone was 30 to 40 percent from 2004 to 2007 based on LEED certification data, total construction data, and interviews and surveys of practitioners and experts. Drivers for growth in green buildings include shifting attitudes among builders and consumers, government mandates, and higher market value (Spiegel and Meadows 2012). Moreover, forecasts offered by McGraw-Hill Construction indicate that by 2010, between 5 and 10 percent of nonresidential construction start-ups would have been designed using green design principles (Bonda and Sosnowchik 2007). A more recent study on the matter conducted by the Canada Green Building Council [CaGBC] and McGraw-Hill Construction (2014) indicates that the share of green building in Canada's construction market is likely to see significant increases by 2017, creating strong opportunities for firms in this market that can capitalize effectively on this shift. Furthermore, the Canadian level of green building activity is generally very satisfying and demonstrates the relative sophistication of the green building market in Canada (CaGBC and McGraw-Hill Construction 2014).

Nevertheless, the growing demand for green building associated with the democratization of environmental concepts worldwide has forced green building programs to evolve and strengthen their environmental commitment. A recent update of the LEED certification scheme, its fourth version, enables practitioners to earn one to two points by using building products with certified life-cycle information (USGBC 2013a, 2013b). Life-cycle information can be provided as an environmental product declaration (EPD) and/or through optimization of multiattribute environmental indicators. Concerning the latter, the product life-cycle performance should be better than the industry average performance in at least three of the environmental impact categories: global warming potential, ozone layer depletion, terrestrial and aquatic acidification, eutrophication, nonrenewable energy depletion, and formation of tropospheric ozone (USGBC 2013a, 2013b). This upgraded version emphasizes the necessity of specifying environmentally and socially responsible building products.

As far as wood building products are concerned, Bowyer et al. (2014) report changes and implications for this category of product in the new LEED version 4 framework. According to the authors, wood product specification in nonresidential buildings could contribute 10 potential points under the new LEED standard. Among credit categories, up to three points could be earned in Building Life-Cycle Impact Reduction—Life-Cycle Assessment (LCA), and up to one point could be given in Building Product Disclosure and Optimization—EPDs.

Considering credit attainment, industry-wide EPDs count as only half product. However, this is valid only if the manufacturers of the products selected are explicitly identified in the published EPDs. Currently, the only industry-wide EPDs available are for North American wood products. For wood products to satisfy the EPD requirement, EPDs would be required from 40 different products and from at least five different manufacturers. The local sourcing multiplier could help to reduce this number in prime forest product–producing regions; nevertheless, gaining a point for use of EPDs will be difficult, at least in the near future. Contrarily, full credit can be obtained with manufacturer-specific EPDs. Specific EPDs will be developed over time by manufacturers that prioritize the environmental performance of their products. This situation will put pressure on the rest of the industry and contribute to lag industry norms. However, Bowyer et al. (2014) explain that the development of manufacturer and product-specific EPDs (or LCAs) are expensive and are needed before anyone can claim optimization credits. Therefore, it is likely to be some time before EPD optimization credits are realistically available and even longer before EPD credits will actually allow informed selection of lower-impact products.

Furthermore, up to two points can be achieved in Building Product Disclosure and Optimization—Sourcing of Raw Materials. Publishing an annual corporate sustainability report can contribute the first point, while a second point can be earned by using certified wood products and recycled content. Products that would qualify under the recycled content provision include standard particleboard, fiberboard, and finger-jointed studs (Bowyer et al. 2014). Up to two points are achievable in the Building Product Disclosure and Optimization—Material Ingredients credit. Untreated and unfinished wood flooring that can be classified as a nonemitting source could contribute one point. If material ingredients are reported, one more point could be gathered. The latter products could also give one point to the Low-Emitting Materials credit. Composite wood products with ultra-low–emitting formaldehyde resins or no added formaldehyde resins and that meet the California Air Resources Board (CARB) ATCM 93120 (CARB 2007) can contribute to a final point in the Low-Emitting Materials credit (Bowyer et al. 2014).

Environmental Assessment and Design

In this context of change in construction practices, building products also need to keep up. Ecodesign, also known as Design for Environment, can be defined as the integration of environmental concerns into product design. The environmental aspects are given the same status as functionality, durability, costs, time to market, aesthetics, ergonomics, and quality (Pigosso et al. 2010). Ecodesign can be seen as a strategic design activity implemented to conceive and develop sustainable solutions and also as a proactive management approach that directs product development toward environmental impact reductions throughout its life cycle without compromising other functionalities (Weenrn 1995, Johansson 2002). It has been largely adopted over the past few years as the concept of sustainable development has grown.

Design for Environment can be implemented following three consecutive steps. First, a target for environmental impact reduction must be defined and possible alternatives identified. Second, a significant amount of environmental data must be collected, analyzed, and interpreted. Finally, results are translated into tools, which may range from simple guidelines and design procedures to more sophisticated software systems (Guidice et al. 2006).

Many tools are available to help throughout the process of environmental profiling. In this case, environmental profiling refers to the assessment of environmental impacts. LCA can be listed among them. LCA is a widely recognized tool because of its holistic view of product or service life cycle. It has been standardized under the ISO 14000 standards (International Organization for Standardization 2006a, 2006b). The LCA approach enables addressing a comprehensive analysis of a product environmental profile that avoids environmental impacts displacement throughout life-cycle stages.

In this study, the ecodesign procedure uses a traditional LCA work path, but it is based on extrapolated LCA results. The main purpose of this study was to give several ecodesign pathways and informed guidance to appearance wood products manufacturers, as well as suppliers, and to help them integrate a more environmentally conscious approach to their product development practices.

Appearance Wood Products

Specification in nonresidential buildings

The government of the province of Quebec, Canada, expressed in 2008 the intention to promote the use of wood in nonresidential buildings (Béchard 2008). In buildings, wood utilization is usually related to structural materials. However, a broad range of wood building material is used for interior finishing, including wood floor covering, decorative wall paneling, ceiling tile, sidings, and mouldings (Robichaud and Lavoie 2010, Drouin et al. 2012). Those materials have an aesthetic function and are often used in large volumes. They also show high added value and represent an application of choice for wood products.

Studies have been published on the development of wood use in nonresidential construction among building professionals in Canada (Fell and Lavoie 2009, Robichaud and Lavoie 2010, Drouin et al. 2012). From these studies, with a specification rate of 66 percent, wooden doors were identified as the most specified appearance wood product by architects. The least specified appearance wood product was wooden windows with 23 percent of nonresidential construction projects. These studies also show that wooden doors are more likely than other appearance wood products to be specified in the Canadian National Building Code (CNBC) class B2 buildings for care and detention (physical and cognitive limitations) and commercial buildings (CNBC class E). Finally, it was shown that the use of appearance wood products, such as millwork, cabinetry, floor covering, and exterior and interior siding, vary in an inversely proportional manner to the built area. On the other hand, products such as windows, doors, and stairs are specified independently from the designed building area. It should be noted that the main limitation for the interior use of wood products in large construction is maintenance.

Environmental profile

In wood-based appearance products manufacturing, adhesives, glues, coatings or paints, stains, and varnishes are commonly used and may contain VOCs. Among VOC-emitting adhesives, the most mentioned is formaldehyde and its derivatives, which are known to have negative effects on human health (Mlhave et al. 1995, Irigaray et al. 2007, An et al. 2010, Gminski et al. 2010). Furthermore, additives, such as halogen-based flame retardant, fungicides, pesticides, and other biocides, improve the material's durability against fire, decay, or mold and are potentially detrimental to human health and result in negative environmental impact (Mlhave et al. 1995, Irigaray et al. 2007).

Werner and Richter (2007) reviewed life-cycle research on wood building products. Conclusions pointed to wood products having a better environmental profile compared with functionally equivalent products made of alternative materials. One of the worst cases for wood products is the impregnation with metal-based preservatives, which appears to be more critical with respect to toxicological effects and/or photochemical oxidation. Incineration of wood products caused higher impacts of acidification and eutrophication than other products in spite of thermal energy recovery. The review of Werner and Richter (2007) also revealed that wood composites, such as particleboard or fiberboard, resulted in higher raw material yield compared with solid wood products. However, the consumption of fossil fuel associated with the production of raw fibers and particles as well as the production of resin and additives were very high.

Finally, various environmental studies have been conducted on interior appearance wood products, but the context of residential buildings is generally considered. Appearance products that have been analyzed are mainly wooden floor coverings, followed by wood-based furniture and doors (Knight et al. 2005; Nebel et al. 2006; O'Connor 2009; González-García et al. 2011, 2012a, 2012b; Mahalle 2011; Cobut et al. 2015b). The present study proposes to address the lack of environmental information for this type of product, taking into account the nonresidential construction contexts.

Aim of the Study

Incorporated within the framework of sustainable building, the aim of this work was to suggest solutions for the ecodesign of interior appearance wood products used in nonresidential constructions based on environmental profiles derived from a case study on the production of commercial wooden door.

Methods

Appearance wood products family selection

In order to represent the interior appearance wood products family in the context of nonresidential construction, key products were selected. Previous qualitative Canadian research projects described their specification rate in nonresidential building projects (Fell and Lavoie 2009, Robichaud et al. 2009, Drouin et al. 2012). Consequently, selecting key products was done according to these results. The products representing the interior appearance wood products family for this study are doors, office furniture, mouldings, architectural paneling, and floor covering. Products are presented in details in Table 1 and displayed in Figure 1.

The choice of raw materials was made to represent practices among appearance wood products manufacturers in eastern Canada, more specifically in the province of Quebec. For that reason, hardwood species selected for the manufacture of most parts of the mentioned products are sugar maple and yellow birch. The door design is based on a manufacturing company based in the province of Quebec. The office desk design was chosen according to data collected from two Canadian manufacturers of office furniture Web sites, Teknion and Global Contract. Wall paneling composition was decided after consulting a manufacturing company in the province of Quebec. Mouldings and floor covering compositions were chosen according to specifications from field experts.

Table 1.—Presentation of selected interior appearance wood products for nonresidential applications.

Type of product	Description	Composition[a]
Doors	Commercial interior wooden door (heavy-duty level)	Particleboard Fiberboard Structural composite lumber Hardwood veneer Hardwood edges PVAc UV-cured coating (Cobut et al. 2015b)
Office furniture	Office desk (wood panel end desk)	Particleboard Hardwood veneer PVAc UV-cured coating
Mouldings, low end (LE)	Composite-based moulding	MDF Alkyd paint
Mouldings, high end (HE)	Solid wood–based moulding	Solid hardwood Acrylic coating
Architectural paneling	Interior wall paneling	MDF Hardwood veneer PVAc Acrylic coating
Floor covering (HWF)	Hardwood flooring	Solid hardwood UV-cured coating
Floor covering (EWF)	Engineered wood flooring	Solid hardwood layer Baltic plywood Polyurethane resin Phenol-formaldehyde resin UV-cured coating

[a] PVAc = polyvinyl acetate; UV = ultraviolet; MDF = medium-density fiberboard.

Environmental profile establishment and generalization

The door environmental case study, presented in Cobut et al. (2015a, 2015b), was used through extrapolation to establish the environmental profile of the interior appearance wood products family. The study should be viewed as generalizing previous findings obtained for interior wooden doors, instead of performing complete LCA for each segment of the studied family of products. LCA results from the door case study were analyzed and adapted based on life-cycle processes similarities and differences among the product family.

Case study.—The comprehensive methodology of the wooden door LCA is presented in (Cobut et al. (2015b). The main features of the LCA study performed on interior wood doors are exposed here for the purpose of understanding upcoming assumptions.

The profile of each component of the family of interior appearance wood products is derived from a commercial and architectural wood door manufacturing company from the province of Quebec. The system boundaries include cradle-to-grave life-cycle stages and exclude the door frame, hardware, and other processes that could have been used for the door installation. This decision was made in order to focus on the manufactured product itself.

The LCA case study on the wooden door was performed using SimaPro 7 software from PRé Consultant. Life-cycle inventories and unit processes, both original and adapted, were mostly sourced in the ecoinvent database, version 2.2. The life-cycle impact assessment methodologies used were IMPACT 2002+ as the main methodology and ReCiPe as the validation methodology.

Extrapolation process.—The extrapolation process to expand on Cobut et al. (2015b) was split into three steps. The first step consisted of identifying the similarities and differences between unit processes used in the door case study compared with the other products of the family, as presented in Tables 1 and 2. The raw material constituting each product from this product family was identified. The raw material of each product was then compared with the raw material found in the door assembly. Then the same procedure was carried out for all other life-cycle stages. It was decided that shipping and the end of life would be the same for all product categories, as in the wooden door case study scenario. Packaging differs for flooring products because additional cardboard is used. Consequently, the use phase is also different for flooring products because they include packaging waste management.

The second step of impact extrapolation was the modeling of ecoinvent unit processes not used in the case study. This is the case for a majority of components (Table 2) and some life-cycle stages shown in Table 3. When processes were different from the door system, it was decided to model the environmental impacts of each appropriate unit process in SimaPro with IMPACT 2002+ and export the results in the extrapolation data set. This was done for medium-density fiberboard (MDF), acrylic coating, alkyd paint, polyurethane, phenol-formaldehyde resins, and cardboard for packaging.

The third step was the calculation of impacts for each product of the family using a common functional unit. The functional unit used was the coverage of the door system already studied, which was an area of 1.92 m^2. For flooring

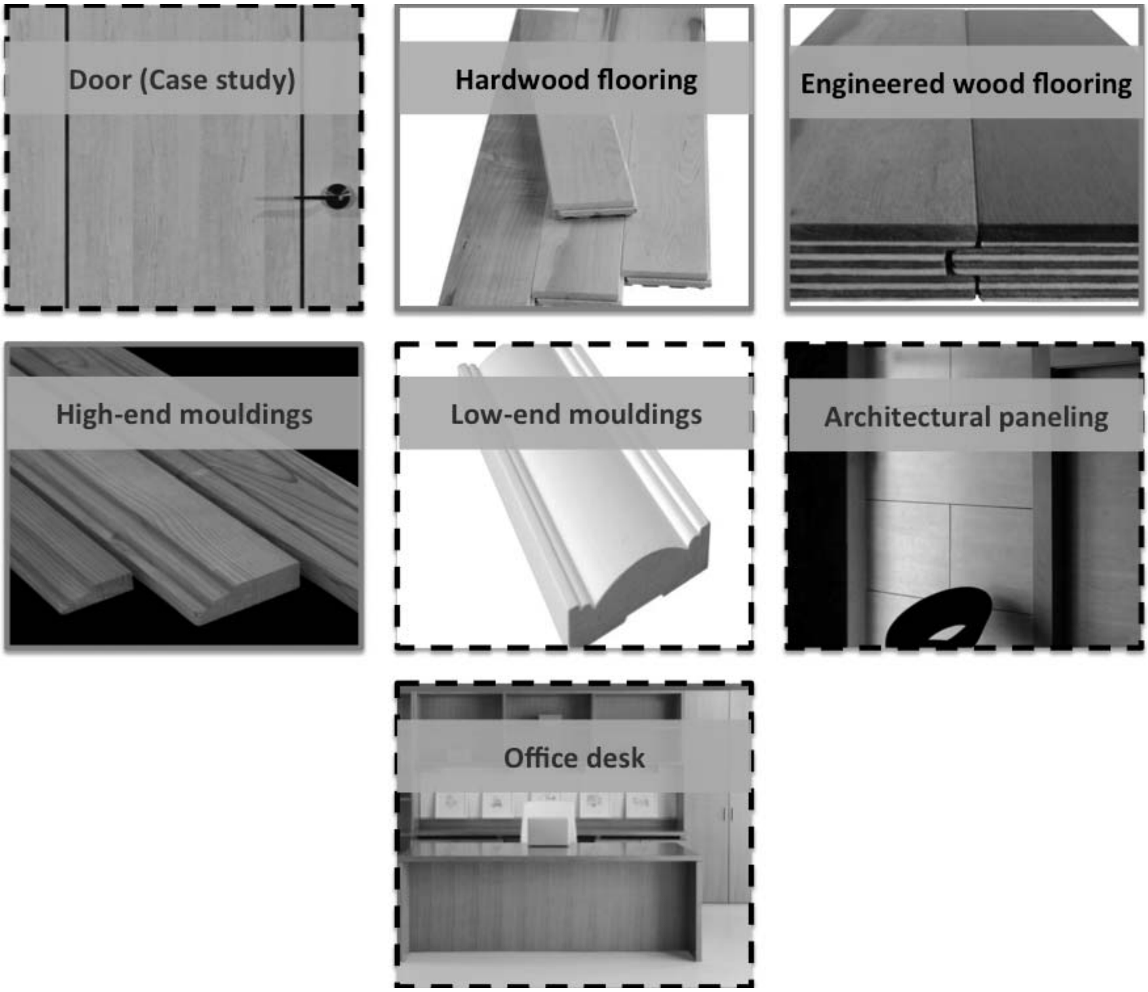

Figure 1.—Illustrations of selected appearance wood products in the current research. Dashed black borders have been applied to composite-based product pictures. Pictures of solid wood– and veneer-based products have plain gray borders.

products, the amounts of additional cardboard, resins, and coating were taken from the work of Mahalle (2011). The amount of polyvinyl acetate (in grams per square meter) needed for assembling products, such as paneling and office desks, was assumed to be equal to the amount of glue in the door system per square meter.

Evaluation of uncertainty.—A sensitivity analysis was performed on data assumptions to assess the validity of the results from Cobut et al. (2015b) on the door modeling results. In this study, which consists in an extrapolation of the door LCA results, some parameters have been tested according to different appearance wood products specificities. It is possible for architectural moulding, paneling, and wood flooring to be shipped at a longer distance, depending on clients. Therefore, for those products, the shipping distance has been increased by 100 percent in the case of road transport or by 300 percent in the case of train transportation. The truck loading has also been assessed as in the door study (+25% and –25% of actual loading) with an additional variation. A possible reduction by 50 percent

Table 2.—Similarities among raw material processes.[a]

	Door case study						
Other appearance wood products	PB	SCL	HDF	Veneer	Hardwood edges	PVAc	UV coating
Office desk	X	—	—	X	—	X	X
Moulding LE	—	—	—	—	—	—	—
Moulding HE	—	—	—	—	X	—	—
Paneling	—	—	—	X	—	X	—
HWF	—	—	—	—	X	—	X
EWF	—	—	—	X	X	—	X

[a] X symbolizes a similar unit process. PB = particleboard; SCL = structural composite lumber; HDF = high-density fiberboard; PVAc = polyvinyl acetate; UV = ultraviolet; LE = low end; HE = high end; HWF = hardwood flooring; EWF = engineered wood flooring.

Table 3.—Similarities among remaining life-cycle stages.[a]

Other appearance wood products	Door case study			
	Packaging	Shipping	Usage	End of life
Office desk	X	X	X	X
Moulding LE	X	X	X	X
Moulding HE	X	X	X	X
Paneling	X	X	X	X
HWF	—	X	—	X
EWF	—	X	—	X

[a] X symbolizes similar unit processes. LE = low end; HE = high end; HWF = hardwood flooring; EWF = engineered wood flooring.

of the actual loading has been assessed. The influence of allocation factor for roundwood (softwood and hardwood) as done in the door LCA study has also been calculated with a reduction of the allocation factor by 5 percent and by 10 percent.

Results: Environmental Profiles of Interior Appearance Wood Products for Nonresidential Buildings

Predicted environmental profiles for the appearance wood product family are presented in two different forms. Figure 2 shows life-cycle stage contributions to the total environmental impacts of each product in the four end-point categories of IMPACT 2002+: human health (HH), ecosystem quality (EQ), climate change (CC), and resources (R).

Life-cycle stage contributions and product weight

When looking at Figure 2, in terms of stage contributions, it is quite obvious that the acquisition and transformation of raw material have the highest contribution to the total environmental impact regardless of the product. Slightly negative contributions found in each product profile for the EQ category are owing to the avoidance of virgin raw material usage in the particleboard manufacturing process through the recycling of trimmings and sanding by-products.

Interior door facts.—From the door study, it has been revealed that the particleboard was the most contributive element to the score of raw materials in each of the four damage categories. The main reasons for this was the production of urea-formaldehyde resin, followed by raw materials transportation to the manufacturing site (Cobut et al. 2015b). The other two life-cycle stages requiring attention were shipping to the building site and the product end of life, respectively.

Office desk facts.—The office desk environmental profile was found to be very similar to the door. In fact, the desk's components are nearly the same. The biggest and heaviest part of the desk is composed of particleboard. In the door, wood components, such as structural composite lumber and hardwood edges that are lighter because they are smaller than particleboard parts, are present. The proportion of particleboard needed to manufacture the desk is higher than in the door, leading to slightly higher environmental impacts for raw materials. This increase in product weight results in

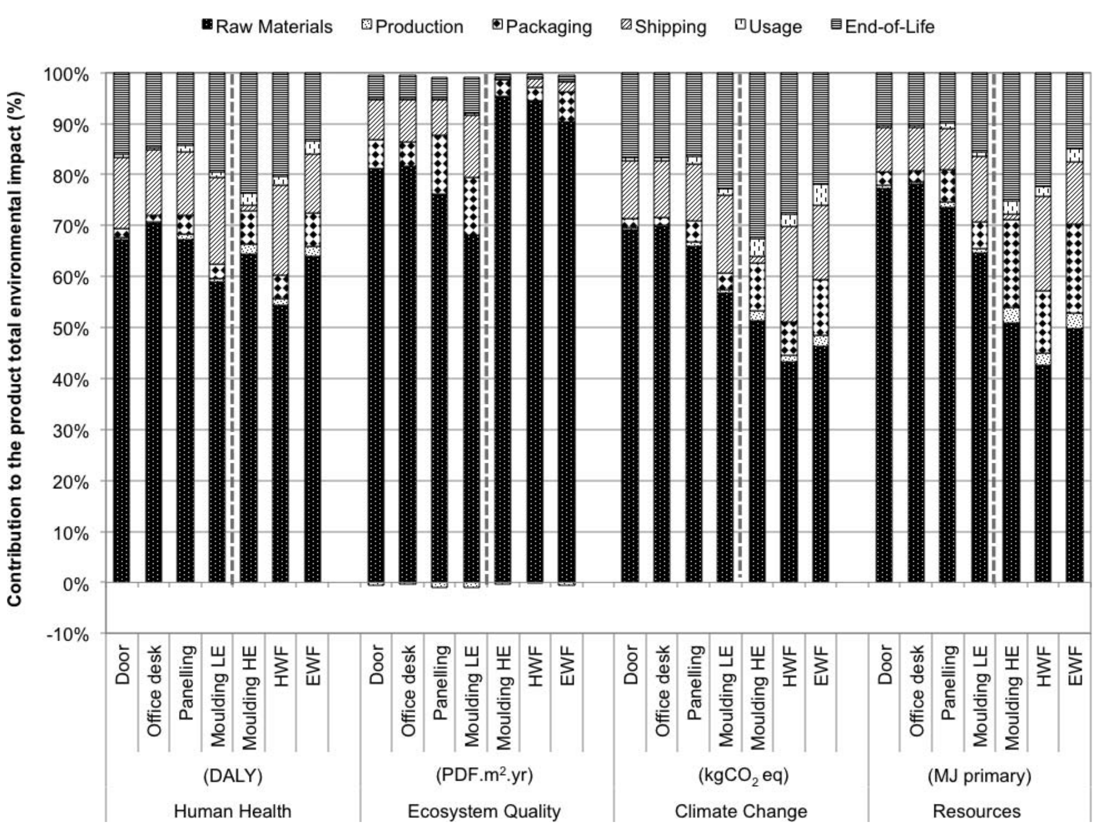

Figure 2.—Appearance wood product predicted life-cycle stage contributions to the four damage categories of IMPACT 2002+. The dotted line separates particleboard- and fiberboard-based products from products made of solid wood or veneer. LE = low end; HE = high end; HWF = hardwood flooring; EWF = engineered wood flooring.

increased shipping (tons per kilometer) and end-of-life (kilogram of landfilled material) environmental impacts. The end of life is the second most contributor to the office desk total impacts, followed by shipping.

Architectural paneling facts.—Figure 2 shows similar contribution behavior for the paneling product compared with the composite-based desk. It is not surprising because it is again the same arrangement of components, except that MDF is used instead of particleboard as the main component. For paneling, raw material is again the largest contributor to the total environmental scores in each of the four damage categories. MDF is the main source of impacts and also accounts for at least 90 percent of total product weight. The end of life is the second most contributing factor to the product's total impacts, followed by shipping.

Moulding facts.—For low-end mouldings made of MDF, raw materials were again responsible for more than half the environmental impact contributions for all damage categories (59% for HH, 70% for EQ, 58% for CC, and 65% for R). MDF production is the main source of impact but not very far ahead of raw material transportation. However, for this product, the contributions of shipping and end of life are quite high and of the same order of magnitude as the raw material transportation contribution.

The high-end mouldings profile is different from that of low-end mouldings. Even though raw materials acquisition and transformation is still the highest contributor to the product total impacts for each damage category (54% for HH, 96% EQ, 42% for CC, and 40% for R), details show a different pattern. Raw materials transportation has similar scores for HH (27%) than raw materials production (28%) but higher scores for CC and R categories (24% and 23%, respectively) than solid wood and acrylic varnish production (18% and 18%, respectively). Damages on EQ are dominated largely by the production of solid wood (94%). End-of-life contribution to CC and R damage scores is higher than the production of raw materials and even raw materials transportation in the same categories. When considering the contribution of life-cycle stages to total environmental impact, raw material is the largest contributor, and end of life the second largest, followed closely by shipping.

Wood-based floor coverings facts.—Hardwood flooring has almost the same profile of contributions as high-end mouldings because the products are really close in terms of manufacturing and raw material. For the raw material stage, raw material transportation has a higher contribution than raw material production except for the damage category EQ, where the production of solid wood has a contribution of more than 90 percent. Another interesting fact is that the coating system has a nonnegligible contribution to CC and R damages, with contributions of 7 and 10 percent, respectively. Here again, the end of life is the second largest contributor to the product total impacts, followed by shipping. In HH, CC, and R damage categories, packaging contributions to total environmental impacts are higher compared with previous door, office desk, architectural paneling, and moulding environmental profiles.

Engineered wood flooring has a contrasting profile of contributions even though the raw materials stage still dominates the total impact contributions. Solid wood's highest contribution still lies in EQ owing to how forest management processes are considered in ecoinvent and in IMPACT 2002+ (Cobut et al. 2015b). The production of veneer for plywood has the highest contribution to HH and the second to EQ. VOCs emitted during the drying process appear to be the main contributor to HH impact score (Bergman and Bowe 2011). Raw material transport also has a high contribution to HH, CC, and R indicators (16%, 16%, and 13%, respectively). Ultraviolet (UV) coating contributes 11 percent of the product CC impacts and 13 percent of the product resource impacts, while total raw materials contribute 46 and 50 percent, respectively. The contribution of phenol-formaldehyde resin to product impact is also noticeable for the resources end-point indicator at 10 percent. The second most contributive life-cycle stage is packaging, followed by end of life and shipping.

Summary of product systems main environmental impacts contributions.—Despite the fact that raw material is the main contributor to the whole life cycle of all product systems, three other cycle stages should also be considered. Shipping and landfilling are generally the other two most contributive stages to the total product impacts. For the majority of products, shipping contributions are higher than landfilling for HH and EQ end-point indicators, while landfilling is higher than shipping for CC and R damage indicators.

Furthermore, packaging impact contributions are sensitive to product weight and composition. The product weights rank, in decreasing order, from the office desk to door, low-end mouldings, high-end mouldings, hardwood flooring, paneling, and engineered wood flooring. As can be seen in Figure 2, packaging has a higher contribution in lighter appearance wood products than in heavier products for every damage category. The influence of the packaging phase seems also to be accentuated when raw materials are mainly solid wood products, such as high-end mouldings, hardwood flooring, and engineered wood flooring, because they are less dense and do not require as much resin input as in composites. This shift in contributions is more appreciable for CC and R damage categories, where resins are susceptible to induce greater impacts when used as raw materials compared with solid wood and veneer products. In the case of the lightest appearance wood product, engineered wood flooring, packaging contributions to total product impacts reach and even exceed end-of-life or shipping contributions in most damage categories. However, this fact is observed only for the lowest-weight product with lower raw material impacts. Paneling is the lightest composite product, but the observations on packaging are not as noteworthy as for engineered wood flooring. Its higher raw materials impact contribution, due to its higher resin content, diminishes the effect previously mentioned.

Glues and coatings

From the door study and from all extrapolated impacts, the contribution of glues in assemblies and coatings to total environmental impacts seems negligible in comparison to the contributions of resins in composite panel production. Nevertheless, in the case of lighter products, such as engineered wood flooring, the contributions of glues and coatings were noticeably higher compared with what was observed in other products. In fact, the weight of coatings and glues is, in general, dominated largely by the weight of wood components. Engineered wood flooring is an exception because of its lower thickness combined with a higher use of coatings for a higher resistance and product longevity. Also, the use of plywood that requires a noticeable amount of glue is also responsible for those results. In the end, glues and coatings still represent a more significant impact contribution in lightweight products.

Solid wood and veneer versus wood composites

Environmental profiles differ between composite-based and solid wood– and veneer-based products. The main reason lies in the type of wood raw materials. For solid wood or veneer products, the required quantity and quality of wood lead to a higher impact on EQ owing to wood selection specificities. In contrast, composite-based products are usually made of residues from the aforementioned processes, so the impact on EQ is of lesser importance. It is logical to see higher scores and contributions for solid wood– and veneer-based products in Figure 2 compared with composites in the EQ category. On the other hand, composite-based products have greater impacts and contributions on CC and R damage categories. Based on Cobut et al. (2015b), resins and additives, as well as processing energy consumption needed for composite board production such as particleboard, high-density fiberboard (HDF), and MDF, have important impacts on CC and R. Considering the HH category, it appears that composite-based products and solid wood– and veneer-based products have similar environmental impact patterns.

Results from Other LCA Studies on Wood Products and Associated Technologies

Wood-based modular playground

González-García et al. (2012a) studied the environmental profile and the ecodesign potential of a wood-based modular playground. The impacts were analyzed from cradle to gate. The main wood material in their products was Scandinavian solid pine (50% of total weight), three-layered laminated board (25% of total weight), and plywood (12% of total weight). The environmental impact assessment (EIA) methodology used was CML 2 Baseline 2000 v2.1 biogenic. As a main contributor to the total environmental impacts, they found the assembling stage had a contribution of from 60 to 83 percent, depending on the impact category. Assembling comprises raw material, such as wood boards, solid timber, metal and plastic pieces, and raw materials transportation. These results are quite similar to what was found in this research, except metal and plastic pieces were not part of our inventory. Packaging had a higher contribution in the study of González-García et al. (2012a) because of the presence of cardboard, and many impacts were also because of metal pieces that were not present in this research. Plastic pieces and lacquering were not noticeable contributors to the total impact.

Indoor furniture for children

In another study, environmental profile and ecodesign of an interior wood product were analyzed, from cradle to gate, by González-García et al. (2012b). The product was a set of indoor furniture for children. The main components were wood materials, such as solid timber (less than 5% of product weight), MDF (nearly 10% of product weight), and particleboard (at least 80% of product weight). The same EIA methodology as in the modular playground study was used (González-García et al. 2012a). The main LCA results were again very similar to the results of the present study, even though the EIA methodology is somehow different from that of the Cobut et al. (2015b) study. Raw materials were found to be the most contributive to total environmental impacts of the product. The particleboard was the main contributor to the raw materials impacts because of its proportion in the product composition, just as in the door case study (Cobut et al. 2015b). Extrapolation results presented in the current study are hence in accordance with the work of González-García et al. 2012a, 2012b).

Floor coverings

Different types of floor coverings, including hardwood flooring, were studied by Mahalle (2011). The study was performed from cradle to grave. A modified version of North American TRACI methodology, CO_2 from air being accounted for as a negative emission to include CO_2 sequestration by forests, has been used as well as the cumulative energy demand method. As for prefinished hardwood flooring, the main findings suggest that the manufacturing stage was the dominant stage in terms of energy and environmental flows. It consumes 72 percent of total energy and emits 30 to 76 percent of environmental emissions among the chosen categories. The manufacturing stage consisted of drying green lumber, milling operations (planning, ripping, trimming, and moulding), and finishing operations (coating and packaging). The drying process was the most contributive to the manufacturing stage. It was also the most energy intensive with 75 percent of energy consumption on a cradle-to-gate basis. Moreover, drying was responsible for most of the greenhouse gas emissions. Finally, drying contributed significantly to all other impact categories compared with the two other manufacturing processes. These results again confirm that raw materials acquisition and transformation are large contributors to the products' environmental impacts as identified by the results from the current study.

Wood building products

Werner and Richter (2007) made a literature review on comparative LCA studies performed on wood building products. From their review, it appears that composite wood products, such as particleboard, HDF, or MDF, obtain a better roundwood yield compared with solid wood products. However, there is generally a very high consumption of fossil energy associated with the production of fibers and chips as well as of resins or additives. The same observations have been made in the door LCA study (Cobut et al. 2015b). They also pointed out that methods used for the impact assessment, at the time of their study, did not allow consideration of the impacts of forests, such as land occupation, impacts on biodiversity, purification of air, and other environmental services. The depiction of toxicological effects of chemical components is also criticized because both existing methodologies and the model structure of LCA do not allow spatial or temporal resolution. These limitations were also observed later in Cobut et al. (2015b).

Wood coatings

The environmental profile of four types of wood coatings has been studied by Gustafsson and Börjesson (2007). They studied two wax-based coatings—rapeseed oil–derived wax and paraffin-derived wax—and two UV cured coatings—one water based and the other 100 percent solid. An LCA from cradle to grave of these four coatings was performed using a common functional unit. The study revealed that the most environmentally friendly alternative was the 100 percent solid UV coating. In fact, the most contributive life-cycle stage was the production of ingredients as well as the application and drying of coatings for which the productive country electricity grid mix could play an additional role in coating global warming impacts. It was seen in a sensitivity analysis that coatings applied or dried under a coal-based electricity grid mix, like in Poland, had a higher global warming score than under a hydro-based and nuclear-based electricity grid mix, like in Sweden. Gustafsson and Börjesson (2007) results led to the exploration of issues of ecodesign, which is done in the next section.

Ecodesign Recommendations for Appearance Wood Products

From the extrapolated environmental profiles, it is possible to devise ecodesign solutions for this family of product. The ecodesign process explored in this section is also derived from previous research findings (Cobut et al. 2015a). The discussion is organized around two groups of appearance wood products: composite-based products as opposed to hardwood- and veneer-based products.

Composite-Based Appearance Wood Products

For composite-based products, it seems reasonable to say that environmental improvements can be achieved through focusing on board design, transportation parameters, reuse, or remanufacturing. Packaging should be considered when dealing with light appearance wood products.

Board design

Particleboards and MDF are the main components for products such as doors, office desks, architectural paneling, and composite mouldings. They also are the most contributory components to those products' environmental impacts. Four types of solutions addressing board design are considered.

Board resins.—It was seen in the door study that using pine tannins in the resin formulation of core particleboards helped reduce the environmental profile of the whole door system by at least 20 percent in all four damage categories: HH, EQ, CC, and R. The observed benefits and the validation of this technology through industrial production of particleboard and MDF in Chile is proof of the concept and makes this solution available in the short term (Cobut et al. 2015a). This can also be applied to the office desk made of particleboards and to the other products made of MDF. A considerable amount of effort has been put into the research and development of alternative resins for wood board manufacture (Pizzi 2013). However, to truly understand their environmental benefits, a full life-cycle analysis should be performed on these alternative adhesives and their use.

Thinner boards.—In the work of González-García et al. (2012b) on the ecodesign of children's furniture, the option of thickness reduction for wood boards was addressed. It showed promising impact reductions. Thinner wood boards, such as particleboard in the case of the office desk, would diminish raw materials–related impacts, such as raw materials consumption, energy used in the manufacturing (thinner equals faster heat distribution for polymerization), and transportation, freight, or end-of-life impacts. However, this recommendation should not be addressed without considering basic functional performances from the product. For example, if thinner products were less durable, that would have a detrimental effect on their overall life-cycle footprint.

Board manufacturing process.—Advanced Systems Marketing International (ASMI; 2009) and González-García et al. (2012b) proposed the optimization of resin usage and the intensification of renewable energy utilization as leads for environmental improvements. In fact, intensification of renewable energy use is required because some board-making processes are very energy intensive (ASMI 2009, González-García 2012b). In the province of Quebec, particleboard manufacturers are less concerned with this issue because the most common source of energy is renewable hydroelectricity.

González-García et al. (2012b) also observed that an increased reuse of internal wastes in the manufacture of products permitted a decrease in overall impacts. The more wastes are reused on-site, the greater the impact reduction will be.

Lightweight panels.—Another ecodesign option that was not mentioned in the door study is replacing particleboard or MDF core with a lighter core. That could be interesting for the office desk, the heaviest product of this group. By reducing the weight of problematic components, their associated environmental impact may be reduced. This could also decrease transport impacts that are calculated on a ton-per-kilometer basis.

There is scientific literature discussing and companies producing boards that can be used for the furniture and door industry as lightweight substitutes for MDF and particleboard. Lightweight panels can be distinguished into conventional wood-based panels with reduced density by lower compaction of the mat or low-density raw materials; tubular boards; sandwich panels with a homogeneous core layer, such as foam core; and sandwich panels with a heterogeneous core layer, such as honeycomb panels. Figure 3 illustrates several types of lightweight panels. These panels are less present in North America than in Europe and are still subjects of research (Thoemen 2008, Sam-Brew 2010, Shalbafan 2013). In general, the reduced weight in panels comes with lower mechanical properties and higher production costs compared with conventional wood panels (Thoemen 2008). Lightweight panels can be up to 75 percent lighter than regular wood boards (Sam-Brew 2010, Cascades Inc. 2013). The highest benefits from lightweight panels may be seen in the transportation of both raw materials and shipping. A reduction of a component's weight is a reduction of both freight costs and freight environmental impacts. Once again, on a whole life-cycle basis, durability of the products, considering their lower mechanical properties, should be considered in their footprint.

Forest product companies, such as DendroLight, are starting to produce interesting panel cores from cellular solid wood ranging in density from 260 to 477 kg/m^3 (Bell 2013a, DendroLight 2013a). Different DendroLight panels are presented in Figure 4. Their products have the advantage of not containing resin. Other advantages that concern mostly interior wood doors are that the door-specific panels are fire rated at 30 minutes and present good acoustic performance with a sound insulation up to 35 dB (Dendro-

Figure 3.—Exposition of multiple types of lightweight panels (Platts 2013).

Light 2013b). A version of these panels exists also for tabletops and may be suited for office desks (DendroLight 2013c). No formal environmental studies have ever been performed on these products, but interesting diminutions in weight-associated impacts can be foreseen.

Lightweight panels may be particularly interesting for heavy products, such as doors or office desks, but a life-cycle analysis could determine their true environmental benefits. It seems essential that manufacturers should be able to make informed decisions, especially when selecting environmentally responsible suppliers, because their raw material choices can definitely have a large influence on the final product environmental profile, especially when the main component is a composite.

Transportation

In the door case study, it was observed that changing transport mode could provide environmental impact reductions on the order of 30 percent of overall transportation impacts (Cobut et al. 2015a). However, these reductions were relatively minor (a maximum of 9% for HH) in comparison to the overall life-cycle door impacts.

Nevertheless, sensitivity analysis results show that shipping characteristics can have a substantial influence on

Figure 4.—Display of different DendroLight panel designs (Bell 2013a).

the LCA results of all studied appearance wood products (Cobut et al. 2015a). For instance, a decrease of truck loading by 25 and 50 percent increases the contribution of the shipping stage, thus exceeding that of the end of life. On the contrary, increasing the loading by 25 percent diminishes the environmental impacts of the shipping phase. Appearance wood products often need extra space owing to packaging to preserve integrity and quality during shipping. This results in higher environmental impacts at the shipping stage. It is then important to consider this parameter when trying to decrease the environmental burden of the product.

As with truck loading, the same observations were made for shipping distances when raised by 100 percent for road transportation and 300 percent for rail transportation (Cobut et al. 2015a). The shipping phase becomes the second most contributive stage to the product's life cycle. Therefore, as rail freight has less environmental impacts than road freight, it should be preferred for longer distances.

In summary, transportation parameters can have substantial impacts on the LCA results of products, and decisions should be made accordingly, whether it is by managing shipping logistics differently (including packaging and loading), promoting shipping by rail, or finding local area suppliers whenever possible or applicable.

Packaging environmental contribution in lighter appearance wood products

With a special view to lighter appearance products or developing lighter panel use, packaging options should be assessed more thoroughly because their contribution to the total environmental impact is inversely proportional to weight. In González-García et al. (2012b), the question of packaging was also investigated. The substitution of plastic bags with cardboard shows interesting impact reductions as well as the use of recycled plastic materials. Therefore, these solutions could also be applied in the studied context.

Reuse and remanufacturing

For the door, the remanufacturing option with the core assembly reutilization exhibited the largest benefits in terms of environmental damage reduction over the whole life cycle (Cobut et al. 2015a). One reuse of the core assembly permitted saving at least 25 percent of the original score regardless of the damage category. Remanufacturing is a short-term option that does not require investing in new technologies or changing suppliers. However, it does involve the implementation of reverse logistics networks.

Remanufacturing could be a reasonable end-of-life option to reduce office desk and architectural paneling impacts. However, the high degree of customization in architectural paneling may bring supplementary difficulties in reuse and reverse logistics. Moreover, highly customized products may not be fitted for remanufacturing since they meet very specific demand for specific functions and building configurations. To counter the problem of high customization, pieces of sanded MDF panels, depending on their conditions, may be reused in the production of other architectural panels of different sizes. Moreover, an office desk has a different fastening system that may require more inspection and attention for remanufacturing. On the other hand, these specific fasteners may make disassembly of the desks into their components easier. The use of standard fasteners can improve the reusability of such products.

For composite moulding, remanufacturing may not be as straightforward as in the previous cases, if possible at all. The value of composite mouldings, in comparison to solid wood mouldings, might not justify the implementation and use of a remanufacturing process. However, composite mouldings could be sanded and shaped to serve as backup or filler raw materials. It could be used, for example, as raw material input for nonconventional-size wood products, including MDF components of different shapes and forms, such as in cabinetry or paneling. This process is already used in the studied door manufacturing plant (Cobut et al. 2015a). Unused particleboard parts serve as raw material input for doors to reach higher and nonstandard dimensions without extra board costs. In addition, González-García et al. (2012b) mentioned the reuse of internal wastes in order to decrease the environmental impacts of products. It was observed that the higher the recycling rate, the greater the environmental benefits (González-García et al. 2012b).

The use of postconsumer boards such as MDF and particleboard as raw materials in composite panels manufacture is also an option (Composite Panel Association 2012). However, the quantity of contaminated wood cannot be over 2 and 10 percent by weight for MDF and particleboard, respectively (Clean Washington Center 2001, 2002).

In any case, the redirection of wood products from landfills and their reintroduction into other similar product life cycles have a high probability of success in reducing the product environmental footprint.

Energy generation

Composite-based products may not be suited for energy generation because they are identified as contaminated waste. In general, contaminated wood is used less frequently or in smaller quantities owing to widespread concern over its potential to produce air contaminants. The option can be one of choice, though, when using a proper high-temperature furnace with a high filtering capacity, considering the interesting results obtained when substituting fuel oil for heat production (Cobut et al. 2015a). Besides, several sources mention that in the context of the province of Quebec, energy production from wood wastes may not be as beneficial environmentally and economically as in other jurisdictions because of the low cost and availability of renewable hydroelectricity (Laurent et al. 2011, Gouvernement du Québec 2013).

Solid Wood– and Veneer-Based Appearance Wood Products

As presented in Figure 2, products made from solid wood and veneer have the highest environmental impacts in EQ end-point category. Actually, as seen in Cobut et al. (2015a), the highest contribution in EQ is through the land use midpoint indicator expressed in square meters of organic arable land per year. Appearance solid lumber and veneer require larger timber, while wood particles and fibers are generally by-products from primary processing industries. Of course, the production of wood requires industrial interventions on vast areas of forested land, but the characterization factors for land occupation in IMPACT 2002+ come from Eco-indicator 99, which is based on an empirical model determining the difference in the quality of ecosystems, through biodiversity, between a given land use type (forestry in this case) and a reference state (the natural Swiss forest of 1850). The database still has to be further developed into being representative of the diversity of ecosystems and of forest management tenures. So far, no data are available to represent the impact of using wood harvested in Canada. In the three other end-point categories, the shipping and end-of-life stages have higher contributions than what is seen in composite-based products owing to the smaller footprint of solid wood production compared with composites.

Ecodesign strategies should then target the solid wood supply chain as well as transportation management and end-of-life options. Concerns about packaging and coating are noticeable for lighter products.

Sustainable wood resource

As solid wood–based appearance products are believed to have a significant impact on the quality of ecosystems compared with composites, it seems legitimate to ensure that solid wood is sourced from sustainable forest practices. The use of certified wood is a valid option for that matter. Information on sustainable forestry certification programs is available in Gulbrandsen (2004), Ozinga and Krul (2004), Cashore et al. (2005), Wingate and McFarlane (2005), Hansen et al. (2006), ITS Global (2011), Cobut et al. (2012), and Tikina et al. (2012).

Freight and local sourcing

For minimizing freight environmental impacts linked to raw materials acquisition, it is important to deal with local solid wood and chemicals suppliers. Optimizing logistics in order to minimize overall transport and the transport footprint is of importance. For all life-cycle stages, the use of rail or waterway freight, wherever possible and available, decreases the environmental impacts linked to shipping compared with conventional truck transportation, according to Horvath (2006).

Packaging and coatings

Packaging strategies, mentioned for composite-based appearance wood products, still stand for solid wood– and veneer-based appearance wood products. For engineered wood flooring, the contributions of UV coating and glues have taken a higher share than in all previous appearance products environmental profiles. Even though the applied UV coating contribution is nonnegligible, a study has shown that 100 percent UV coating is the most environmentally friendly option considering its resistance to wear compared with solvent-based UV coatings and wax-based coatings (Gustafsson and Börjesson 2007). Replacing chemical nonrenewable resources with renewable ones could enhance their environmental profile. However, it is necessary to ensure, through a life-cycle analysis, that such substitution brings real environmental benefits.

Reuse and remanufacturing

Architectural woodwork was often valued for its character and beauty, making it a prime candidate for salvage and reuse (Jeffrey 2011). Therefore, the cost of salvaging architectural woodwork is easier to justify during the demolition process because of the prohibitive costs associated with its reproduction. Reclaiming wood is actually a growing industry. This market appeal lies in the material's environmental story and history, its unique visual patina, and its strength and stability (Bell 2012). Furthermore, landfilling wood construction waste has been banished in the province of Québec since 2014 (Ministère du Développement durable, de l'Environnement et des Parcs [MDDEP, currently MDDELCC] 2012). In the case of hardwood mouldings, salvaging appears to be one viable end-of-life option. The diversion from landfill will avoid greenhouse gas production and substitute virgin solid wood production, in the end reducing related raw material impacts. Reclaiming hardwood floors is actually more common than is seen for other wood products. Hardwood floors can be recovered for more versatile applications than hardwood mouldings due to their shapes and sizes. Wall coverings, furniture, and floor coverings are potential applications. Innovation in the installation system, possibly through clickable systems, could enhance the recovery potential of hardwood floorings.

To summarize, additional care should be brought to hardwood mouldings and hardwood and engineered wood floors during removal to maximize their recovery potential. Innovations in the installation system may also help enhance this potential.

Recycling

If hardwood mouldings or flooring are not worth being kept in the same condition because of deterioration or wear, they could easily be used as raw materials for other products. It is easier, of course, when they are free of finishes or glue. For that, it would be recommended to sand them before removal. Textured wood walls are potentially interesting for reusing hardwood waste as tiles because of their value and quality. It is also interesting to notice that textured wood wall markets are emerging in North America (Bell 2013b). Other applications that use reclaimed wood are potentially interesting for reusing hardwood mouldings. All of these remain niche applications and need further commercial development.

Energy generation

Energy generation from hardwood-based product waste is conceivable, especially when the solid wood is free as much as possible of contaminants, such as glues and finishes. In some facilities, wood wastes used for fuel are tested to ensure that contaminant levels are kept at the required level (Jeffrey 2011). Negative impacts of contaminated wood wastes can be controlled through the use of proper high-temperature and high-filtration furnaces. The use of clean waste wood as a fuel source for heat and electricity production is a well-established practice in many countries, including Canada and the United States (Jeffrey 2011). Several studies established that postconsumer wood recovery for energy generation is beneficial for net greenhouse gas reduction mostly when substituting fossil energy (Jungmeier et al. 2003, Sathre and O'Connor 2010, Laurent et al. 2011, Cobut et al. 2015a). Jungmeier et al. (2003) are very specific about the fact that using this kind of bioenergy, although generating a substitution benefit, it is not CO_2 free, and there is a need to assess through proper LCA all energy production from wood waste before making decisions. As an example, in the context of the province of Quebec, there are benefits when such projects substitute diesel or bunker energy production, but not when substituting hydroelectricity. The last question to be addressed is whether it is economically profitable to use high-value products such as hardwood flooring or hardwood moulding for energy generation in comparison to reuse or remanufacturing options.

Indoor Air Quality

In its current state, life-cycle analysis does not allow assessing indoor air-quality impacts, even though this is an important issue for building materials, such as appearance wood products. To get around the sick building issue, it is important to address viable solutions. Among them, it is reasonable to consider ecolabeling as an effective option. Getting appearance wood products certified for indoor air quality standards is a good way to tackle problems that are, for the moment, not well implemented in life-cycle impact assessment methodologies.

Limitations

The present study is limited in many ways. Simplifications were necessary to extrapolate the door case study impacts without making supplementary LCA for every other appearance wood product category. These simplifications have surely brought uncertainties to the final results.

Regarding life-cycle stage extrapolation, packaging modeling has been based on the door case study for most products except flooring. This may induce uncertainties in the related impacts. The manufacturing stage is based on the door study and thus may not represent the reality of all products in the family. For example, mouldings as well as wood flooring require a larger amount of machining than other products, and they also produce more sawdust. Impacts related to manufacturing may then be underestimated becuase each specific manufacturing process is not modeled. Another limitation would be at the usage phase. Maintenance of products or coatings has not been addressed because this phase is based on the door study. This phase may be a source of further impacts, as presented in the work of Mahalle (2011).

Life-cycle environmental impacts calculation methodology

Finally, methodological choices such as the use of IMPACT 2002+ damage categories and data adapted to North America and the province of Quebec bring more limitations to the presented findings. One such limitation certainly lies in the high level of controversy on the capacity of IMPACT 2002+ to assess correctly the diversity of forest management situations for the EQ impact end-point indicator. For all wood products, this is a serious limitation because the raw material procurement stage is in all products the main contributing factor.

Biogenic carbon

The carbon stored in wood products has not been accounted for and added in our model. The ecoinvent database, used for LCA, has been selected to assess wood products processes. However, the carbon storage benefit from carbon storage in wood products is not accounted for in the LCA results because IMPACT 2002+ does not take into account carbon intake when calculating environmental impacts. This is a limitation in the LCA methodology. Many scientists assess this benefit becaues it does exist, but it is not yet encompassed in LCA methodology.

Wood products in landfills have a slow rate of decomposition, and deposition in landfills is widely considered as a means to enhance carbon storage, assuming that landfill gases are recovered properly (Skog 2008, Sathre and O'Connor 2010, Larson et al. 2012). Nevertheless, in this study, appearance wood products disposal in a sanitary landfill was not considered as carbon storage, following the assumptions of the used impact evaluation methodology of IMPACT 2002+. Thus, it is fair to expect that accounting for carbon storage during landfilling may improve the environmental record of the end of life to the total score of appearance wood products, which may balance waste transportation impacts to the landfill site.

Conclusions

The aim of this research was to identify solutions for the ecodesign of interior appearance wood products used in nonresidential construction based on their environmental profiles extrapolated from a previous wood door case study. Environmental profiles were very distinctive, depending on the nature of raw materials. Composite-based products had higher contributions related to raw materials than solid wood–based products. Solid wood–based products had the highest negative impact on the quality of the ecosystem. The product weight was also decisive in the contribution share and global score in each damage category. Lighter products exhibited higher relative contributions for shipping, end of life, and packaging and lower contributions of raw materials than heavier products. In general, heavier products obtained higher scores for most damage categories (HH, R, and CC) compared with lighter products. This pattern has been observed but divided between solid wood products and composite products for the EQ indicator. The predicted environmental profiles were considered to be viable data because the trends were similar to those found in the scientific literature.

Ecodesign solutions for composite-based products are strongly related to remanufacturing and decreasing the composite component weight by design through, for example, the use of lightweight panels or thinner panels. For solid wood–based products, ecodesign solutions include remanufacturing or reclaiming used products, using locally certified sustainable wood. The use of hardwood waste may be environmentally beneficial for energy purposes, mostly in the context of heat production in substitution of fossil fuels. But that solution might not be as relevant as reuse and recycling because of the value of solid wood products and the longer carbon storage potential. As a general comment, diverting used appearance wood products from landfills by remanufacturing, reclaiming, and thus extending their life span appears to be the most effective ecodesign path. The remanufacturing process in wood products calls for supplementary expertise, such as closed-loop supply chains, including the development of retrologistics systems and services. Thus, more research and development should be performed to successfully apply remanufacturing in an industrial environment. Finally, it seems that design for recovery should be included in appearance wood products development to divert end-of-life options from landfills even though properly managed landfilling is considered carbon storage.

Freight environmental impacts are noticeable enough to be considered in every product system. Logistics systems, including loading, packaging, transport mode choice, and the distances to be traveled from suppliers and to customers, need to be optimized to reduce transport impacts. Ecolabels for sustainable wood sourcing or for indoor air quality are viable ecodesign options to address issues specific to indoor appearance wood products that have thus far not been properly addressed in LCA methodologies.

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