Digitalisation Impacts on Material Usage

A short summary of studies on Aluminium Recycling, Building Information Modelling and the LifeCycle Analysis (LCA) of Buildings Regulations in Europe.

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Executive Summary

Reducing GHG emissions without reducing living standards implies recirculating materials rather than discarding or downcycling them, together with designing and constructing buildings to use fewer materials or those with a lower embodied energy or lower thermal transmission, or both.

The first part of this summary covers improved sorting of scrap aluminium shred to significantly reduce downcyling of high quality wrought aluminium into lower quality cast aluminium. Cast aluminium is expected to have diminishing uses as internal combustion engined vehicles (ICEs) are replaced by EVs.

The second part looks at the benefits of greater penetration of Building Information Modelliing (BIM) as a design and construction tool, and the third part covers LifeCycle Analysis (LCA) of new buildings as mandated across the EU by 2030 through the EPBD(2024), which is enabled by BIM.

The findings show that the introduction of Laser Induced Breakdown Spectroscopy could greatly reduce the downcycling of wrought aluminium into cast grades, potentially eliminating a forecast surplus of cast aluminium by 2040. The technology is coming available and implementation has started: the change is driven by market forces and there are no initiatives are required from governments. However, projections are very dependent on the actual phase-out profile of ICE's, the amount and type of aluminium used in EVs, and the amount of manual disassembly of EVs which takes place before shredding (which reduces the need for sorting shred), all of which are speculative at present.

The second study, on BIM rollout, suggests that it could save about 5.6% of building materials used in new buildings by 2050. Cost savings, including labour, would be somewhat higher. Savings would come primarily from early detection of design incompatibilities and highly accurate bills of materials. However, interviews showed that currently BIM is barely used for deliberate reduction of material content or the selection of materials with low embodied emissions. Architects lack incentives and databases to do so: these may be provided by the LCA legislation stemming from EPBD(2024).

The final study, on the implementation of LCA for all new EU buildings by 2030 [as mandated by EPBD(2024)], subject to an overall and reducing limit on the total emissions per square metre, suggests that emission saving could be of the order of 32% by 2050, if implemented thoroughly. However, this requires significant levels of training for architects, contruction workers and municipal building departments (who act as a quality control on the process). It also needs more regulatory flexibility to approve alternative building materials more rapidly: structural material regulations in many EU states are based around the properties of emission-intensive Portland cement. The governments of member states will be instrumental in the success of this legislation, or otherwise.

Most importantly, the calculations show clearly that the potential emissions savings from LCA / EPBD(2024) are multiples of the savings from BIM implementation alone.

Keywords

Aluminium Recycling, Laser Induced Breakdown Spectroscopy, BIM, LCA, EPBD (2024)

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Abbreviations

CircEUlar	Developing circular pathways for a EU low-carbon transition
EU	European Union
IIASA	International Institute for Applied Systems Analysis
WP	Work Package

Digitalisation Impacts on Material Usage

1. Introduction

Some 41% of all GHG emissions relate to buildings (Ramboll, 2023) and around 34% of all GHG emissions relate to industrial activity (including associated energy production (IPCC, 2022)). There is considerable overlap between these figures: about 66% of the industrial material emissions relate to four bulk materials - cement, steel, aluminium and plastics – about half of which are used in buildings and mobility sectors (Material Economics, 2018).

The purpose of CircEUlar's study is to project emissions in these sectors through to 2050: this element of the wider study looks at the potential impact of digitalisation of material usage as it relates to the Circular Economy (CE), firstly in the recovery, recycling and reuse of bulk materials and secondly in the design and construction of buildings.

Recovery and recycling of materials is most cost effective if the recovered material is in its purest form: for example, for metal alloys, with bulk scrap separated into containers of like alloys which have been identified and sorted from the bulk. It is this separation and sorting process that digitalisation could potentially assist with.

For buildings, nearly all buildings in Europe are designed on a digital platform, either 3D Computer Aided Design (CAD) or Building Information Modelling (BIM). Theoretically, it is possible to iterate a building design for minimum total of embodied energy and projected operational energy by using this digital data: the study looked at why this is not happening and the barriers to it occurring.

This document outlines how projections of the impact of digitalisation have been prepared on the basis of research work undertaken. Some explanations of the reasoning behind assumptions are given in the text below: more details can be found in two documents on the CircEUlar website: 'Does Digitalisation of Building Design and Construction enable real-world material and energy savings in Europe? A Circular Economy study of Building Information Modelling (BIM) use' https://circeular.org/wp-content/uploads/sites/21/2023/06/CircEUlar-Working-Paper-No.1_Bulk-Materials.pdf and 'Bulk material manufacture: the potential impact of digitalisation and provenance systems on materials recirculation'. https://circeular.org/wp-content/uploads/sites/21/2024/10/Report-Martin-Burgess-v1.3.pdf

Three applications of digital technologies:

- Section 2: Scrap aluminium sorting: application of Laser Induced Breakdown Spectroscopy
- Section 3: Impact of BIM on the Circular Economy and Net Zero.
- Section 4: Life Cycle Analysis legislation following EPBD 2024.

2. Scrap Aluminium sorting

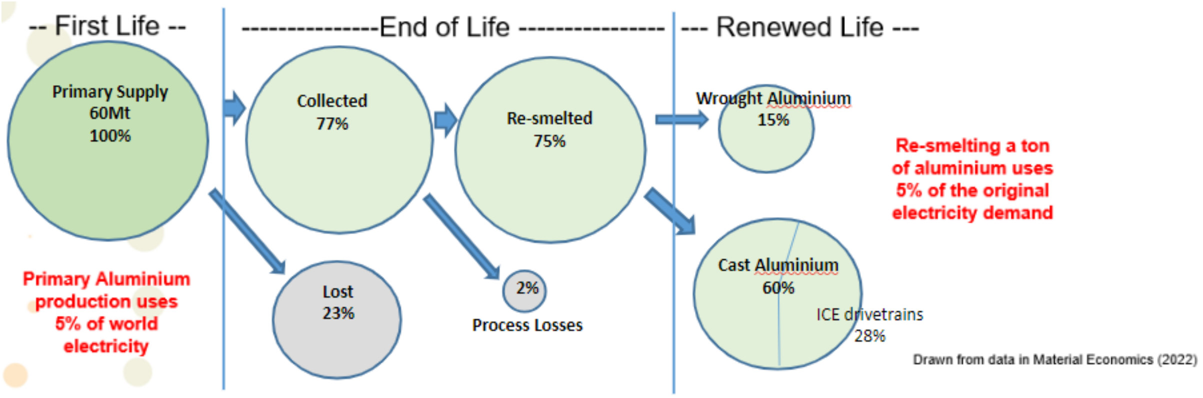
2.1 Background

Worldwide, about 100 Mt (million metric tons) of aluminium are currently produced per year, about 35% of which comes from post-consumer scrap and 40% from processing or fabrication scrap (Raabe et al., 2022). In Europe, about 10 Mt (million metric tons) of aluminium are currently produced per year, about 60% of which comes from scrap (both post-consumer scrap and processing or fabrication scrap) (Alucycle, 2022). Its high strength to weight ratio combined with its ductility means that it is a preferred material in both transportation (planes, road vehicles, trains) and construction (cladding, architectural shapes, smaller girders and fixings). Its relatively high conductivity combined with low weight make it ideal for power lines, and it is also used in a wide variety of consumer goods.

Due to the very high electricity consumption when alumina is smelted in the production of aluminium, recycling takes only about 5% of the energy that it takes to create virgin aluminium (Material Economics, 2018).

There are multiple grades of aluminium within each of two classes: wrought and cast. Wrought aluminium contains small specific percentages of alloying elements such as magnesium, zinc and manganese. Cast aluminium contains higher levels of silicon and can tolerate higher levels of impurities – these same alloying elements that are key in wrought alloys - than wrought can itself.

When wrought is recycled in Europe, fabrication scrap lots from a single factory are normally of known grade and kept separate for recycling directly back into a similar wrought grade. Mixed post-consumer scrap is shredded (wrought and cast together). The shred is in the form of separately identifiable pieces, some cast, some wrought, mixed together. This is either shipped to low-wage countries for hand sorting (wrought and cast shreds can be separated by skilled eye) or both are remelted together, downcycling the wrought into cast, because of casts' tolerance of impurities. In this case not only will expensive alloying metals be lost and more will have to be mined to produce new wrought grades, but as the cast aluminium is repetitively recycled they can build up and restrict or eliminate use of the metal (Pedneault et al., 2023). Cast aluminium, containing high levels of silicon, can never be used as wrought, unless diluted very heavily by pure virgin aluminium.



Drawn from data in Material Economics (2022)

2.1.1 Foreseeable constraint

The major use of cast aluminium is in internal combustion vehicles, principally in the engine block. With the widespread introduction of EVs this use will disappear rapidly in Europe if the EU retains its policy that no ICE cars will be sold in Europe after 2035. In any event, the numbers of new ICE cars will fall steadily. Projections vary, but all suggest a surplus of cast aluminium in Europe in the near future (Eynde et al., 2024; Krall & Pogatscher, 2024; Pedneault et al., 2023). One of the few papers to use a detailed series-by-series level model of the different wrought grades to forecast the cast surplus suggests a global surplus of 5.4Mtpa by 2030 and 8.7Mt by 2040 (Van den Eynde et al., 2022). The European share would be about 14% {13.5Mtpa/95Mtpa

(Material Economics, 2020) / (International Aluminium Institute, 2021)}, or 0.8Mtpa in 2030 and 1.2Mtpa in 2040.

While the engine blocks as a sink for cast aluminium do not exist in EVs, it is expected that the demand for wrought aluminium grades will increase (e.g. (Ducker, 2022)) both as part of the battery housings and for general increased lightweighting, so that overall the weight of aluminium will increase in an average EV and overall demand will rise.

2.1.2 Potential solutions

There are three possible digital solutions to this problem in development or early rollout. All sort the shred using different methods: (a) optical recognition technologies (b) XRF with XR background scattering analysis or (c) Laser Induced Breakdown Spectroscopy (LIBS). Optical recognition uses an image of the shred and compares it to a stored bank of images, to decide whether it is wrought or cast. Both XRF and LIBS irradiate the shred and capture the emitted response: they are reading the impurities in the shred to decide what the aluminium is alloyed with, and therefore whether it is wrought or cast. Theoretically, these can split the wrought shred into sub-classes of alloys, rather than just ‘wrought’ and ‘cast’. Summarising, each method is used to identify the chemical formulation of a shred and it is separated from its compatriots by a puff of compressed air.

Of these, LIBS is the most promising: three major waste sorting equipment manufacturers (Tomra, Steinert and Austin AI) all have equipment on the market, claiming 95% separation at around 4-5tph (e.g. https://steinertglobal.com/sorting-systems/sensor-sorting/libs-sorting-systems/). Steinert customer Metallco AS in Norway and TOMRA customer Alutrade in the UK both claim 99% separation using it, and sub-sorting wrought into grade series 1xxx to 8xxx depending on chemical composition (https://steinertglobal.com/showcases/metallco/): customer Intals SpA in Italy claims the same series sort without quoting an overall percentage separation figure (https://steinertglobal.com/showcases/intals/). How generalisable these results are is unclear.

In this study we calculated that LIBS has potential to reduce downcycling of wrought aluminium into cast at sufficient scale to eradicate the surplus of cast alloy in Europe. In material and energy terms this saves the production of new aluminium from bauxite (saving 95% of the energy) and also saves the production of the alloying metals that would otherwise be lost into the cast alloy surplus. In conceptual terms this is a reduction of imported virgin aluminium into Europe: the CO2 savings occur elsewhere, typically in Asia. No regulatory actions to facilitate the implementation of LIBS are required: there is enough value in separation of wrought aluminium that rollout is market driven.

2.2 Method and Assumptions

To calculate the potential for LIBS to reduce downcycling, we used the following steps and assumptions:

1) It was necessary to ensure that enough shredded aluminium is likely to be available for LIBS to act on, so a projection for the demand for aluminium was produced by use category, turned into scrap arisings with suitable time lags by use category. Derivation of this scrap Aluminium boundary condition is given in Appendix 1.

2) We determined from the leading European manufacturers (Steinert and TOMRA) websites that each LIBS line can sort 20,000tpa of mixed shred.

3) We used a separation accuracy of 90%. This was perhaps considered optimistic two years ago when the original study was carried out: now both Steinert and TOMRA cite client statements that 99% separation accuracy is being achieved (see above). However, it is not clear how widespread this result is or will be in the future in other conditions.

4) We noted that volumes of aluminium used in EVs become significant, so we had to make assumptions about the end-of-life recovery of the materials from the car. The more aluminium is removed by hand from the vehicle before the remainder is shredded, the less aluminium is available for LIBS to separate and the less benefit that can be attributed to it. For example, it is probable both that the battery housing will be made from wrought aluminium and that regulations around battery recycling will mean that the housing is also removed. We assumed that 50% of the aluminium in the car is manually removed before the remainder is shredded.

5) We modelled two potential rollout speeds: 15 and 20 LIBS lines per year.

2.3 Results

At 15 LIBS lines installed per year, the amount of downcycling of wrought alloy avoided (ie the amount separated) is 3.1 Mtpa by 2050 (Appendix 1). The equivalent figure for 20 LIBS lines per year installed is 4.0 Mtpa. Against a demand forecast of 17.2 Mtpa this is very significant (18%-23%). Neither rate of rollout would cover Van Den Eynde's projected cast surplus in 2030 (0.80Mt), but both would cover it by 2040 (1.4Mt)(Van den Eynde et al., 2022). Note though that the short-term projections for EV volumes are looking less likely to be filled, so there may be no cast surplus, or a smaller surplus, in 2030. Also, it is likely that were a surplus to arise by 2030 then the rate of LIBS rollout would increase to meet the availability of low-priced mixed aluminium scrap.

Beyond a rollout rate of 20 LIBS lines a year the model indicates that the market for LIBS may reach practical saturation by 2050 with all the shredded wrought separated and recycled.

The derived aluminium demand figure for passenger cars and light trucks is about 4.6Mt, compared to 2022's 3.35Mt (www.fastmarkets.com/insights/european-automotive-aluminium-demand-set-to-slow-fastmarkets-analysts/). This is based on Ducker figures for aluminium in cars in Europe (Ducker, 2022). It is a much lower rate of growth than in many projections (e.g. [Global] "aluminium use in passenger cars is likely to quadruple towards 2050" (Billy & Müller, 2023)) which appears to be due to higher starting figures for aluminium content per vehicle in some major global markets, extrapolation from assumptions about the mix of vehicles becoming ever larger, the aluminium proportion continuing to rise unchecked and growth in global sales forecasts.

2.4 Conclusion

We calculate, based on the assumptions above, that the projected surplus of cast aluminium can be fully eliminated by the use of LIBS as a digital solution for more precise sorting of shredded scrap by 2040. If 15 LIBS lines per year were installed then annual savings in wrought aluminium not downcycled would be 3.1Mt by 2050. Conceptually, this is tonnage of aluminium that is not imported into Europe from Asia where it would be mined and smelted at significant environmental cost.

3. Impact of Building Information Modelling (BIM) on the Circular Economy and Net Zero

3.1 Background

Digitalisation of the Architecture, Engineering and Construction industry (AEC) has resulted in nearly all European buildings being designed on CAD and/or BIM. Digitalisation provides clarity, speed and flexibility to architects and 2D plans/3D visualisations for constructors. Each BIM model can be thought of as a database of design images, each with supporting data (e.g. dimension, specific density, thermal conductivity, tensile strength). Within BIM software useful information can be produced such as Bills of Materials and detection of design clashes. Third party software ("tools") can link data extracted from the model to external databases and calculate numerous factors such as structural load bearing capacity, acoustic transmission or thermal losses. There are various providers of the basic design skeleton and multiple producers of tools.

The two major differences between BIM and CAD are (i) the level of detail held against each building element, and (ii) parameterisation. Parameterisation is best demonstrated by an example: a wall is a linked collection of components such as plasterboard, windows and doors (Eastman et al., 2011). Using BIM, if the wall height is changed, then the plans do not have to be redrawn: the component heights will all change automatically (brick skin, timber pillars, plasterboard liner, etc). So great flexibility to readily change complex designs is possible, but time and rigid procedures are needed to set up the model in this way and with all the added data necessary to enable the tools to operate. Implementing BIM will cost time, effort and money well in excess of the hardware and software cost (Eastman et al., 2011). Data output and input is through a commonly agreed system known as IFC ("Industrial Field Classes"). Later 3D CAD systems have some potential to work with parameterisation but not to the same levels of complexity as BIM.

Building Information Modelling (BIM) has long been promoted by the EU and certain member states. The EU Commission explicitly supports BIM as a method of achieving cost savings, suggesting 13%-21% from design and construction and 10%-17% in operations (BCG, 2016; ECTP, 2022)[1]. For constructors using BIM it can assist with build accuracy, job scheduling and progress chasing to improve speed of delivery and reduce costs.

We interviewed 41 architects, consultants and constructors across 11 European countries showing that BIM is little used by smaller architects and constructors (Burgess & Wilson, 2025), similar to previous research. Larger firms use BIM as a design and data processing tool to enable collaboration between project partners: if certain coordinates are fixed in advance then different specialists (e.g. structural, electrical, escalator, ventilation) can work simultaneously on copies of the model, speeding design greatly. These copies can then be uploaded to the main model and checked for design clashes. Most digital tool innovation is to speed construction: current evidence of BIM-enabled calculations impacting material usage, or embodied emissions, or lifetime emissions through the design process is minimal and limited to environmental specialists. So in general, digital systems have not been used with the intention of reducing material usage or advancement of the CE.

Sizeable commercial buildings would most likely be designed and built with BIM in any event. However, interviews revealed that this is ensured because the compliance process for buildings to obtain 'Green Certification' standards, which is the main driver of GHG emissions reduction in the commercial buildings sector, requires BIM. Certification, which included elements of embodied and operational emissions, increases the building's value to end investors by adding perceived protection against obsolescence. In addition, there are a small number of environmentally conscious architect's firms which influence design and materials within their remits.

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[1] These figures come from a Boston Consulting Group 'Internal calculation' – details unknown - which have made their way into EU documentation.

After the building is completed and embodied energy is fixed, Net Zero goals can be furthered by reducing operational emissions during the life of the building, whether in heating, cooling or lighting, and also by maintaining the building more efficiently to avoid unnecessary replacement of fittings. However, the inflexibility of data handling in BIM, together with the training and access controls required to use it, make it unsuitable as a basis for Facilities Management (FM) software. The information within BIM on spatial dimensions, materials and parts used is all useful for planned maintenance programs and reduction of replacement parts, clearly a CE aim, but the data interoperability issue commonly leads to a break point in the data trail when the building is completed, with apparent loss of much of the building information. While this break point is starting to be addressed by third party software companies, it implies that many buildings coming to the end of their first lives will continue to be BIM-less.

3.2 Quantifying the volumes of materials potentially saved by use of BIM

No interviewee put a figure to material savings from BIM use by architects. They occur in four areas:

i) in accurate specification of Bills of Materials, although commonly these are still prepared by Quantity Surveyors even where BIM is in use;

ii) in reduced mistakes during design and build;

iii) through enabling the use of prefabricated modules, where 40% to 66% less CO_2 is embodied in the module than the equivalent conventionally built equivalent;

iv) in aiding reuse of materials at End-of-Life.

Discussing each of these in turn with relevant literature, and deriving the assumptions for the study:

i) Accurate specification of materials.

There is minimal academic work quantifying the purchased materials which are wasted during the build. Most papers and statistics refer to Construction and Demolition Waste as a combined category or study demolition waste alone. Most papers in this area are also non-EU and so base their findings on different styles of construction. A South Korean study assessed two buildings where the design was revalidated by BIM: it achieved savings of 4.3% and 15.2% of materials (Won et al., 2016). Also useful is a 1994-6 study in the Netherlands (Bossink & Brouwers, 1996), showing that the amount of waste for each building material lies between 1% and 10% of the amount purchased. The average amount of the purchased construction materials that end up as construction waste is 9% (by weight, pre-BIM). This paper also cites four earlier European studies which suggest that construction waste is around 25% - 30% of the total, but these are historic figures. Much of the waste is mortar, concrete, bricks and roof tiles, all of which are downcyclable into aggregate. It is perhaps logical to assume that higher value items will be specified somewhat more accurately. We know that 92% of construction waste is recycled into aggregates for other buildings in UK (DEFRA, 2020).

Turning to BIM papers focused on ROI, they show that the labour savings from clash detection – estimated avoidance of rectification work – dwarf the materials savings, and furthermore the material savings are not separately identified (e.g. Azhar, 2011; Giel & Issa, 2013). Gauging BIM's economic value is complex and very few studies involve real-world cases (Gharaibeh et al., 2024). In addition, this paper’s detailed review of other papers show none recording materials savings alone (ibid). Most relevant is their survey result that the tender prices for the contract can reduce 6%-10% - the tender price being a mix of labour and materials (ibid). (Scopus was searched using “BIM” and either “waste”, “savings” or “material efficiency” – this paucity of data is the summary of the findings).

Assuming that these two studies are representative (and there is no other data to rely on), use of BIM could perhaps save c.7% of materials, split between design economies (say 4%) and less on-site waste achieved through better Bills of Materials (say 3%). But the supporting data is thin. This 7% figure is used for both residential and non-residential buildings.

ii) Reduction of errors during design and build

This is included in both the Korean study (Won et al., 2016) and the Dutch study (Bossink & Brouwers, 1996) quoted above, and so the estimate of the savings is included in the c.7% figure above for saving of materials.

iii) Use of prefabricated modules

Modular home builders (also called volumetric buildings in the USA) claim very significant embodied emissions savings over traditional buildings, up to 66% claimed by the CEO of one US company (Vaughan Buckley, 2024). However, comparison is difficult, particularly as the lifetime of the modular building is likely to be less than a conventional one. An Australian thesis suggests that embodied emission savings vary from -13% (ie higher emissions) to +20% depending on the materials selected for the module (Green, 2017). A detailed Hong Kong study derives a 20.7% saving between modular construction and a theoretical conventional equivalent for a public building (Wei et al., 2024): the building service life assumption appears to be equivalent in both cases. The same authors cite numerous other studies with savings through modular construction of between 3.1% and 21%: building materials and the proportion of modularisation in the building varies between studies.

Assuming that the modular elements last 50 years – the building lifetime set down in EU legislation (EPBD, 2024) – a figure of 15% for prefabricated sections will be used.

iv) Aiding reuse of materials at End-of-Life.

Relatively few, if any, buildings with a live BIM will reach end-of-life before 2050, so no value is placed on savings during the projection period.

However, commercial buildings will probably be refurbished every 20 years or so. As noted above, a small proportion of these will have relevant data from the BIM imported into a Building Management System: this should save an unknown amount of emissions as a result of a smoother refurb retaining more of the original fabric. Estimating the value of this is highly imprecise, but if 10% of commercial buildings have relevant details passed from BIM into a Building Management System, 5% are refurbished each year and 5% of materials are saved by the use of the data, this amounts to 0.025% ($^{1}/_{4000}{}^{th}$) of the annual materials (and embodied emissions). This is *de minimus* and uncertain: it will be ignored.

It is also necessary to estimate what proportion of the EU material spend results from architects and constructors using BIM: this can be used as the basis for savings.

Interviewee data would suggest that substantially all commercial and public buildings in northern Europe are built with BIM, although this is far from the case in the remainder of Europe. Penetration rates for BIM are unavailable: the only figures are from voluntary surveys where the responders are self-selecting, likely to be more interested in progress and development and therefore liable to overstate the true numbers. Data from interviewees place the users of BIM as a small proportion in parts of Europe, e.g. a Belgian software house suggested its target market was about 100 companies out of 90,000 registered construction businesses, and a Spanish interviewee stated that only special buildings, such as the new Real Madrid stadium, were built with BIM. The requirement by some governments that an as-built BIM is produced for new buildings does not mean that it is designed and constructed using BIM, simply that one has to be produced and submitted: this is apparently often done after the build. It is possible to design and construct buildings to meet reducing LCA limits with 3D CAD as well as BIM, and 3D CAD is used throughout Europe where BIM is not. This implies that there will be a residual body of architects and constructors who never adopt BIM, probably varying broadly by the degree of overall adoption in any country. Figure 1 shows the geographical split of countries according to the historic level of government support for BIM (Charef et al., 2019): this approximates to the relative degrees of adoption of BIM by industry. For the projections, countries were split into three groups of different BIM penetration levels based on literature and information generated through the interview process.

3.2.1 Assumptions

1) Currently, all commercial and public buildings in northern Europe built with BIM in Belgium, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Luxembourg, Netherlands, Norway, Sweden, UK (referred to as Group 1 countries). In these countries apartment blocks over 6 stories built with BIM also, and that this comprises 10% of residential building. (This is based on the observation that many counties with low BIM penetration rates have many apartment blocks of about 6 stories (e.g. Portugal), which must have been built with CAD, together with an UK housebuilder interviewee whose company built apartment blocks with CAD. The 10% is purely an estimate). The proportion of residential properties built with BIM increases by 3%pa until 2028 (when the EU LCA regulations take effect) and by 10%pa thereafter, up to a maximum penetration of 70%.

2) Currently, 50% of commercial and public buildings in northern Europe built with BIM in Austria, Italy, Lithuania (Group 2 countries). No residential penetration of BIM. The proportion of all properties built with BIM increases by 3%pa until 2028, then 8%pa for commercial and public properties and 10%pa for residential, up to maximum penetration rates of 80%, 80% and 50% respectively.

3) Currently, 10% of commercial and public buildings in northern Europe built with BIM in Bulgaria, Croatia, Cyprus, Czechia, Greece, Hungary, Iceland, Poland, Romania, Slovakia, Slovenia, Portugal, Spain (Group 3 countries). No residential penetration of BIM. The proportion of all properties built with BIM increases by 3%pa until 2028, then 5%pa for all properties up to maximum penetration rates of 60% for commercial and public and 40% and residential.

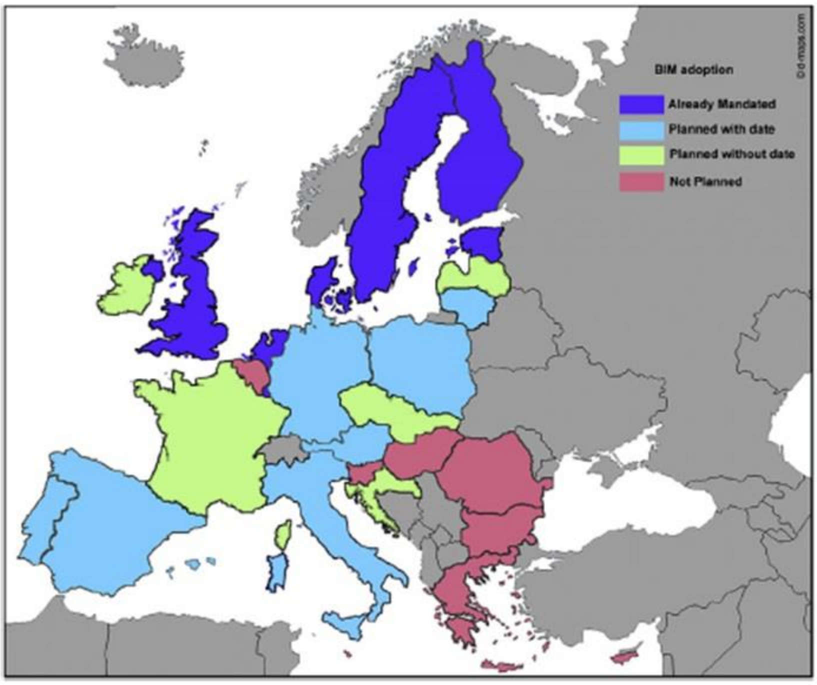


Figure 1: State of adoption of BIM across Europe, May 2017. Source: (Charef et al., 2019)

Figure 1: Charef's classification of European countries based on government mandation levels.

Table 1: Full set of assumptions for BIM rollout, stimulated by the requirements of EPDB 2024

		Commercial	Public	Residential	
Group 1 countries					
Starting BIM Penetration	Assumed	100%	100%	10%	
Increasing BIM Penetration pa	Assumed			3%	from 2024
				10%	from 2028
Maximum BIM Penetration	Assumed			70%	
		Commercial	Public	Residential	
Group 2 countries					
Starting BIM Penetration	Assumed	50%	50%	0	
Increasing BIM Penetration pa	Assumed	3%	3%	3%	from 2024
		8%	8%	10%	from 2028
Maximum BIM Penetration	Assumed	80%	80%	50%	
		Commercial	Public	Residential	
Group 3 countries					
Starting BIM Penetration	Assumed	10%	10%	0	
Increasing BIM Penetration pa	Assumed	3%	3%	3%	From 2024
		5%	5%	5%	From 2028
Maximum BIM Penetration	Assumed	60%	60%	40%	
Off-site Prefabrication					
Starting penetration – all groups	Assumed	1%	1%	0.5%	
Group 1 - Increasing Prefabrication penetration pa	Assumed	1%	1%	0.5%	From 2024
Groups 2 & 3 - Increasing Prefabrication penetration pa	Assumed	0.5%	0.5%	0.5%	From 2024

Material savings attributable to BIM will therefore be the base case tonnages multiplied by the increased BIM penetration (to create the tonnage subject to new BIM software) and multiplied by the BIM savings in the relevant category.

3.3 Results

The first point to note is that in the (provisional) SSP2 material demand figures, the residential demand is 94% of the total, so assumptions made about residential impacts are far more influential than those for non-residential building.

The analysis shows that savings purely from the adoption of BIM run at 3.7% of total materials by 2050 (7.9Mtpa out of 215.6Mtpa). Increased prefabrication penetration – enabled by BIM, and which only runs at 0.5% increase per year in each country Group - saves a further 1.9% (4.1Mtpa). The year-by-year analysis is given in Appendix 2.

In total this is a 5.6% (12.1Mtpa out of 215.6Mtpa) combined saving in materials.

Any change in the percentage savings (assumed at 7%) from the adoption of BIM feeds proportionately through into the final result. So an uncertainty range of 4%-9% would lead to savings of 2.1% to 4.8% of total materials by 2050 (4.5 - 10.2Mtpa). Similarly, any change in the percentage savings (assumed at 15%) from increasing adoption of BIM-enabled prefabrication feeds proportionately through into the final result. An uncertainty range of 10%-20% would lead to savings of 1.3% to 2.5% of total materials by 2050 (2.7 – 5.5Mtpa).

3.4 Conclusion

The materials savings alone from implementing BIM are relatively modest, projected at 5.6% or 12.1Mtpa out of 215.6Mtpa. However, the labour savings from better clash detection and better control throughout the design and construction process should, according to literature and logic, be considerably in excess of this (e.g. Gharaibeh et al., 2024).

4. Life Cycle Analysis legislation following EPBD 2024, enabled by digital design systems

4.1 Introduction and Literature

Theoretically, it is possible to calculate embodied and projected operational emissions for buildings at the design stage. Use of digital design tools (BIM or 3D CAD), combined with external databases giving the embodied emissions for each item or unit of material, and makes it possible to iterate designs to achieve a minimum total emissions value, subject to a total cost constraint. This process is a form of Life-Cycle Analysis (LCA), and the EU has mandated that LCA takes place across Europe for all new buildings by 1st January 2030. It is significant for both the CE (in terms of reduced material use and reduced embodied emissions) and Net Zero (reduced embodied emissions and reduced operational emissions).

A number of elements have led up to this legislation. Firstly, buildings (design, construction, maintenance, and operation) are responsible for about 41% of EU GHG emissions (Ramboll, 2023), so controlling these emissions more tightly is a key to reducing climate change. Secondly, thermal efficiency regulations have been tightened successively so that embodied emissions are many times the annual emissions of a new building (Ness & Xing, 2017), and have hitherto been unregulated. Thirdly, politicians have recognised that embodied emissions primarily happen now, which is a time of climate crisis, rather than over the life of the building (ibid). Finally, iterative processes to reduce total emissions do not readily occur: we established during interviews that this does not happen for the vast majority of buildings at present.

The legislation has been enacted through EPBD (2024) and mandates member states to introduce LCA legislation. It allows them to set their own emission limits for different type of buildings and their own targets for reduction in these limits over time, to cater for different climates, building methodologies and stages of digitalisation of design and construction.

In the last five years legislation limiting embodied emissions in buildings has been passed in four states and well before 2030 these limits will have legal force: buildings exceeding the limit will be denied occupation permits, creating incentives to design and construct to reduce embodied emissions. These states are Denmark, France, Sweden and Netherlands: limit levels set mean that material changes will not be forced until limits reduce in 2025-2030. However, the ideas are already adopted by environmentally conscious firms so benefits may come earlier. For example, a vertically integrated Dutch constructor currently builds to the Dutch LCA limit level less 30%-60%, depending on the building type. Additionally, an architect working for the Danish architects association stating that he believed 6kgCO2/m^2/yr is achievable against a current target of 12kgCO2/m^2/yr. Limited literature suggests 25.0% savings (Heydari & Heravi, 2023) without introducing legal emission limits: the cost of fuel was key to payback calculations, though none of the additional investments in the revised buildings were economically worthwhile once time value of money was included. These examples all suggest that use of new materials and limits on the LCA totals could reduce the total emissions significantly, though at some upfront cost.

4.1.1 General Assumptions

Several factors will impact the effectiveness of emissions reduction through LCA legislation in different parts of Europe.

1) The current level of use of BIM and 3D CAD. Using the same country groups as for the BIM penetration analysis above, in the Group 2 and 3 countries there will be a lesser BIM penetration. However, the remainder of the buildings will be designed using 3D CAD, and in principle broadly the same technical results are achievable on embodied emissions, although with more complexity linking to external databases. Projected operational emissions will be possibly not as accurate as the level of detail on the building geometry and composition available to input into the projection will not be as great as with BIM.

For the purpose of this analysis it is assumed that there is no difference on average between accuracy of calculations arising from BIM or 3D CAD designs, and that calculation inaccuracies from 3D CAD will be normally distributed around the ‘correct’ figure.

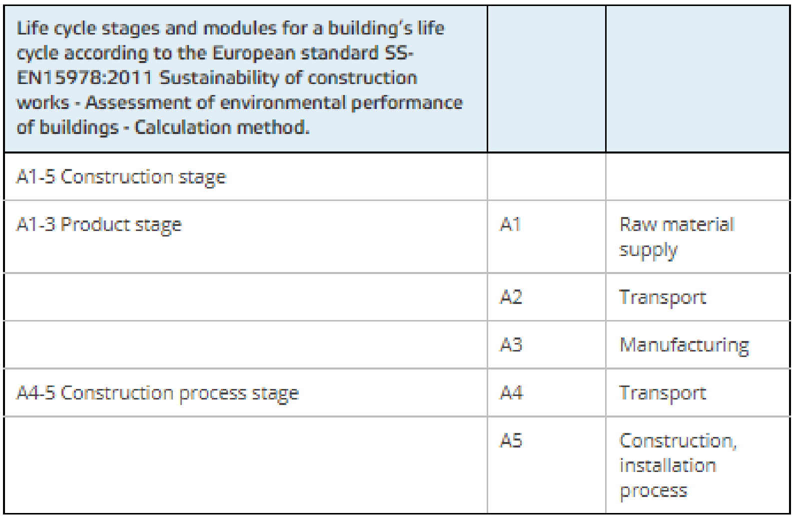
2) Interviewees were generally unimpressed with the knowledge and abilities of municipal departments to analyse and check BIM models. For LCA constraints to work, is it assumed that education and training of municipal planning staff is stepped up and reaches a level where it is an effective control on accuracy of the calculations and that the calculations reflect the as-built building.

3) To achieve material efficiencies it is necessary to use different and often newer materials. It is assumed that building codes across Europe adjust more rapidly than hitherto to enable enough low-carbon building material availability that this is not a constraint on ambitions. In particular, that there is enough wood to make cross-laminated timber and glulam beam in the quantities demanded to replace concrete and steel beams. The validity of this assumption is perhaps unclear at present.

4) EPBD 2024 allows each member state to set its own targets, but all must have a ratchet downwards on the target kgCO2e/m^2/yr number. It is assumed that Group 1 countries are more ambitious than Groups 2 & 3. Group 1 countries target profile will be set according to the published intentions of Sweden, Denmark, France and the Netherlands. Groups 2 & 3 targets will be stepped down from these both in size and timing.

5) The legislation is intended to cover embodied emissions in all stages of the material’s extraction and fabrication, covering the five modules in construction set out below (A1-A5, according to the European standard SS-EN15978:2011). The inclusion of A5 (emissions in the construction and installation processes) in particular encourages the use of offsite prefabrication, which is heavily dependent on BIM usage.

Table 2: Life Cycle stages of a building



Life cycle stages and modules for a building’s life cycle according to the European standard SS-EN15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.		
A1-5 Construction stage		
A1-3 Product stage	A1	Raw material supply
	A2	Transport
	A3	Manufacturing
A4-5 Construction process stage	A4	Transport
	A5	Construction, installation process

4.2 Methodology and methodological assumptions and for the LCA rollout projections of cuts in emissions

4.2.1 The published statements of intent from Sweden, Denmark, France and the Netherlands were tabulated and turned into projections.

Table 3: The Danish, Dutch, Swedish and French published intentions

Published statements of intent:												
Denmark	2023 12.0 kg/m^2/yr limit			2025 10.5 limit (-12.5%)			2027 9.0 limit (-25%)			2029 7.5 limit (-37.5%)		
Netherlands	2018 €1.0/m^2/yr limit			2021 limit €0.8 (-20%)			2027 est limit €0.65 (-35%)			2030 est limit €0.5 (-50%)		
Sweden	1.7.25	75th percentile, enforced from 2027				2030	40% down on 2027 limits			2043 80% down on 2027 limits		
France:				2022-24	2025-27	2028-30	2031-->		2025-27	2028-30	2031-->	
Industrial and terraced housing:			kg/m^2	640	530	475	415		-17.2%	-25.8%	-35.2%	
Flats:			kg/m^2	740	650	580	490		-12.2%	-21.6%	-33.8%	

Note that these limits are all given in different units. Denmark's units are kg/m^2/yr: the French multiply this by 50 to give a lifetime figure. Sweden has only percentage targets at present, until the regulators understand the range of outcomes currently being achieved. The Dutch MPG figure includes various other measures (such as material toxicity) which are turned into a financial measure, €/m^2/yr. To combine these into a single measure, they have been turned into percentages (Table 4). This represents the target percentage fall in emissions.

Table 4: The tabulated intentions. Percentages represent limit declines from previous levels, which are both different absolute levels and differently expressed in each member states units

Turning this into grid form, the LCA limits fall as follows:											
		2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Denmark			-12.5%	-12.5%	-25.0%	-25.0%	-37.5%	-37.5%	-37.5%	-37.5%	-37.5%
Netherlands		-20.0%	-20.0%	-20.0%	-35.0%	-35.0%	-35.0%	-50.0%	-50.0%	-50.0%	-50.0%
Sweden			-23.5%	-23.5%	-23.5%	-23.5%	-23.5%	-40.0%	-40.0%	-40.0%	-40.0%
France			-12.2%	-12.2%	-12.2%	-21.6%	-21.6%	-21.6%	-33.8%	-33.8%	-33.8%

This does not mean that overall emissions will fall in line with reductions in the limits. Only a proportion of building will be overlimit: some reduction in emissions is also likely in the bulk of the buildings that fall below the new limit, as illustrated in Figure 2.

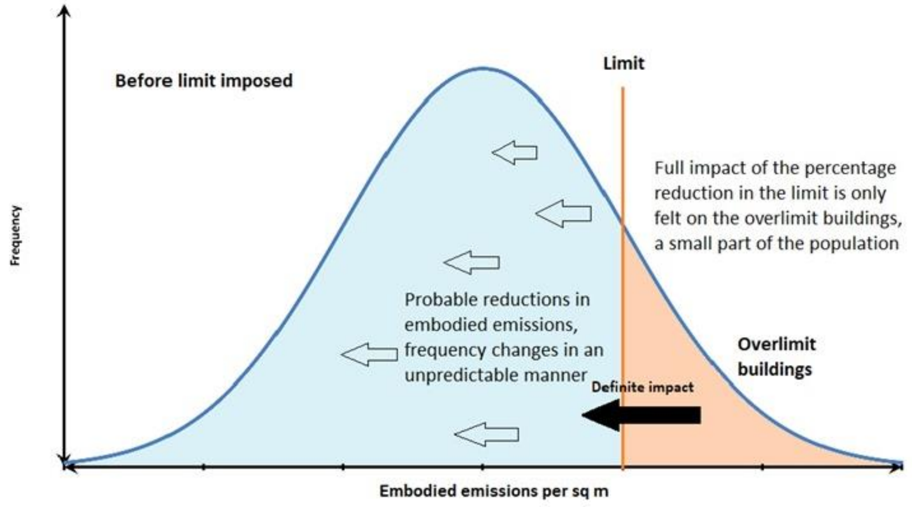


Figure 2: Impact of an initial limit on emissions reduction on the frequency distribution of emissions per sq m.

Note that the reality is that the frequency distribution of emissions is not known: it may not be a normal distribution as illustrated.

The frequency distribution of the new building population following the imposition of a limit will no longer resemble a normal distribution, as shown in Figure 3.

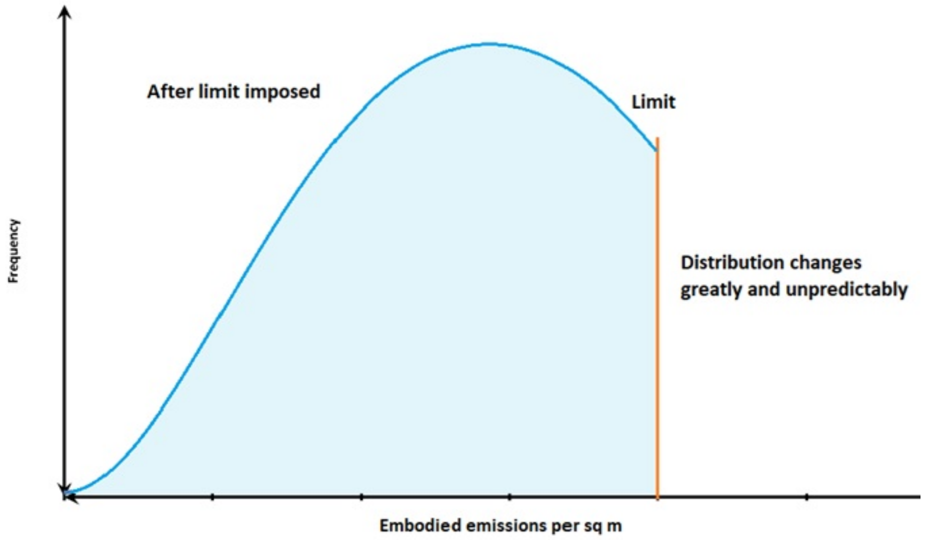


Figure 3: Revised frequency distribution for emissions per sq m in the years following the imposition of a limit

In practical terms, this implies that the imposition of the first limit is likely to have a smaller impact on total emissions than subsequent limit reductions, as for later reductions, a greater proportion of the overall new building stock will be close to the existing limit prior to the limit reduction.

4.2.2 This leads to the following assumptions:

i) When the first limit is introduced, then if the headline reduction is x then the overall saving is 50% of x, made up of larger savings in overlimit buildings and small savings in the bulk of new buildings which will already be underlimit.

ii) When the limit is reduced for the second time, if the headline reduction is y then the overall saving is x plus an additional 66% of y.

iii) When the limit is reduced for the third time, if the headline reduction is z then the overall saving is x plus y plus an additional 75% of z.

4.2.3 Derivation of a savings profile

Firstly, the individual percentages in Table 3 for each of the 4 countries are multiplied by the assumed effectiveness factors (50%, 66% & 75%) dependent of whether the Table 4 entry represents a first, second or third reduction in the limit (Table 5). The result is a table in similar form to Table 4 but with reduced percentage reductions.

Table 5: Table 4 numbers reduced by the effectiveness factors

Applying the effectiveness factors of 50%, 66% and 75% reflecting the number of times the limit has been reduced													
		2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Denmark			-6.3%	-6.3%	-20.8%	-20.8%	-34.4%	-34.4%	-34.4%	-34.4%	-34.4%	-34.4%	-34.4%
Netherlands		-10.0%	-10.0%	-10.0%	-10.0%	-29.9%	-29.9%	-29.9%	-46.3%	-46.3%	-46.3%	-46.3%	-46.3%
Sweden			-12%	-12%	-12%	-12%	-12%	-12%	-30.4%	-30.4%	-30.4%	-30.4%	-30.4%
France		-5.0%	-5.0%	-8.6%	-8.6%	-8.6%	-18.4%	-18.4%	-18.4%	-30.7%	-30.7%	-30.7%	-30.7%

Secondly, the revised table percentages are weighted by the relative sizes of the construction sectors for each of the countries from ACE (2020), and then the weighted percentages are summed (Table 7).

Table 6: Table 5 numbers weighted by the relative construction sector sizes

Apply weights:													
	Weight[2]	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Denmark	0.102	0.000	-0.006	-0.006	-0.021	-0.021	-0.035	-0.035	-0.035	-0.035	-0.035	-0.035	-0.035
Netherlands	0.264	-0.026	-0.026	-0.026	-0.026	-0.079	-0.079	-0.079	-0.122	-0.122	-0.122	-0.122	-0.122
Sweden	0.156	0.000	-0.018	-0.018	-0.018	-0.018	-0.018	-0.018	-0.047	-0.047	-0.047	-0.047	-0.047
France	0.478	-0.024	-0.024	-0.041	-0.041	-0.041	-0.088	-0.088	-0.088	-0.147	-0.147	-0.147	-0.147
	1.000	-5.0%	-7.5%	-9.2%	-10.7%	-15.9%	-22.0%	-22.0%	-29.2%	-35.1%	-35.1%	-35.1%	-35.1%

The last line of this table then gives the percentage reduction applied to SSP2 forecasts of materials used starting from date of adoption (Table 7). The derived percentage in Year 12 (35.1%) is used for all subsequent years to 2050. A maximum saving across the entire building spectrum of 35.1% appears plausible against the results in (Heydari & Heravi, 2023) cited above. The same profile is applied to each group of countries.

Table 7: Profile of savings from the introduction of the LCA regulations

Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**
-5.0%	-7.5%	-9.2%	-10.7%	-15.9%	-22.0%	-22.0%	-29.2%	-35.1%	-35.1%	-35.1%	-35.1%

Application to the different country groupings

i) Country group 1 includes the 4 countries with existing legislation: these countries have already started and the factors in Table 4 are used without a time lag. All other countries in Group 1 are assumed to start from 2030 except for the UK (not bound by EPBD) and is assumed to start from 2033.

ii) Each member state is allowed to set its own targets, and they must always ratchet downwards. Country Groups 2 and 3 have lower levels of sophisticated digitalisation (less BIM and less of a culture of digitalised controls) and it is assumed that they set more modest goals than those in Group 1: 10% cut from 2030, 20% from 2033 and 30% from 2037, savings to start from 2031.

iii) Each country has its contribution to savings based on its own forecast material use (projected figures under SSP2 scenario from Alessio Mastrucci, CircEULar/IIASA, December 2024), and aggregated into the country groups.

4.3 Results

As with the savings due to BIM and prefabrication (Study 2 above), the (provisional) SSP2 material demand figures show residential demand as 94% of the total, so assumptions made about residential impacts are far more influential than those for non-residential building. This being the case, together with the assumptions for residential and non-residential buildings being identical, all buildings have been combined in this analysis.

The projections show that savings from the planned adoption and roll out of digitally-enabled LCA legislation are 32.2% of total emissions by 2050. If materials and techniques remained unchanged, this is equivalent to 69.4Mt out of 215.6Mt, though clearly the intention of the legislation is to enable the use of materials with lower embodied energies and greater insulation properties, implying that the tonnage will fall by a lesser figure to achieve the equivalent benefit. This saving is over 8x the savings from BIM implementation alone. It covers both CE and NZ benefits, which are conflated together in the national target figures and cannot be separated. The year-by-year analysis is given in Appendix 3.

Note that compliance with LCA legislation is possible using 3D CAD as well as BIM, though it requires interfacing with more databases. So digitalisation through CAD makes it theoretically possible to achieve the larger level of savings from LCA legislation without achieving the additional savings (especially from clash detection, accurate Bills of Material production and offsite prefabrication) due to BIM implementation.

The key point to emphasise is that digitalisation will not inherently deliver significant savings: it needs to be implemented in such a way as to motivate the users to deliver its potential. The LCA legislation looks likely to do this.

The Group 1 countries (those with more advanced construction digitalisation) initially contribute 100% of the savings: as the rollout increases this falls to 67% by 2050, with 61% of the materials demand coming from Group 1 countries. The difference between materials usage and projected savings is due to assumptions of lower savings targets in Group 2 & 3 countries, which in practice could be amended by 2050.

The analysis demonstrates the key difference a thorough and well supported implementation (through training and political support) could make. Additionally, no attempt has been made to quantify benefits from the inclusion of refurbishments and extensions of existing non-BIM buildings in the LCA regime, which is highly likely to be implemented if the regime governing new building is successful.

4.4 Conclusion

The projected emission savings from the planned adoption and roll out of digitally-enabled LCA legislation are equivalent to 32.2% of total materials by 2050 (69.4Mt out of 215.6Mt), over 8x the projected savings from BIM implementation alone. In reality the use of lower embodied emission materials will lessen the tonnage reduction to achieve an equivalent benefit.

While both projections (Study 2: BIM implementation and Study 3: LCA enactment and rollout) are made using multiple assumptions, it is possible to make three conclusions:

a) Digitalisation of design and construction offers a major contribution to the CE and NZ;

b) Savings from LCA enactment and rollout dwarf those from BIM implementation alone;

c) Simply giving making digital tools available will not deliver particular results unless the users are trained and motivated to deliver those results. Today BIM is used by many architects and constructors, but not to save materials or embodied and operational energy.

Appendices

Appendix 1

Derivation of European Aluminium Demand through to 2050

Demand is a total of all the use classes: the expectation is that aluminium use in EVs will increase in terms of kg per vehicle, and that the number of EVs sold will increase also. Vehicles currently use 30%-35% of all aluminium in Europe.

Variables which potentially impact the final demand for aluminium are:

a) The expectation of increased content per vehicle, from 205kg in 2022 to 256kg in 2030[2]

b) The mix of EVs sold. Hitherto, higher specification EVs have been overrepresented in EVs sold, compared to ICE vehicle sales. Higher spec EVs are heavier and contain more aluminium[1].

c) Penetration of EV sales is not going as fast as planned. Limited investment in infrastructure, particularly to enable home charging in cities and easy charging in rural areas, has deterred buyers[3]. Penetration of EV sales, currently at 22%-25%[2,4], is flattening off[5]. Sales incentives have been reduced, notably in Germany, where they were withdrawn in late 2023, resulting in a sales fall of 29% in 2024[2].

d) Life expectancy of EVs is looking better than expected (Personal communication, Harald Desing, Futoram project), suggesting an overall reduction in volumes sold and an increase in the time lag before scrapping.

e) Life expectancy of EV batteries is looking much better than expected (Personal communication, Harald Desing, Futoram project).

f) In April 2023 Ducker forecast CAGR in aluminium content per vehicle of 3.8% between 2022-2026 and 1.9% between 2026-2030. They believe that their projections of content per vehicle are more accurate than sales projections for the same periods[1].

g) The forecast increase in solar and wind energy generation (tripling and doubling are EU targets by 2030). This will have implications for aluminium demand for cables and panel frames. Demand for Cables and Electrical: Other Use Categories currently run at about a quarter of vehicle demand.

h) Ducker's sales forecasts to 2030[1] have been used. The level then pertaining (16.5m units) is assumed to continue to 2050, particularly in view of the potential lifetime extensions referred to above. I have not seen forecasts for total aluminium demand growth beyond 2030.

It is clear from the above list of variables that there are a vast range of plausible projections which could be made. The two main factors used in these projections are (i) increased unit sales forecasts to 2030 (an additional 3.65m units per year at 0.205t/unit, or 750kt of Al) and (ii) increased penetration of EVs (an extra 50kg of Al per unit, totalling 560kt pa when penetration has risen from 22% to 90% by 2040. [16.5m x (.90 - .22) x 0.05t]).

Other factors specifically affecting the amount of wrought aluminium which LIBS could sort are:

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[2] Aluminium content in passenger vehicles, Ducker Research & Consulting, April 2023

[3] Financial Times, 29.11.2024, 'Who can convince more customers to buy EVs?'

[4] eea.europa.eu/en/analysis/indicators/new-registrations-of-electric-vehicles and roadgenius.com/cars/ev/statistics/sales-by-country/

[5] Financial Times, 2.10.2024, 'European carmakers brace for deeper and longer downturn'

a) How much of the aluminium content in an EV is removed by hand at end-of-life and how much is shredded. The more that is removed, the less there is left for LIBS to sort. This partly depends on how much design for disassembly there is. We have assumed 50% of the weight of wrought is removed.

b) How much of the aluminium placed on the market eventually becomes scrap arisings. We have limited this to 58% of the aluminium placed on the market in that year. This is similar to current rates, which have improved sharply in recent years[6].

On the basis of the considerations (a)-(g), the following assumptions have been used:

	2025	**2026-2030** **CAGR**	**2030-2040** **CAGR**	**2040-2050** **CAGR**
Buildings and Construction	2700	1%	1%	1%
Auto & Light truck	3500	Built organically from AL per vehicle and penetration rates	Built organically from AL per vehicle and penetration rates	Built organically from AL per vehicle and penetration rates
Aerospace	150	1%	1%	1%
Truck/bus/rail/marine	1600	1%	1%	1%
Packaging: cans	1200			
Packaging: other (foil)	1000			
Machinery & Equipment	700			
Electrical: cables	500	5%	5%	5%
Electrical: other incl solar	500	5%	5%	2%
Consumer durables	650			
Other (excl: destructive uses)	200			
Destructive uses	300			
Total	13000			

The assumptions about electrical cables and solar panels may seem aggressive, but with a 40 year life time they do not impact the scrap arisings during the period to 2050, so they do not affect the impact of LIBS.

Scrap arisings have been further adjusted to reflect a decline in scrapping of ICEs (implying less cast shred) 15 years from date of sale.

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[6] Derived from https://alucycle.international-aluminium.org/public-access/public-regiona-cycle/

Projections for the tonnage of wrought aluminium saved from downcycling by LIBS to 2050

1) With 15 LIBS lines per annum rolled out after an initial uptake period to 2030

			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Volume of mixed old scrap to treat through LIBS		kt	4636	4917	5212	5523	5848	6191	6550	6928	7324	7610	7710	7811	7916	8023	8133	8246	8316	8389	8463	8540	8619	8700	8784	8870	8959	9050
Each LIBS line can treat	20000	tpa																										
Number of lines required			232	246	261	276	292	310	328	346	366	381	385	391	396	401	407	412	416	419	423	427	431	435	439	444	448	453
Annual increase in Number of Lines installed				5	10	10	10	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Total Number of Lines installed			5	10	20	30	40	55	70	85	100	115	130	145	160	175	190	205	220	235	250	265	280	295	310	325	340	355
Tonnage treated		ktpa	100	200	400	600	800	1,100	1,400	1,700	2,000	2,300	2,600	2,900	3,200	3,500	3,800	4,100	4,400	4,700	5,000	5,300	5,600	5,900	6,200	6,500	6,800	7,100
Separation efficiency			90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Tonnage recovered that was previously downcycled wrought		**ktpa**	**24**	**67**	**134**	**201**	**269**	**370**	**471**	**573**	**708**	**822**	**939**	**1,057**	**1,178**	**1,301**	**1,426**	**1,553**	**1,696**	**1,843**	**1,993**	**2,147**	**2,304**	**2,464**	**2,628**	**2,794**	**2,942**	**3,091**

The saving builds to 3.1Mtpa by 2030

2) With 20 LIBS lines per annum rolled out after an initial uptake period to 2030

			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Volume of mixed old scrap to treat through LIBS		kt	4636	4917	5212	5523	5848	6191	6550	6928	7324	7610	7710	7811	7916	8023	8133	8246	8316	8389	8463	8540	8619	8700	8784	8870	8959	9050
Each LIBS line can treat	20000	tpa																										
Number of lines required			232	246	261	276	292	310	328	346	366	381	385	391	396	401	407	412	416	419	423	427	431	435	439	444	448	453
Annual increase in Number of Lines installed				5	10	10	10	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Total Number of Lines installed			5	10	20	30	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460
Tonnage treated		ktpa	100	200	400	600	800	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,000	4,400	4,800	5,200	5,600	6,000	6,400	6,800	7,200	7,600	8,000	8,400	8,800	9,200
Separation efficiency			90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Tonnage recovered that was previously downcycled wrought		**ktpa**	**24**	**67**	**134**	**201**	**269**	**403**	**539**	**674**	**849**	**1,001**	**1,155**	**1,313**	**1,473**	**1,636**	**1,801**	**1,970**	**2,159**	**2,353**	**2,551**	**2,754**	**2,962**	**3,174**	**3,391**	**3,611**	**3,808**	**4,006**

The saving builds to 4.0Mtpa by 2030

Appendix 2

Projections for material savings due to the increased penetration of (a) BIM and (b) offsite prefabrication

Residential buildings

The figures for both Residential and non-Residential buildings are based on a 7% savings from BIM implementation alone as set out in 3.2.i

		2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Total Demand	Mt	204.68	201.46	198.23	195.01	191.79	188.57	189.28	189.98	190.69	191.39	192.10	193.22	194.35	195.47	196.60	197.72	198.82	199.91	201.00	202.10	203.19	204.17	205.15	206.12	207.10	208.08
Savings due to:																											
BIM penetration	Mt	0.00	0.42	0.83	1.98	3.10	4.19	5.35	6.43	6.97	7.15	7.18	7.22	7.27	7.31	7.35	7.40	7.44	7.48	7.52	7.56	7.61	7.64	7.68	7.72	7.75	7.79
Prefabrication	Mt	0.00	0.15	0.30	0.44	0.58	0.71	0.85	1.00	1.14	1.29	1.44	1.59	1.75	1.91	2.06	2.22	2.39	2.55	2.71	2.88	3.05	3.22	3.38	3.56	3.73	3.90
		0.00	0.57	1.13	2.42	3.68	4.90	6.20	7.43	8.12	8.44	8.62	8.82	9.02	9.22	9.42	9.62	9.82	10.03	10.24	10.44	10.65	10.86	11.06	11.27	11.48	11.69
% savings																											
BIM penetration			0.2%	0.4%	1.0%	1.6%	2.2%	2.8%	3.4%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%
Prefabrication			0.1%	0.2%	0.2%	0.3%	0.4%	0.5%	0.5%	0.6%	0.7%	0.8%	0.8%	0.9%	1.0%	1.1%	1.1%	1.2%	1.3%	1.4%	1.4%	1.5%	1.6%	1.7%	1.7%	1.8%	1.9%
Total			0.3%	0.6%	1.2%	1.9%	2.6%	3.3%	3.9%	4.3%	4.4%	4.5%	4.6%	4.6%	4.7%	4.8%	4.9%	4.9%	5.0%	5.1%	5.2%	5.2%	5.3%	5.4%	5.5%	5.5%	5.6%

Non-Residential (Public and Commercial) Building

		2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Total Demand	Mt	21.26	20.87	20.47	20.07	19.68	19.28	18.20	17.13	16.05	14.98	13.90	13.26	12.63	11.99	11.35	10.71	10.31	9.91	9.50	9.10	8.70	8.45	8.21	7.96	7.72	7.48
Savings due to:																											
BIM penetration	Mt	0.00	0.03	0.06	0.11	0.16	0.20	0.22	0.24	0.26	0.26	0.27	0.28	0.28	0.28	0.26	0.24	0.23	0.22	0.21	0.20	0.18	0.18	0.17	0.16	0.16	0.15
Prefabrication	Mt	0.00	0.02	0.04	0.06	0.08	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20	0.20	0.21
		0.00	0.05	0.10	0.17	0.24	0.30	0.33	0.36	0.39	0.40	0.41	0.43	0.44	0.44	0.43	0.41	0.41	0.40	0.39	0.38	0.37	0.37	0.37	0.37	0.36	0.36
% savings																											
BIM penetration		0.0%	0.2%	0.3%	0.6%	0.8%	1.0%	1.2%	1.4%	1.6%	1.8%	1.9%	2.1%	2.2%	2.3%	2.3%	2.3%	2.2%	2.2%	2.2%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.0%
Prefabrication		0.0%	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%	1.1%	1.3%	1.4%	1.5%	1.6%	1.7%	1.8%	1.9%	2.1%	2.2%	2.3%	2.4%	2.5%	2.6%	2.8%
Total		0.0%	0.2%	0.5%	0.8%	1.2%	1.5%	1.8%	2.1%	2.4%	2.7%	3.0%	3.2%	3.5%	3.7%	3.8%	3.9%	3.9%	4.0%	4.1%	4.2%	4.3%	4.4%	4.5%	4.6%	4.7%	4.8%

Appendix 3

Projected savings from a rollout of LCA legislation with a well-managed and supported implementation

Group 1 countries Incoporate in model from 2030 - assume regs bite from 1.1.30 **The % is a % of total materials saved by the LCA regs** **Group 1 countries are split into 3 sub-groups for timing of impact: 4 pioneer countries, the UK, and the others**

		2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Belgium	Ireland																											
Estonia	Latvia																											
Finland	Luxembourg																											
Germany	Norway																											
	Mass, Mt	50.45	50.45	48.96	47.47	45.97	44.48	42.98	42.93	42.87	42.82	42.76	42.71	42.83	42.95	43.07	43.19	43.31	43.49	43.66	43.84	44.02	44.20	44.28	44.37	44.46	44.54	44.63
	Saving %							-5.0%	-7.5%	-9.2%	-10.7%	-15.9%	-22.0%	-22.0%	-29.2%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%
	Saving, Mt	0.00	0.00	0.00	0.00	0.00	0.00	-2.16	-3.22	-3.95	-4.58	-6.82	-9.41	-9.43	-12.56	-15.14	-15.18	-15.22	-15.28	-15.35	-15.41	-15.47	-15.53	-15.56	-15.59	-15.62	-15.66	-15.69
UK	Mass, Mt	29.19	29.19	29.49	29.78	30.08	30.38	30.68	30.90	31.11	31.33	31.55	31.77	32.10	32.43	32.75	33.08	33.41	33.81	34.21	34.60	35.00	35.40	35.77	36.14	36.50	36.87	37.24
	Saving %										-5.0%	-7.5%	-9.2%	-10.7%	-15.9%	-22.0%	-22.0%	-29.2%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%
	Saving, Mt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.57	-2.37	-2.93	-3.43	-5.17	-7.21	-7.29	-9.77	-11.88	-12.02	-12.16	-12.30	-12.44	-12.57	-12.70	-12.83	-12.96	-13.09
Denmark																												
Netherlands																												
Sweden																												
France	Mass, Mt	47.60	47.60	47.70	47.81	47.92	48.03	48.13	48.32	48.51	48.70	48.88	49.07	49.23	49.38	49.54	49.70	49.85	49.89	49.93	49.97	50.01	50.06	50.16	50.27	50.37	50.48	50.58
	Saving %	-5.0%	-7.5%	-9.2%	-10.7%	-15.9%	-22.0%	-22.0%	-29.2%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%
	Saving, Mt	-2.39	-3.57	-4.39	-5.11	-7.64	-10.58	-10.60	-14.13	-17.05	-17.11	-17.18	-17.25	-17.30	-17.36	-17.41	-17.47	-17.52	-17.54	-17.55	-17.56	-17.58	-17.59	-17.63	-17.67	-17.70	-17.74	-17.78
Group 1 material demand		127.24	127.24	126.15	125.06	123.97	122.88	121.80	122.15	122.50	122.85	123.20	123.55	124.15	124.76	125.36	125.97	126.57	127.19	127.80	128.42	129.04	129.65	130.21	130.77	131.33	131.89	132.45
Total Group 1 saving, Mt		-2.39	-3.57	-4.39	-5.11	-7.64	-10.58	-12.76	-17.35	-21.00	-23.27	-26.36	-29.58	-30.17	-35.09	-39.76	-39.93	-42.51	-44.70	-44.92	-45.14	-45.35	-45.57	-45.76	-45.96	-46.16	-46.36	-46.55
Total Group 1 impact %		-1.9%	-2.8%	-3.5%	-4.1%	-6.2%	-8.6%	-10.5%	-14.2%	-17.1%	-18.9%	-21.4%	-23.9%	-24.3%	-28.1%	-31.7%	-31.7%	-33.6%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%	-35.1%

Group 2 countries Assume -10% from 2030 -20% from 2033 -30% from 2037

		2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Austria																												
Italy																												
Lithunania																												
Group 2 material demand	Mt		21.28	21.25	21.21	21.18	21.15	21.12	21.25	21.38	21.50	21.63	21.76	21.92	22.07	22.23	22.38	22.53	22.65	22.76	22.87	22.98	23.10	23.14	23.19	23.23	23.28	23.32
	Saving %								-5.0%	-5.0%	-5.0%	-16.6%	-16.6%	-16.6%	-16.6%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%
Total Group 2 impact Mt									-1.06	-1.07	-1.08	-3.59	-3.61	-3.64	-3.66	-6.11	-6.15	-6.20	-6.23	-6.26	-6.29	-6.32	-6.35	-6.36	-6.38	-6.39	-6.40	-6.41

Group 3 countries Assume -10% from 2030 -20% from 2037 -30% from 2042

Bulgaria Greece Romania Spain
Croatia Hungary Slovakia
Cyprus Iceland Slovenia
Czechia Poland Portugal

		2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Group 3 material demand	Mt		77.42	74.92	72.43	69.93	67.44	64.94	64.09	63.24	62.39	61.54	60.69	60.42	60.15	59.87	59.60	59.33	59.29	59.25	59.22	59.18	59.14	59.27	59.40	59.52	59.65	59.78
									-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-16.6%	-16.6%	-16.6%	-16.6%	-16.6%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%	-27.5%
Total Group 3 impact Mt									-3.20	-3.16	-3.12	-3.08	-3.03	-3.02	-3.01	-9.94	-9.89	-9.85	-9.84	-9.84	-16.28	-16.27	-16.26	-16.30	-16.33	-16.37	-16.40	-16.44

	2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Europe-wide LCA impact	-2.39	-3.57	-4.39	-5.11	-7.64	-10.58	-12.76	-21.62	-25.23	-27.46	-33.03	-36.23	-36.83	-41.76	-55.81	-55.98	-58.56	-60.77	-61.01	-67.71	-67.95	-68.18	-68.43	-68.67	-68.92	-69.16	-69.41
Europe-wide material demand Mt		225.94	222.32	218.70	215.09	211.47	207.85	207.48	207.11	206.74	206.37	206.00	206.49	206.97	207.46	207.95	208.44	209.13	209.82	210.51	211.20	211.89	212.62	213.36	214.09	214.82	215.56
% savings		1.6%	2.0%	2.3%	3.6%	5.0%	6.1%	10.4%	12.2%	13.3%	16.0%	17.6%	17.8%	20.2%	26.9%	26.9%	28.1%	29.1%	29.1%	32.2%	32.2%	32.2%	32.2%	32.2%	32.2%	32.2%	32.2%
Proportion due to Group 1 countrie		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	80.3%	83.2%	84.7%	79.8%	81.7%	81.9%	84.0%	71.2%	71.3%	72.6%	73.6%	73.6%	66.7%	66.7%	66.8%	66.9%	66.9%	67.0%	67.0%	67.1%
Group 1 proportion of material demand			56.7%	57.2%	57.6%	58.1%	58.6%	58.9%	59.1%	59.4%	59.7%	60.0%	60.1%	60.3%	60.4%	60.6%	60.7%	60.8%	60.9%	61.0%	61.1%	61.2%	61.2%	61.3%	61.3%	61.4%	61.4%

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