The Construction Material Pyramid - Integrating health and toxicity parameters

P Munch-Petersen¹, M Lewis²

¹The Royal Danish Academy, School of Architecture, IBT/Cinark
²Henning Larsen Architects

mle@henninglarsen.com
pmun@kglakademi.dk

Abstract. This article investigates how hazardous substances and toxicity information can be integrated into the Construction Material Pyramid [Pyramid] in order to showcase the potential health impacts of material choices in architecture. The current Pyramid indicates different materials’ upfront environmental impacts in the initial life phase of a building product, specifically in the Life Cycle Assessment phases A1-A3. The success of the Pyramid hinges on its communicative strength of conveying complex data in a simple format, easily understood by architects and planners. Can other aspects of material impacts be conveyed with a similar graphic ease to provide a more complete material assessment? Material health and toxicity is notoriously difficult to assess, as data is insufficient and hard to acquire due to proprietary concerns from manufacturers and lack of proper legislation to ensure transparency. The Pyramid has not yet dealt with health and toxicity as a parameter and there exists no predefined method as to how these problems can be included in a comparative model such as the Pyramid. This article’s first line of inquiry is to discuss a suitable methodology to disclose the potential health impacts of construction materials and their associated, often invisible, chemical products applied for mounting, finishing, mold or fire resistance. The Swedish Chemicals Agency’s and the European Chemicals Agency’s evaluation of substances will inform the framework for a comparative system. Secondly, the article will address how the model can graphically convey the potential health and environmental impacts from the production and construction phases of prime and associated materials. This augmentation of the Pyramid would enable architects and designers to more easily obtain information regarding potential health impacts resulting from hazardous chemical content and could provide incentives for selecting less-toxic alternatives. By drawing on H-phases and SundaHus’s product assessment, a ‘stop-sign method’ is used to indicate hazard levels of construction materials.

Keywords: building products, hazardous chemicals, LCA, building declarations, transparency

1. Introduction

Building materials have an impact on global warming potential, and other environmental impacts are tallied; however, the data indicating human and environmental toxic impacts of problematic substances contained in building materials is not readily available through life cycle data. The Construction Material Pyramid [The Pyramid] provides an easily accessible means for architectural consultants to access comparative data regarding the environmental categories defined in life cycle analysis including global warming impact and four other impact categories [1]. It can provide a first step into a longer necessary
inquiry concerning the sustainability of the material choices in architecture. As such it is an initial and generic indication of embedded impacts of materials, but many questions come to mind concerning material sustainability that The Pyramid does not begin to answer. The global warming impacts indicate the environmental burden of the production of the material, and thereby the impacts to planetary health; however, this does not directly address the impacts on human health due to toxic content. The ambition is to introduce a new layer of information into the graphic Pyramid, so that it can be possible to toggle between LCA impacts and hazardous substance of material choices. This additional layer concerns both substances directly contained in materials and substances in associated material, which would augment the basis of knowledge in the material selection process and broaden the discussion of sustainability in The Pyramid.

Figure 1. The Construction Material Pyramid with example of toxicity evaluation.

New data indicates that the fifth planetary boundary, “Novel Entities” has been exceeded [2] [3]. Novel entities refer to non-geological substances such as synthetic chemicals, plastics, as well as heavy metals. This is highly relevant for the construction sector, as construction is the largest end-market for global chemical production [4].

The chemical industry is expected to grow in part due to the petroleum industry searching for new markets, and expanding chemical markets is seen as new revenue potential [5]. Providing adequate information on building material toxicity is highly valuable for construction consultants due to long phase out periods for substances identified as high concern. Integrating this knowledge into The Pyramid would provide the indications which could then encourage further analysis and substitutions of materials.
containing specific restricted substances and/or those slated for phasing out based on the Swedish and the European Chemicals Agencies (ECHA) evaluations.

2. Approach
This article discusses the potential and challenges for introducing data on health and toxicity into the pyramid. First, the lack of sufficient data is addressed. Second, three different approaches to evaluating chemical content in construction materials are analysed in relation to their level of applicability into The Pyramid. Lastly, this article discusses possible ways to graphically integrate the data into The Pyramid in a way that does not compromise the data quality.

In this article materials are divided into two main categories: Prime materials and Associated Materials. They are defined as follows:

Prime materials: Construction articles that are in a static physical state. Examples thereof are bricks, tiles, wooden cladding, stone flooring, screws, and nails etc.

Associated materials: Construction materials, mixtures or preparations, whose physical state changes in application. Examples thereof are, mortar, adhesives, impregnation, sealant etc.

3. Sources for product content data (lack of data and transparency)
In the northern European context there are several sources for construction product content information, although many products, in particular prime materials such as boards, flooring, and insulation lack data for content of hazardous substances, as there are currently no regulatory requirements for comprehensive content documentation of these construction articles.

Existing documentation on content of hazardous substances is difficult to find, however the following sources contain some of the necessary data:

- Safety data sheets (SDS)
- The Swedish Building Product Declaration (Swedish eBVD)
- 3rd party assessments of the eBVD in Sweden (SundaHus, BASTA and Byggvarbedömmingen)
- Product certification systems such as Nordic Swan Ecolabel, Cradle to Cradle and Declare Label EU

3.1. SDS
SDS are legally required declarations of hazardous substances intended for workers’ safety during the construction phase and conveying information on the likely routes of exposure (inhalation, ingestion, skin and eye contact) and regulated precautions. This documentation is obligatory for dangerous substances or mixtures and contains names of hazardous substances assessed by European REACH legislation, an acronym for the Registration, Evaluation, Authorisation and Restriction of Chemicals. SDSs are a notoriously error ridden form of documentation; however, there is the possibility to identify the hazardous content via CAS numbers. According to ECHA 33% SDS are deficient [6]. Information gaps in SDSs are legitimized by a system which allows for withholding content data to protect trade secrets. SDS can be sources for data for associated materials, but are rarely available for the Pyramid’s prime materials, which are articles, and not mixtures.

3.2. The Swedish Building Product Declaration
The Swedish Building Product Declaration has existed for 30 years; the digitalized version was established in 2015. It is not obligatory, however it is a de facto license to operate and there are currently over 40,000 declarations in Sweden, covering articles as well as mixtures. The eBVD lists hazardous substance content compliant with the EU required Classification and Labeling 1272/2008 (CLP) Regulation including H-phrases, codes defined under the Global Harmonized Standard indicating hazardous characteristic end points. Examples of H-phrases include “H340 - May cause genetic defects” and “H372 – Causes damage to organs through prolonged or repeated exposure.” In addition, the eBVD requires disclosure of non-classified substances that are present in amounts over 2%.
3.3. 3rd party assessments of the eBVD

3rd party assessments of the eBVD are the most reliable source of data, as these evaluations involve a control of the declaration. There are three companies that offer 3rd party assessments in Sweden: SundaHus, BASTA and Byggvarubedömningen. Assessments include CAS numbers of all ingredients (a so-called “positive list”) as well as the H-phrases for the substances. All evaluations implement the prioritization scheme published by the Swedish Chemicals Agency. All criteria are based on REACH regulations, however the Swedish PRIOR initiative provides two concise prioritization charts: one defining characteristics (H-phrases) of phase out substances, the other defining characteristics of priority restriction substances. The advantage of the PRIOR charts is instead of working with long and complex lists of CAS number and substance names, the charts zone in on the essential undesired properties conveyed by the H-phrases, such as “Carc. 1A/1B, H350: May cause cancer.” The BREEAM-SE building certification system implements the PRIOR prioritization for screening of construction materials, see Figure 2 below:

| Property                      | Classification according to the CLP regulation for determination of the intrinsic properties | Maximum concentration |
|-------------------------------|-------------------------------------------------------------------------------------------------|------------------------|
| Carcinogenic                  | (Carcinogenicity, Category 1A and 1B) H350: May cause cancer...*                               | 0.1%                   |
| Mutagenic                    | (Germ cell mutagenicity, Category 1A and 1B) H340: May cause genetic defects...*               | 0.1%                   |
| Toxic to reproduction         | (Reproductive toxicity, Category 1A and 1B) H360: May damage fertility or the unborn child...*  | 0.3%                   |
| Endocrine disrupter           | Substances classified in categories 1 and 2 in the EDs database (List from the European commission available at http://ec.europa.eu/environment/archives/docs/pdf/bkh_annex_01.pdf) | 0.1%                   |
| Particularly hazardous metals (Cd, Hg, Pb) | Mercury, cadmium, lead and compounds of these metals are all phase-out substances. Specific criteria are not because the presence of these metals is enough. | Cd 0.01% Hg 0.1% Pb 0.1% |
| PBT / vPvB Persistent, Bioaccumulating, Toxic / very Persistent, very Bioaccumulating | Criteria available at www.kemi.se | 0.1% |
| Ozone-depleting substances (0.1%) | (Hazardous to the ozone layer) EUH059: Hazardous to the ozone layer H420: Harms public health and environment by destroying ozone in the upper atmosphere. | 0.1% |

Figure 2. Screening requirements from BREEAM SE 2017, List of phase-out substances as defined by the Swedish Chemicals Agency, Kemikaleinspektionen, KEMI.

3.4. C2C Material Health Certificate

C2C Material Health Certificate reveals limited product specific information - indicating that a certified product is Cradle to Cradle Certified™ Restricted Substances List compliant, but not listing a positive list of product ingredients. H-phrases associated with the products’ content are not listed and neither are hazardous substances that may not be on the C2C Restricted Substances List (2021), which only includes approx. 100 substances.
4. Methods for evaluating chemical content in construction materials

In addition to exploring the existing options for evaluating chemicals in a life cycle framework, the main point to convey in this section is that the ECHA dictates the assessments on a substance level through CLP regulation and through REACH’s Annexes. However, REACH is not helpful in providing a means of prioritizing negative impacts from these substances. Therefore, we look to the recommendations of the Swedish Chemicals Agency’s PRIOR initiative, which is grounded in REACH chemical assessments, and is more operational for the purpose of integrating data into the Pyramid.

Chemical impacts from construction products have been integrated into at least two LCA modeling frameworks, and chemical impacts are also assessed based on contents of products. What follows is a discussion of the data, the characterizations and the identification of chemicals in product content for the different approaches.

There are several different options for modeling LCA toxicological characterizations. Since the Pyramid is currently based on LCA data and includes five environmental impacts, this would seem to be well aligned with the current methodology. LCA characterizations included in GABI with human and ecological toxicity expressed in LCI values could augment the LCI data in the Pyramid. The characterizations include the following:

- Freshwater Aquatic Ecotoxicity Potential (FAETP) (in kg DCB-eq./m2/year)
- Human Toxicity Potential (HTP) (in kg DCB-eq./m2/year)
- Marine Ecotoxicity Potential (MAETP) (in kg DCB-eq./m2/year)
- Terrestrial Ecotoxicity Potential (TETP) (in kg DCB-eq./m2/year)

These toxicological impact categories derive from the CML2001 LCIA methodology. However, there is no international consensus on the use of these toxic characterizations, and the data is not widely available [7]. This data is not included in either A1 or A2 EN15804 EPD.

Use-Tox is the other option for expanding the Pyramid by continuing within the life cycle framework [8]. UseTox is a database that includes eco and human toxicity expressed in LCI values for various generic products. It is approved by the UNEP and is under development. USEtox addresses four different scales: indoor, urban, continental and global, and includes characterisation factors for human toxicity and freshwater ecotoxicity via three different fates:

- Environmental fate, where the distribution and degradation of each substance is modelled
- Exposure where the exposure of humans, animals and plants are modelled and
- Effects, where the inherent damage of the substance is researched

Use-Tox introduces a high level of complexity, and the risk for including Use-Tox is that simplifying the multiple fates addressed in UseTox in order to communicate with Pyramid users, would compromise the Use-Tox data. Reconciling the complexity of USEtox with the simplicity of the Pyramid may not be possible.

The final approach for assessing hazardous content is to review product ingredients, and to control for hazardous substances based on content. This approach identifies chemical exposure relevant in production and in construction site phases but is less reliable for defining exposure in use or in end-of-life phases. This approach is based on linking particular identified substances with the associated H-phrases, and the evaluations of these substances under REACH. The advantage is that there is data available for mixtures and for some construction articles, although the data is primarily Swedish. This is the approach implemented by building certification systems in screening for hazardous substances to promote optimized health and environmental conditions. With this approach it is possible to review the health and environmental impacts of the product based on the impacts of chemical contents.

This approach with a direct review of content would provide reliable data that could be used in the Pyramid on a generic level to raise awareness of potential human health and environmental hazards.

This content-oriented evaluation is implemented in two different ways in existing screenings systems: either by aligning with restricted lists of substances, “red lists” or “banned lists” - in some cases
very long list with substance name and CAS number, often grouped into chemical classes. The other way of implementing content evaluation is to identify undesirable properties (carcinogenic, mutagenic, repro-toxic) and via their associated H-phase and flag the use of products with substances with these H-phrases. This reflects the prioritization approach of the Swedish Chemicals Agency’s PRIo initiative. Substance with H-phrases that are on the phase out list are given the highest priority for elimination. A second list, the priority restriction list, targets next level hazardous substances for reduction. This prioritization lends itself to easily understandable graphic communication in the Pyramid: substances containing phase out properties would be flagged with red, the priority restriction properties flagged with yellow and the products without H-phrases for either PRIo level receive a green light. See more below concerning the ‘stop-light method’.

The two implementation paths for content evaluation are demonstrated in building certification systems. Certification systems using red lists such as LEED 4.1, DGNB, and BREEAM-NO are far less effective in targeting the hazardous substances actually used in the relevant market, while certification systems that screen based on end point characteristics such as BREEAM-SE and Nordic Ecolabeling for buildings have a more effective screening potential [9].

5. How to graphically express health data: Generic or specific products – the “stop-sign method”

The existing Pyramid is primarily based on life cycle data from Ökobau.dat. And when possible, it was based on generic EPDs (not product specific EPD’s). When generic EPDs do not exist the aim of the data collecting process is to collect as many EPDs as possible for each material category to get an overview of ranges within each impact category. Then the EPD that has the average impact levels is chosen to represent the material in the pyramid to retain the overall generic quality of the Pyramid. This generic approach allows for information to be released without targeting specific manufacturers.

The challenge is that a generic approach is more difficult concerning hazardous content, as there can be fundamental differences in content in similar products, resulting in complete absence of generic qualities within material categories.

As the Pyramid is a simplification and a generic tool it is important to ensure that the reduction of complexity of data available does not compromise the data quality. To graphically ensure that data is not compromised, a ‘stop-light method’ mentioned above is chosen. By placing materials in red/yellow/green and with a hover text it is possible for the viewer to understand that some products are red = contains phase-out substances, yellow = contains restricted substances green = no known substances of concern. The hover text can then reveal more details about the potential hazards and furthermore about the potential hazards in associated materials, see Figure 3 below.

![Figure 3](image-url)
6. **Primary materials, intrinsic properties and associated processes**

One material points to the next: There is no brick wall without mortar for instance. Therefore, it is beneficial if the Pyramid can show the content of primary materials as well as hazardous substance content of typical associated processes necessary for the material’s integration into a building. For example, a particular window may receive a finish in the factory or may be available in an untreated version. Many construction materials are available in two or more versions with different treatments. Wooden façade cladding can have a fire retardant integrated into its primary material, but it can also be produced without. There may also be varying degrees of hazards with additive substances, for example the binder in an insulation may be a problematic substance, or it may be benign. The potential hazardous substances in a primary material can be an intrinsic part of the material, however the primary material may exist in a version without these additives.

The associated processes can be relevant for the particular application of the primary material. Associated processes include adhesives used for installation, treatments applied on-site such as protective finishes and sealants, fire retardants and biocide treatments, joint compounds, fillers and mortars, none of which appear in the Pyramid today. But they are especially important when it comes to health and toxicity, as no building material ‘works’ on its own. Materials used in associated processes are often noteworthy sources of substances of very high concern (SVHC) in a construction assembly, and as such it is important not just to show information on a given primary material but also for its common associated materials. This provides a challenge as the current Pyramid only address primary materials’ embodied impacts and materials used in associated processes are not addressed.

However, a solution can be to add information on the hazards concerning associated materials in the hover text. The array of possible hazards concerning different types of associated material is shown by pointing at the prime material. That means that for the user two levels of information is present. First, stop-light on the primary material and second, the hover text that addresses the associated material hazards.

7. **Resulting graphic output**

It is a clear challenge when the primary material and its potential associated materials contain very different degrees of hazardous properties (oil treatment for wood floors for example can contain classified substances and in other cases contain no classified substances, binders in insulation can also have a range of impacts). How should wood flooring plus an associated surface treatment be expressed in a comparative ranking? Positioning the prime material at the top or bottom of the pyramid is dependent on 1) intrinsic content and 2) a range of associated processes, both of which may have varying degrees of negative impact, making a realignment within the pyramid impossible. This could be solved either by ‘hover text’ explaining the spectrum of potential substances on both the level of the prime material and the level of the associated processes, see Figure 1. Alternatively, graphically highlighting other associated material in The Pyramid or in a sub-pyramid (the associated material pyramid) could be a solution. As many of the associated materials do not (as of now) show in the The Pyramid highlighting them is impossible but associated material could be shown or described in the ‘hover text’.

Due to the generic product approach of the Pyramid, the intrinsic properties of the primary materials may vary and due to the building or a component specific application, the associated processes will also vary. What is important is to show the Pyramid users the range of options and potential impacts. Graphic effective communication would be to use the stop-sign analogy to highlight levels of potential hazard with red, yellow and green. Perhaps a gray level indicating lack of data, or lack of certainty is also necessary. To maintain the simple yet effective communication of today’s Pyramid, it is important that the health impacts of primary products can be understood via a corresponding realignment of the products in the Pyramid, with top revealing the most toxic products and the bottom the less toxic products.

8. **Discussion**

It is possible to include data on hazardous substances in the Pyramid. It is not as straight-forward as environmental data from EPD’s but by using the ‘stop-sign method’ the data could be made accessible in a novel way. One option is to navigate using existing data and focusing on H-phrases. By doing so
we get a system where products with H-phrases that correspond to the ‘phase-out list’ are flagged with red in the Pyramid. The products with H-phrases that correspond with priority restriction properties are flagged with yellow and the product without phase-out or restriction H-phrases are green. The difficulty with this approach is that due to the complexity of building product composition and due to chemicals used in manufacturing processes but not necessarily present in the final product, such a simple categorization is not possible. A survey of assessments of wood windows in SundaHus indicates that there are more than 30 different substances listed in the production of each window, and in the majority there are 4 to 5 phase-out substances as well as 6 to 9 restriction list substances included in the products. Only one product had no phase-out substances, however includes 14 restriction list substances. The products range from an A assessment to a C- assessment in the SundaHus system. Implementing additional criteria is necessary for a valid prioritization in the Pyramid.

This could be achieved by using the evaluation criteria developed by SundaHus, which rates materials form A, B, C+/− to D [10]. The main health relevant criteria for A products is a minimal health or environmental impacts associated with the phase-out end-point properties defined by the Swedish Chemicals Agency. In addition, A products do not contain substances classified as hazardous to health in the construction phase and do not have high volatile organic compound or formaldehyde emissions. B assessed products do not meet the health criteria for A products, yet do not fall into the C+ or C- rating. The C+ rating includes products that impact workers, local communities, and the environment due to substances of very high concern used for the manufacture of polymers. Health criteria included in the C- rating are products that lead to exposure to phase-out substances with toxic properties such as carcinogenic, toxic to reproduction, endocrine disruptors, allergens, or products that risk affecting the indoor environment due to high emissions of volatile organic compounds. The D-rating is for products with insufficient documentation; the relevance of this in a generic evaluation should be reviewed.

This will result in a Pyramid that firstly distributes prime material into green level = A, Yellow level = B and Red level = C+/− & D all based on the existing criteria implemented today in the SundaHus system. Secondly, the associated material can be viewed in separate ‘sub-pyramids’ highlighting the fact that many health impacts are tied not just to the prime material but rather are consequences of associated materials. As SundaHus’s current assessments are based on product specific data, one challenge for integrating into the Pyramid would be to present an evaluation on a generic level. This could for example entail that a product lands simultaneously in several levels, with information to indicate incremental prioritizations. Such information would be especially helpful for establishing requirements in tender specifications.
However, there are many possible associated materials for any primary material (paints, adhesives, fungicide, fire retardant etc.) and even harmless prime materials can become hazardous when actual application in the building is addressed. A hover text was chosen as this gives the opportunity to point towards possible hazards in common associated processes and to lead the user to the ‘sub-pyramids’. This is a deviation from the current interface of the Pyramid as it now holds no hover information or ‘sub-pyramids’. Simplicity is key, but in this case hover text is necessary as results can be misleading otherwise.

It was found that the existing Pyramid needs to be revisited and revised as its categories are too loosely defined. More precise descriptions of primary materials are needed if the stop-sign method is to be employed without misleading the user. For instance, the material entry ‘Modified wood’ should be either ‘Chemically modified wood’ or ‘Thermally modified wood’ as the intrinsic composition of the two vary a great deal. For this system to be successful, a revision of the Pyramid is necessary. Due to the complexity of assessing building material content, it would be an advantage to work with well-established and transparent evaluation criteria such as that used in SundaHus’s product evaluations.

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