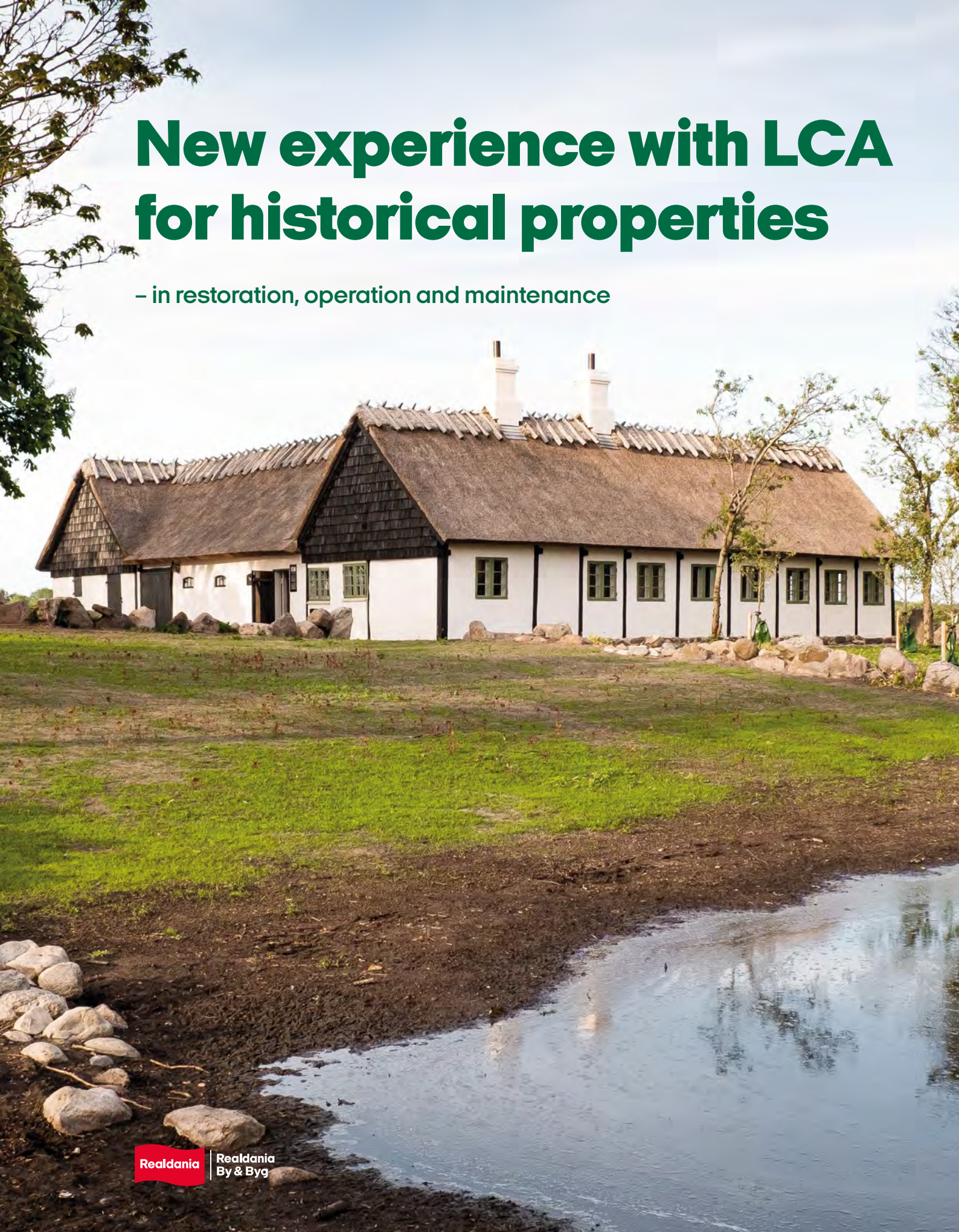
New experience with LCA for historical properties

– in restoration, operation and maintenance



Realdania | Realdania By & Byg

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Foreword

In 2022, Realdania By & Byg published its *Life cycle assessment for historic buildings*, which presented experience with mapping carbon emissions from completed restorations and transformations of buildings in the company's portfolio of properties.

Realdania By & Byg's almost 70 historical properties represent 500 years of Danish building culture – from the late Middle-Age Odense Secular Convent for Noblewomen, to architect Poul Erik Thyrring's 1971 Brutalist house in Herning. Common for all the properties is that Realdania By & Byg acquired them to preserve Danish building culture by restoring them and renting them out for contemporary purposes.

Over the past almost four years, the carbon footprint of all the restoration projects has been mapped using life cycle assessment [LCA]. Over the past two years, all the data on emissions of CO_2 and other greenhouse gases from the restorations has been supplemented by data on operating the buildings, i.e. the carbon footprint of heating and maintenance. Today, LCA is used to support decisions on the restoration of newly acquired properties and on ongoing operation and maintenance.

Restoring a historic building is a balancing process, in which preservation values, aesthetics, present use, finances, the climate and the environment have to be weighed against each other. The primary objective for Realdania By & Byg is to secure the preservation values in the properties in a financially sustainable way, but with the smallest possible carbon footprint as well.

Readers of this publication will meet some of the key people at Realdania By & Byg who work to preserve, operate or maintain the historical buildings: now with LCA as a permanent element.

In most cases, restoring or transforming an existing building is usually better in terms of climate impact, than building new. However, there is good reason to apply LCA in order to look critically at the consequences of the options – including in the long-term operation and maintenance of existing building stock.

Realdania By & Byg
Juni 2024

INTERVIEW

“The good thing about LCA is that using it actually makes a difference”

LCA – a tool for making better decisions

INTERVIEW
with Anne Mette Rahbæk, Development Director, Realdania By & Byg

Life cycle assessment (LCA) has become a permanent part of operating and maintaining Realdania By & Byg's portfolio of historical buildings. A short path from decision to implementation and close cooperation between the project department and the operating organisation have motivated us to use LCA throughout the organisation, says Development Director Anne Mette Rahbæk in this interview.

Should we tear down old buildings and build new, or should we preserve and renovate them instead? From a carbon footprint perspective, the clear answer is often that restoring and extending the service life of existing buildings is common sense.

This was the main conclusion of Realdania By & Byg's first experiences with LCA of historical buildings back in 2022. Now, Realdania By & Byg has taken a big step forward on their LCA journey by no longer just looking at material consumption during the actual restoration. LCA is now being brought into play in the operation and maintenance of historical buildings as well. This makes LCA much more effective and accurate as an assessment tool for existing buildings, since carbon-intensive parameters such as the building's heating consumption are also included in the overall footprint calculation.

“The good thing about LCA is that using it actually makes a difference. It would be absolutely ridiculous if it turned out as just another administrative exercise. It's a tool for making better decisions, and we're starting to realise that LCA can also make a huge difference in setting priorities in operation and maintenance,” says Anne Mette Rahbæk, Development Director at Realdania By & Byg.

LCA in two phases

As described in the *Life cycle assessment for historic buildings* publication from 2022, Realdania By & Byg has worked to establish a solid database from restorations and transformations of existing buildings. Life cycle assessments have been completed for almost 70 historical buildings in the Realdania By & Byg portfolio which have been restored or transformed since 2003. In parallel with this, meters have been installed and energy management has been introduced in all buildings. As sufficient data has been collected via reports on energy use, it has been possible for the operations department to prioritise investments in terms of carbon footprint.

The buildings include Arne Jacobsen's private holiday cottage at Sejerøbugten on Zealand, Odense Secular Convent for Noblewomen and Hindsgavl Castle on West Funen. More specifically, a carbon footprint has been calculated for the relevant restoration or transformation of a building based on tender lists, drawings and descriptions

→ Architect Poul Erik Thyrring's private home in Herning is one of the latest buildings added to Realdania By & Byg's portfolio. LCA was therefore actively used in the restoration, which was completed in spring 2024.

of processes. Moreover, the scientific LCA method has been adapted to individual areas to make it more suitable for calculations of restorations and transformations of existing buildings instead of new building. This work is described in more detail in the 2022 publication mentioned above.

Realdania By & Byg has received help from BUILD – Department of the Built Environment at Aalborg University to develop an LCA method for restorations. Data from the LCA work is freely available to research educational institutions, but not yet for commercial use, as the method is still under development.

Industry has increasing focus on climate
Since 2022, several developments have taken place in the field. For example, the market has seen much more accurate environmental product declarations (EPD) from manufacturers of materials such as insulation and bricks. Furthermore, the construction industry has become more aware of the climate benefits of holding back on carbon-intensive new building.

"We're seeing increasing interest in moving away from new building and replacement and instead focusing on renovation, maintenance and service-life extension as part of work to reduce our carbon footprint," says Anne Mette Rahbæk.

In 2024, the LCA method for restorations and transformations is still under development. However, the method has become significantly more accurate within the past two years.

"We can see that many stakeholders are interested in determining when, in terms of climate impact, it pays to renovate a building rather than build a new one. We still can't say anything in general about that, but we *can* say something about which building components we should keep a particular eye on, and when it pays to renovate old windows rather than fitting new ones, for example," says Anne Mette Rahbæk.

Even though an individual assessment should always be made in each situation, Realdania By & Byg's general experience is that, in terms of the climate, it is better to restore than to build new, provided the energy source after restoration is district heating or a heat pump.

More accurate LCA
Naturally, operating a building has a significant impact on the climate footprint, for example whether it is heated by natural gas or an oil-fired boiler, or by district heating or a heat pump. It is well known that natural gas and oil-fired boilers have a much greater impact on the climate than district heating and heat pumps. Therefore, an important step in the applicability of LCA for historical buildings is that the method now includes operation and maintenance of buildings as well. It simply gives a more accurate picture of the situation.

In parallel with this development of the method, the domestic energy mix has also changed in the wake of the energy crisis in 2022, which is now impacting the climate footprint of buildings and can be documented with specific figures from LCA.

"We're beginning to see the results of the large public investments in energy conversions to district heating, for example. The Danish energy mix has become significantly greener, and this only benefits our historical buildings that are not as well insulated as new buildings. The new energy mix significantly improves the carbon footprint of the buildings, and we're beginning to see this in our figures," says Anne Mette Rahbæk.

A specific example of a greener heat source is one of Realdania By & Byg's historical buildings, Skagen's Grey Lighthouse, from 1858. Here, an oil-fired boiler has been replaced with a heat pump, as district heating was not an option due to the remote location of the lighthouse. As expected, LCA calculations have subsequently documented that the change to a heat pump had a positive impact on the climate accounts, and actually more positive than first assumed.

Another consequence of this development in the energy mix is that, at some point, it no longer pays to increase the thickness of the insulation in a building. This means that, after a number of years, focus on increasing insulation in new building will reach a turning point and, in some cases, it will no longer make sense to re-insulate existing buildings due to the climate footprint from producing the insulation material. This will also affect how Realdania By & Byg plans and prioritises restorations and maintenance of historical buildings.

Waste presents new challenges
Material consumption and waste volumes on a construction site are often more difficult to manage during restoration and transformation of historical buildings. This is primarily because restoration and transformation projects often involve more stakeholders than new building. Even though the sector has more focus on this, some stakeholders are still better at

obtaining the relevant figures for LCA calculations than others," says Anne Mette Rahbæk.

In the waste area, even correct separation can be challenging – sometimes because the historical buildings are located in densely built-up city centres, where it can be difficult to find enough space for containers to cover all waste fractions.

At the time of writing, a specific project still needs to be clarified. But one thing is certain: Realdania By & Byg is on the way with a pilot project on eco-labelling with the Nordic Swan Ecolabel. The Development Director hopes that the pilot project will provide Realdania By & Byg with ideas to make it easier for contractors and builders to manage the waste issue on building sites.

"I think the pilot project will give us some useful tools so that we can be clearer in our tendering procedures regarding management and registration of waste on building sites," says Anne Mette Rahbæk.

Better decisions regarding operation and maintenance

Realdania By & Byg is increasingly being questioned about how to implement LCA in the operating organisation. Realdania By & Byg is largely motivated by the fact that LCA as a tool makes it possible to make better decisions from a climate perspective:

→ Arne Jacobsen's own summerhouse in Odsherred. Realdania By & Byg restored the house in 2012-2013 and during restoration improved the energy efficiency of the house by installing geothermal heating.

← The almost 200-year-old Gammelby Mill at Fredericia constitutes a cultural environment with a waterwheel, miller's house, farm buildings and surroundings with the millpond. Realdania By & Byg acquired the mill in 2021 and soon after began to restore it over several years.

"This is change management. We've defined it as a learning project, where there is a short distance from decision to implementation, and the project department and the operating organisation have worked closely together to develop the way we work with LCA," says Anne Mette Rahbæk, and she continues:

"We've seen an enormous enthusiasm for LCA in our operating organisation, because it can help people make better decisions when setting priorities in operation and maintenance. There's a lot of energy, and people are eager to try it out."

Realdania By & Byg's LCA model

Since 2019, Realdania By & Byg has been applying LCA when preserving and operating historical properties. Recently, carbon data from restoration has been supplemented by data from operating the building.

When Realdania By & Byg applies LCA, the aim is to have an accurate picture of the carbon emissions linked to restoring or transforming, and then operating a historical property that is to be preserved and rented out for contemporary purposes.

The outset for the LCA model is the European EN 15978 standard, which is also used in the widely applied DGNB certification system. The standard model has been developed to assess the climate impact of new building, which, in the context of LCA, always considers construction, operation and demolition over a period of 50 years.

AAU BUILD has helped Realdania By & Byg to produce a new, adapted version of the model for restoration of historical buildings. As the basic template is the same, the historical buildings are also assigned a lifetime of 50 years from the date of the restoration, even though, in principle, they are to be preserved for eternity.

Realdania By & Byg's LCA model is not a full LCA for *the buildings*, as their original construction, sometime in the period from 1504 to 1969, has not been included. This would be extremely difficult and irrelevant, because the buildings are already there, and the LCA is about what will happen to them in the future, from the moment Realdania By & Byg acquires them.

→ Realdania By & Byg's LCA model

The most important differences between the usual LCA model for new building and Realdania By & Byg's model for restoration are:

- The measured consumption of materials in restoration of the buildings.
- In the use phase, Realdania By & Byg uses module B2 "Maintenance" instead of B4 "Replacement", as is normally applied in LCA of new building. This choice was made because Realdania By & Byg will own the building and therefore can record the maintenance of the building, and proper maintenance reduces the need for replacement.
- Finally, Realdania By & Byg has added a new module about the demolition of old materials to the standard model. Realdania By & Byg's LCA model includes the carbon emissions from the old materials removed during the restoration, and the planned future demolition of the materials added.

Work method
In LCA work by Realdania By & Byg on the almost 70 properties in the portfolio, each restoration or transformation is thoroughly analysed for the quantity and type of materials used. After this, the carbon footprint is calculated with the LCAbyg programme, using environmental product declarations for a large number of different building materials.

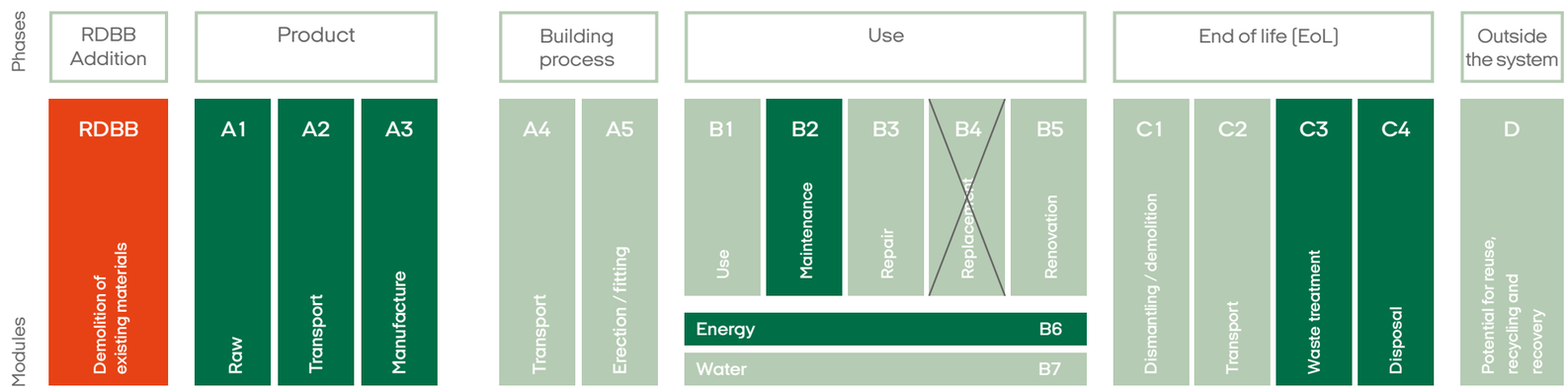
Data on carbon emissions from maintenance and ongoing operation (heating) of the properties has now also been included in Realdania By & Byg's first round of retrospective LCA, which was started in 2019 with assistance from AAU BUILD. This was after implementation of energy management in all the properties, to make it possible to collect valid data on an annual basis. Similarly, routines for incorporation of LCA for maintenance have been integrated into the organisation.

Maintenance is only measured retrospectively
However, there is a significant difference in how Realdania By & Byg calculates carbon emissions from heating and from maintenance. While heating is calculated for the future by comparing tenants' average heating consumption with current and future emission factors for energy for heating, the model does not operate with projected maintenance.

This is because accounting for future maintenance is much more uncertain. Realdania By & Byg has therefore only calculated retrospectively on the basis of observed carbon emissions from maintenance and repairs, which were not a part of the main restoration. These calculations go back to 2016, and therefore, at the time of writing, eight years of maintenance has been calculated for the properties that were in operation at that time. Maintenance data is updated every year with the actual maintenance work carried out.

This makes projection of carbon emissions from maintenance particularly difficult, not least because the expected frequency of larger and smaller maintenance initiatives over a 50-year period is very different. In the long term, when timelines are somewhat longer, it will be possible to project expected, ongoing maintenance of the property. This will build up data that can illustrate the relationship between good ongoing maintenance and the lifetime of building components.

Note that, while future maintenance of the properties is not reflected in the figures, the "double demolition", in which Realdania By & Byg de facto takes responsibility for previous owners' "end-of-life phase", is included in the overall carbon accounts. The philosophy has been that data can contribute to elucidating choices between replacement or retention and between maintenance or replacement, which in practice is crucial for decision-makers.



“We primarily apply LCA in cases where we are in doubt about the effect of initiatives, or where the result could go in several directions”

From retrospective to active use of LCA

INTERVIEW
With Troels Frey Andersen, project manager, Realdania By & Byg

Heating consumption and routine maintenance of Realdania By & Byg's portfolio of historical properties have moved into the company's LCA core. This has made LCA more accurate and it means that LCA can now actively be applied by both the project department and the operating organisation to prioritise decisions.

How do you make LCA a fixed part of your toolbox to make valid decisions for operation and maintenance of the almost 70 historical properties and for restoration of the new properties in the portfolio?

At Realdania By & Byg, project manager Troels Frey Andersen has tackled the task in two steps. The first step was to go back in time and examine the restorations of the historical properties. This retrospective work is the foundation for the way in which LCA is now used at Realdania By & Byg and it is described in the 2022 publication: *Life cycle assessment for historic buildings*.

However, even though this was an essential step, the retrospective look at the properties was not enough to make LCA fully applicable at Realdania By & Byg. The second step in development of the LCA model was therefore to convert the LCA from a retrospective tool to an active tool that can be used to make decisions on operation and maintenance for the future. Moreover, a tool that can be used to make decisions about restoration initiatives for new properties.

It has been particularly important to get operation of the buildings integrated into the LCA calculations. Without figures for heating consumption, it is difficult to provide an accurate view of the climate impact of different restoration options.

“Previously, our LCA was incomplete, because we lacked the whole part of the lifecycle called *operation*, where you make calculations for a 50-year use period for the property. With respect to the historical properties, the operation phase is precisely the phase that emits most carbon, because the properties are often poorly insulated. Therefore, it's been important to get operation into the LCA model so that we can make decisions about reducing heating consumption, for example,” says Troels Frey Andersen.

More accurate LCA

Besides operation of the buildings, maintenance is now also included in LCA calculations. This includes recording consumption of materials during maintenance tasks, as well as construction waste, for example old bricks, and waste materials, for example sawn-off fragments of plasterboard.

Realdania By & Byg has opted for this level of detail to take a leading position and show the way for others. Clearly, this makes LCA calculations more accurate, but in practice such thoroughness can lead to challenges, which we will come back to.

Realdania By & Byg's LCA model today consists of two main components, the LCAbyg tool and an Excel spreadsheet. LCAbyg is a freely available tool for calculating LCA developed by BUILD and Aalborg University. Continued development is currently funded by Realdania and Villum Fonden. LCAbyg cannot yet perform calculations for maintenance, and for this reason the results from LCAbyg are entered in an Excel spreadsheet that can manage maintenance work and that is regularly updated with the most recent data. Realdania By & Byg's operating organisation has access to the spreadsheet and completes the relevant fields for maintenance itself.

The spreadsheet now contains more than 200 different activities for maintenance work alone, including painting, insulation and plastering work. More will be added as the operations department requires, and keeping the spreadsheet up to date is a job in itself," says Troels Frey Andersen.

The plan is now to develop the LCA model so that employees in the project department can make LCA calculations for use in restorations themselves, without help from a specialist. This will optimise the decision-making process and saves time and resources.

"I hope that a time will come when I no longer have to update the spreadsheet with new activities. But it will take some time to ensure that all the activities are pre-defined in the spreadsheet, because it is difficult to know exactly what tasks will crop up for the properties during a project," says the project manager.

Major developments in EPDs

Over the past couple of years, there have been major developments in both the number and the accuracy of EPDs [environmental product declarations] that describe the carbon footprint of a material. In general this is a good thing, says Troels Frey Andersen, because it makes LCA calculations even more precise. During the retrospective part of the LCA work, the project manager experienced a general lack of EPDs for many building products on the market, and the EPDs generally contained only generic figures; i.e. a general average that was not necessarily correct for the carbon footprint of the specific product.

On the other hand, the many new EPDs over the past couple of years have meant that Troels Frey Andersen has had to prioritise work on entering them in the Excel document. In short, it is too cumbersome to enter all the details on all products.

"You can very quickly spend a long time setting up 100 different types of insulation, for example. I have decided to base calculations for some of the less common insulation products on generic data, and then accept a little uncertainty in these figures," says Troels Frey Andersen.

Vilhelm Lauritzen's own house in Hellerup from 1958, and a look into the kitchen, which the renowned architect fitted with sliding doors to the living room.

← Troels Frey Andersen at Realdania By & Byg's more than 400-year-old dwelling in Odense: The Maternal House of Oluf Bager.

Lack of heating-consumption figures
The historical properties in Realdania By & Byg's portfolio extend up to about 500 years back in time and are therefore generally poorly insulated compared with new buildings. As mentioned previously, it has been crucial to include operating data on the buildings, and not least on the heating consumption, in LCA calculations to make them as accurate as possible. Heating consumption in the individual buildings is measured, and then an associated carbon footprint is calculated based on the type of heating.

However, the LCA model is clearly only as accurate as the figures we enter into it, and challenges have arisen during work to develop and improve the LCA model with regard to obtaining the necessary data for the calculations.

"Throughout our work on energy management over the past couple of years, we've had to recognise that obtaining data on heating consumption in all our properties will not always be straightforward. Some properties have been difficult to collect data from, and this has resulted in missing data for some months. Individual utility companies differ in how they work with data, and in how well they collect and share the data. In other places, we've had to install data-logs directly on the physical meters at the properties to secure digital data collection. We're working to optimise this process, and we're studying the market to find the best solutions for us," says Troels Frey Andersen.

New legislation will also ensure that the end customer and the end user of a property regularly receive figures for the energy consumption of a building. Since 2022, this has been a requirement in the Executive Order on energy data *(energioplysningsbekendtgørelse)*.

However, Realdania By & Byg has not only experienced problems securing optimal data collection for the LCA model in the supply area. Habits and culture can also be a barrier to obtaining the necessary figures for LCA. Realdania By & Byg has specifically experienced this at construction sites, where not all players are used to incorporating LCA into their daily work. This issue is reinforced by the fact that more players are usually involved in restoration of an older building than in building new.

Difficult to separate electricity consumption
The LCA model has now reached a level at which the calculations can illustrate it can pay to restore an older building purely in terms of the carbon footprint. The model is also used actively to assess the effect of different renovation initiatives on buildings in the portfolio of historical properties. For example, the LCA calculations showed that it makes no sense in climate terms to increase insulation from 200 mm to 400 mm at Marcussen's Yard in Aabenraa. The energy savings from the increased thickness of insulation do not measure up to the carbon footprint from producing the additional quantity of insulation.

"In this context, LCA helped clarify the issue in real time," says Troels Frey Andersen.

Even though the LCA model has now become far more complete than it was in the first retrospective phase, the electricity consumption of the properties still has yet to be included in the calculation. This omission is firstly because, in climate terms, electricity consumption is much less significant in a building's total energy consumption than heating consumption. Therefore, heating consumption has been prioritised. Secondly, so far it has proved to be difficult to distinguish between electricity consumption for operating the building and tenants' other electricity consumption.

However, the plan is that electricity consumption is also to be included in the LCA calculations in the long term.

"It's been more cumbersome to obtain data on electricity consumption than on heating consumption because we are currently not able to separate consumption by a ventilation system, which has to be included in the LCA calculation, from consumption by a TV, refrigerator and computers, which is not to be included," says Troels Frey Andersen.

Overall, the project manager and Realdania By & Byg are now left with an LCA model that is much more practicable for analyses of the carbon footprint of restoration, operation and maintenance of the historical properties.

Troels Frey Andersen stresses that preservation of many of the historical properties automatically sets limits for how the buildings can be renovated and improved in terms of energy consumption. For example, it is not possible to install new triple-glazed aluminium windows in a listed building which historically has had wooden windows with secondary glazing. You do not need LCA calculations for this type of decision, and generally common sense and concrete experience will often be sufficient. In other words, LCA should only be used where it makes sense.

"We primarily apply LCA in cases where we're in doubt about the effect of initiatives, or where the result could go in several directions. But at all events, we've taken on LCA actively."

Restoration is usually better than building new: the source of heating is important

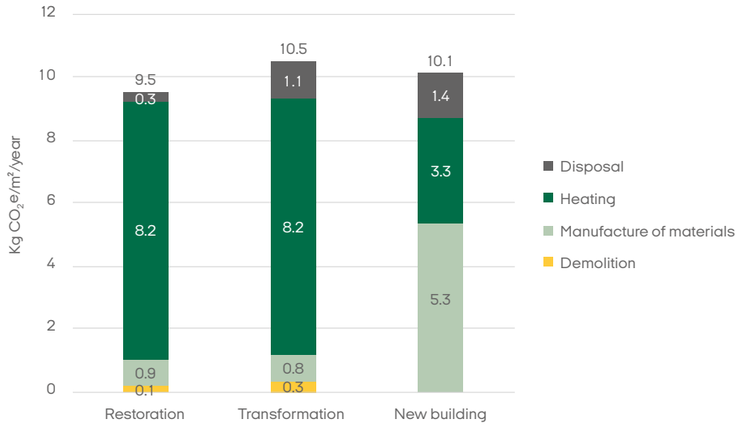
In its 2022 publication *Life cycle assessment for historic buildings*, Realdania By & Byg demonstrated that new building emits more carbon from material consumption than restoration and transformation of a historical property. However, what is the effect of including emissions from heating in the calculations? In this situation, Realdania By & Byg concludes that, in carbon terms, it is still best to preserve an old property, but only on the condition that future heating is with district heating or electric heat pumps - and not with oil or gas.

Broadly comparing Realdania By & Byg's portfolio of properties with new buildings using existing emission factors for energy sources (emissions projection as at 2020), the difference is generally not very large, and for transformed properties, carbon emissions are even slightly higher. However, this is because many of the historical properties are heated with gas or oil-fired boilers, for example, which are not used in new buildings today.

The transition to more green energy in society as a whole, however, makes a big difference for the assessment of long-term carbon emissions from the historical properties. Comparing Realdania By & Byg's properties that have district heating with new buildings in general, new buildings emit slightly less carbon if the relevant emission factors for district heating from 2020 and onwards are applied. However, using the amended emission factors that apply from 2025 and onwards changes the picture in favor of the preservation alternative.

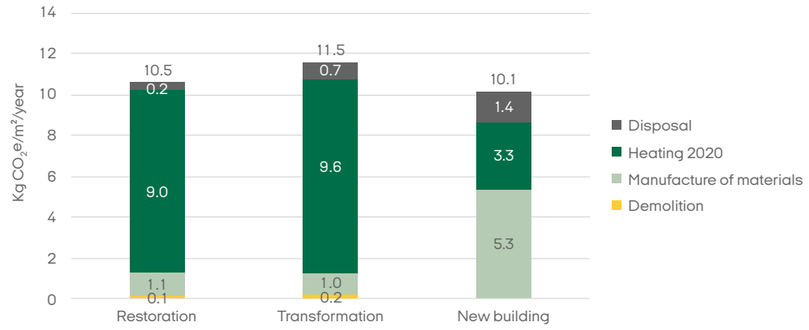
In this context, it is important to note that the calculated carbon emissions from heating individual properties in Realdania By & Byg's portfolio are very different, depending on when the properties were restored. This is because the reference period in LCA is always 50 years, so a property restored in 2010 will have ten years less with the 2025 emission factors than a property restored in 2020.

Average carbon emissions from restoration, transformation and new building

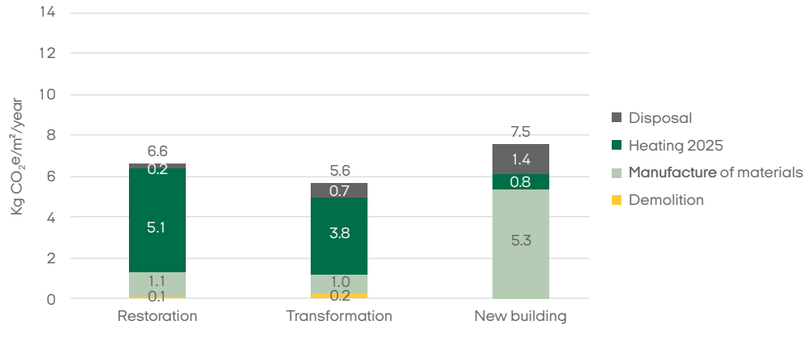


Carbon emissions from Realdania By & Byg's historical properties from and including initial restoration and transformation after acquisition of the property. Operation (heating) has been included on the basis of the emissions projection as at 2020 using different energy sources. The columns show the average for restored and transformed properties, respectively, in Realdania By & Byg's portfolio, as well as the average for a new building for comparison.

Average carbon emissions from restoration, transformation and new building for properties with district heating – 2020 emission factors



Average carbon emissions from restoration, transformation and new building for properties with district heating – 2025 emission factors



These two graphs demonstrate the difference arising when carbon emissions from heating with district heating are officially assessed to be considerably lower from 2025 and onwards than previously assessed. See the fact box on energy and emission factors on pages 52-53.

Theme 1

LCA in restoration

Restoring or transforming a listed or preservation-worthy building, while at the same time making it a suitable framework for contemporary use is a balancing act. Carbon emissions must be weighed against preservation considerations, aesthetics, function, comfort, budgets, etc. In this context, LCA can be very useful to clarify carbon emissions.

Today, Realdania By & Byg uses LCA actively to describe the specific choices and dilemmas linked to restoring a historical building. On the following pages, employees from Realdania By & Byg's project department share their experiences from working with LCA.

“We can use the example value in our projects to identify dilemmas that the rest of the sector can also discuss”

LCA is still new on the construction site

INTERVIEW
with Per Troelsen, Project Manager, Anders Brüel, Project Manager, and Frants Frandsen, Head of Projects, Realdania By & Byg

LCA highlighted a long time ago the climate benefits of restoring instead of building new in Realdania By & Byg's portfolio of historical properties. But on the construction site, LCA is still a new instrument that many contractors and other operators will have to get used to in their day-to-day work. This is the message in this interview with three project managers from Realdania By & Byg.

A lot has happened in the LCA area since autumn 2020, when Realdania By & Byg began to implement LCA in earnest. After having carried out retrospective LCA calculations on almost 70 historical properties, the company has recently taken yet another step forward by taking account of operation and maintenance in its LCA calculations.

This means that LCA has now become an integrated part of work in both the project department and the operations department at Realdania By & Byg. However, there is still some way to go before LCA is a flexible and routine process in restoration projects. Out on the construction site, LCA is still a new element in everyday activities, and it needs getting used to.

“LCA has become extremely relevant in restorations today. The retrospective review of our historical properties clearly showed in black and white that it makes sense to preserve and possibly transform a property rather than tear it down. But we're still struggling with LCA calculations because it can be difficult to get contractors to report correctly and on time,” says head of projects Frants Frandsen.

Reporting has to document what materials are added and disposed of, and may include anything from procurement of plasterboards, insulation or paint, to disposal of construction waste. To make this as easy as possible, on a trial basis Realdania By & Byg has prepared an online Excel spreadsheet for reports, with ongoing support, to make it easy for contractors to enter the necessary figures in the document. Each trade has its own spreadsheet with an associated list of materials to choose from. The plan is eventually to convert the spreadsheets into a permanent web-based solution. Furthermore, LCA today is a fixed item on the agenda for all construction site meetings.

However, experience so far shows that there is still a good way to go before there is general acceptance of the routine.

“Ultimately, we feel that the Excel spreadsheet was a good solution for LCA reporting. But we have to face the fact that it's extremely difficult to get contractors to use it. It's still very new for many of them,” says Frants Frandsen.

→ The large house at Bakkekammen 40 in Holbæk was acquired by Realdania By & Byg in 2016 in order to preserve one of Denmark's finest examples of the Better Building Practices style.

Reports are currently regularly monitored by project manager Troels Frey Andersen from Realdania By & Byg The lack of reporting could, with changed habits on the construction site, get better as producers deliver ever more complete carbon data with their products.

LCA gave new insight into properties
As described in this publication, LCA calculations weighed heavily in several important decisions during restorations of Realdania By & Byg's historical properties in recent years.

In Præstø on Zealand, LCA calculations have been used to assess the climate footprint of a terrace made of cast iron compared with a concrete terrace. And Skagen's Grey Lighthouse has had its old oil-fired boiler replaced before time with a heat pump that will pay for itself very quickly both financially and in terms of carbon emissions. The two historical properties are specific examples of how LCA today is a fixed tool, which, together with several other parameters, such as preservation values and financial aspects, is included in considerations regarding restorations.

It is a new way of viewing properties and it is significantly different from how Realdania By & Byg viewed properties when it began acquiring historical properties in 2003.

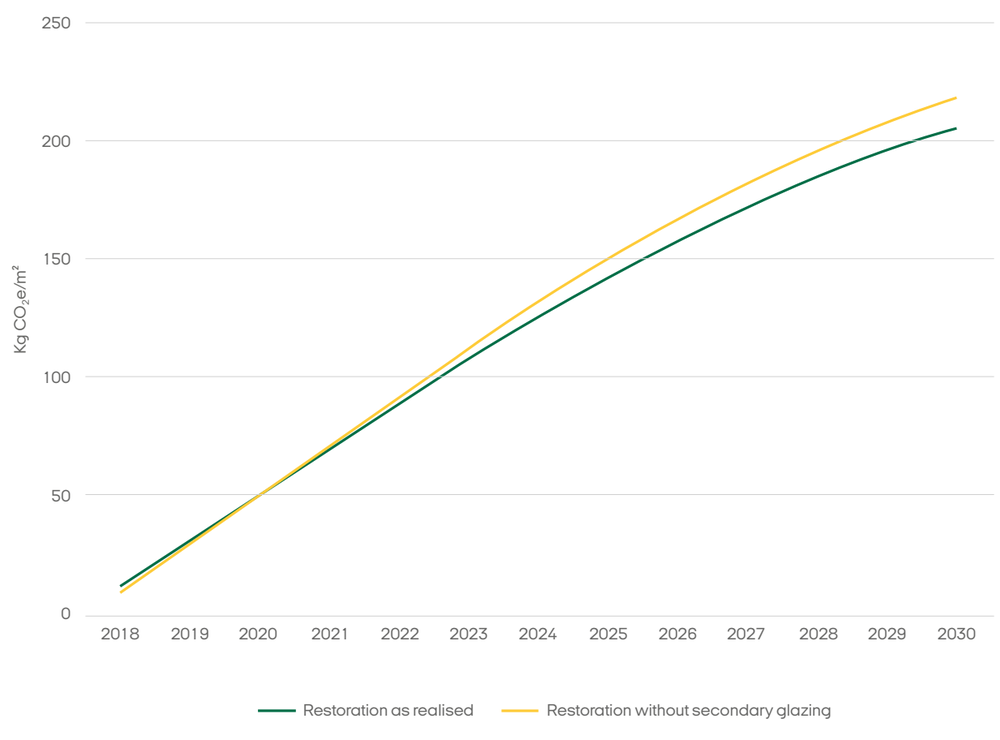
"Parameters such as insulation and heating technology have always had strong focus, but at that time it was primarily to make the properties attractive for tenants. Much of what we did was to ensure that tenants didn't get excessive heating bills. That focus reversed suddenly when we received LCA figures for the historical properties," says project manager Per Troelsen.

Heat sources and preservation values
Per Troelsen mentions the listed merchant's house at Bakkekammen 40 in Holbæk as an example of a historical property, which, viewed in terms of LCA, looks somewhat different than before. The house's windows have been fitted with secondary glazing made with energy-efficient panes, which are energy-saving and thus climate-friendly measures. But on the other hand, the gas-fired heating in the house has a large negative impact for the climate. Specifically, it has been important for Realdania By & Byg to include operation in the LCA model in order to cover the type of heating, which has a major impact on the carbon footprint.

"Bakkekammen 40 is a good example of a property, which can intuitively be thought of as sustainable. But the gas-fired boiler makes a dramatic impression on the LCA accounts, and this means that the carbon emissions of the property won't really start to drop until it has a less carbon-intensive heating system," says Per Troelsen.

This will come is future years when the Municipality of Holbæk rolls out district heating in the area. Another example of how the LCA accounts could be improved considerably by replacing a gas-fired boiler is Skagen's Grey Lighthouse, where an air-water heat pump has yielded positive results. However, it is not always that simple to just change to the most energy-efficient solution for a historical property.

Carbon emissions from restoration of Bakkekammen 40, with and without secondary glazing.



← Marcussen's Yard in Aabenraa was built from 1723 and onwards, and since 1830 it has been an organ factory. It still produces organs using traditional craftsmanship.

At Skagen's Grey Lighthouse, the choice would otherwise have been geoexchange heating, if it were not for the preservation values. In other places, an air-water heat pump may not be relevant because the outdoor part of it may conflict with the preservation values. LCA will increasingly lead to this discussion.

"Listed buildings are extremely challenging to energy-optimise and to improve comfort and indoor climate, while still taking into account the preservation values and aesthetics," says Frants Frandsen.

"On the one hand, you want to move the energy label up a couple of notches. But if this requires a lot of additional insulation outside on the façades, or replacing windows, it is not certain that we can just do it. For the simple reason that we buy historical buildings that are unique," says Frants Frandsen.

Dropped additional insulation

Both the type of heating and insulation have historically been considered as effective means to make a building more energy-efficient. Of course, this still applies, but for Realdania By & Byg, LCA calculations have helped illustrate that more insulation does not always make sense in a climate perspective. This is partly because an increasing number of municipalities have transferred to greener heating technologies such as district heating, and heat pumps are increasingly powered by electricity from renewable energy sources. This means that an increase in energy consumption due to less insulation does not now lead to the same increase in climate footprint as it did just a few years ago. Developments in the energy sector are gradually moving towards less carbon emissions.

During work by Realdania By & Byg to develop the LCA model for historical properties, the Danish energy mix has changed to such an extent that it has made its mark on the LCA calculations. For example, this happened for Skagen's Grey Lighthouse, where changing to a heat pump has proven to be better in the carbon accounts than first assumed. In Aabenraa, LCA calculations for insulation of the ceiling of the organ factory at Marcussens Gård, which Realdania By & Byg acquired in 2022, not surprisingly showed a huge difference from no insulation and to 200 mm insulation. On the other hand, it was not worthwhile investing in 400 mm insulation after the carbon footprint in the operation phase was compared with the footprint from production of the insulation.

"The leap from 200 mm to 400 mm meant just 25 kg less carbon per year in the operation phase. Therefore it was not at all worthwhile, and the 400 mm insulation would also require a damp course, which is hard to make watertight in such an old building," says project manager Anders Brüel.

The three project managers agree that it is important not to be blinded by LCA and carbon emissions during projects. It is important to keep in mind many other parameters. For example environmental parameters such as the toxicity of materials, and not least preservation values for properties of historic interest.

"LCA is by no means God's gift to humanity. It is just one of many parameters, and every time you adjust one parameter, it may have consequences for all the others. But LCA and carbon emissions should, of course, have greater weight than in the past," says Anders Brüel.

Basically, it is about making LCA a fixed part of the toolbox, and this means that LCA has to be as easy as possible to apply in practice.

"It mustn't be so complex that the whole sector rolls its eyes at the concept. We can use the example value in our projects to identify dilemmas that the rest of the sector can also discuss," says Per Troelsen.

→ From left to right: Anders Brüel, Frants Frandsen and Per Troelsen, who all manage restoration projects from start to finish.

Maintenance is better than replacement

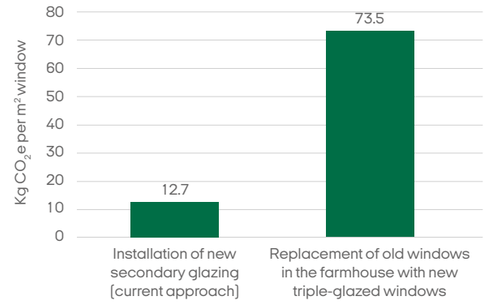
Preserving or reusing old building components in historical buildings is not just an advantage in relation to retaining the cultural assets of buildings as much as possible. It is also better for the climate than replacing with new components.

This makes maintenance a precondition for a long service life. For example, some windows can last for several hundred years if they are properly maintained, which is several times longer than the service life in the LCA model.

This is also why Realdania By & Byg has decided to drop the module "Replacement" in favour of "Maintenance" in the LCA model used for the almost 70 historical properties in the company's portfolio.

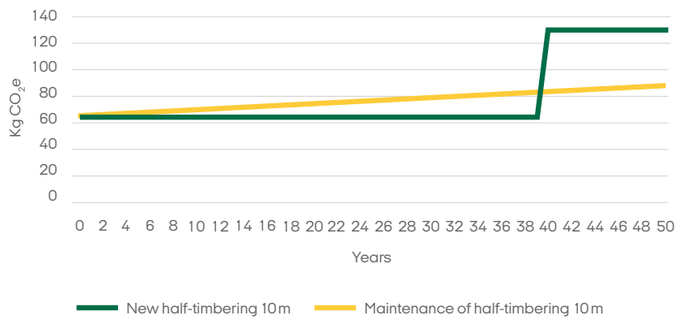
↓ Restoration of windows at Højergård

Restoration of windows at Højergård



If the old windows are worn out, and perhaps heating consumption is a little too high in a historical building, one solution could be to replace the windows with modern triple-glazed windows. But in terms of the climate, it would be better to repair the old windows and solve the energy issue by installing secondary glazing that matches the style of the existing windows. Realdania By & Byg did this in the Højergård marshland farm, where the LCA showed that carbon emissions from material consumption would have been almost six times as high if the windows were replaced by triple-glazed windows.

Maintenance compared with replacement over 50 years
10 m half-timbering



This graph illustrates the climatic significance of keeping half-timbering in good repair. If not maintained, the entire half-timbering will have to be replaced at some point, and the carbon footprint will be bigger in the long run. The maintained half-timbering will also remain attractive at all times.

“It goes without saying that when we rebuild a wall, we use the old bricks”

Recycled bricks and no steel skeleton reduces the carbon impact in Præstø

INTERVIEW
with Anders Brüel, Project Manager, Realdania By & Byg

In an old iron foundry in Præstø in southern Zealand, it makes both architectural and climate sense to use recycled bricks during the transformation of the 126-year-old building, which will serve as a citizen service centre and a community centre for residents in Præstø. LCA calculations document the climate advantages of using recycled bricks, although there is a monetary price. The calculations have also determined the selection of materials and basic construction decisions.

LCA of the foundries in Præstø has confirmed that good architectural choices and climate mitigation measures can go hand in hand: and it has convincingly ruled out the opposite.

The foundries were built in 1898 with a green area and Tubæk Å watercourse on the one side, and Præstø high street, Adelgade, on the other. The plant is a historical testimony of a time when industrialisation was gaining real momentum in Denmark. Realdania By & Byg acquired the property for restoration and transformation in 2020, so it could be rented out to Vordingborg Municipality and used as a citizen service centre, local history archives and community centre.

The foundries in Præstø are a good example of a historical building project that confirms the positive climate experiences with restorations and transformations described in Realdania By & Byg's LCA 2022 publication *Life cycle assessment for historic buildings*. The publication shows the results of LCA calculations for a number of the almost 70 historical buildings built over the past 500 years that Realdania By & Byg has acquired and restored since 2003.

“Our retrospective LCAs of the historical buildings have shown that preserving is a good idea. And it's such a good idea that you must always think very hard before tearing down something old and building new. If we can get anything out of the old buildings, we've done our part to avoid more climate impact than is absolutely necessary,” says Project Manager Anders Brüel.

The foundries in Præstø are an example of historicism in Denmark – the architectural style imitating former styles. Even though the foundries were mainly built with function in mind – production of iron articles – the buildings are characterised by several fine architectural details such as gable windows with cast-iron stars and cast-iron pillars with decorative detailing. The aim is to preserve these details in the restoration of the property.

LCA ruled out steel

From the very beginning, LCA has helped make important decisions and choices in connection with the restoration. Preliminary statistical calculations showed that it would be a good idea to reinforce the building construction from 1898 with an internal steel skeleton. Cracks and subsidence damage in the brickwork indicated

→ The saw-tooth shed roof on the foundries in Præstø from 1898 is characteristic for the industrialisation period.

that the building needed reinforcement to be safe for many years to come. However, after Realdania By & Byg had completed LCA calculations for the solution, it was rejected.

"In terms of LCA, the solution was absolutely crazy," says Anders Brüel.

Climate-wise, it made no sense to attach the old brickwork to a steel skeleton. The building construction was re-assessed with a consulting engineer. The foundries are built on a loose surface, making the buildings "float" in practice, says the Project Manager. However, together with a chartered structural engineer, Realdania By & Byg has decided to accept this as a basic premise for the building – just as the original contractor on the building did more than a century ago.

"The building is totally lopsided, it has subsided and has cracks, but it's been standing there for more than a century, so it's not likely to subside anymore," says Anders Brüel and continues:

"Accepting that the building is 'floating' will save us a lot of money and even more on carbon emissions. And if a new crack appears in five years, we'll patch it up. A principle known from our medieval churches. This is an example of a decision driven by an LCA mindset," says the Project Manager.

A compromise between carbon, aesthetics and price

Ditching the steel skeleton solution will better preserve the buildings' original architectural expression. During the restoration, recycled bricks have played an important role several places in order to preserve the original expression as much as possible. Not least on the buildings' gables facing towards Adelgade. A more expensive and more modern red machine-made brick was originally chosen, while white limestone and yellow bricks were used inside.

Recycled bricks from the building itself were used during the rebuilding, while other bricks were obtained elsewhere if the original bricks were missing. These include surplus stocks of recycled limestone bricks purchased by Realdania By & Byg from the local preservation association. The transition between recycled bricks and new bricks is evident in several places in the old foundries, and the transition is not only visible to the eye, it is also testimony to the great differences in carbon footprint, aesthetics and price.

Aesthetically, it makes sense to preserve and reuse the original bricks as far as possible in the foundries, which despite its few architectural details, is basically a simply designed industrial plant.

"Of course we use the old bricks when we rebuild a wall. Aesthetically they're all we've got to work with in the absence of gold leaf or other finery in the buildings," says Anders Brüel.

Aesthetic considerations therefore prevailed in the decision to utilise recycled bricks in the foundries in Præstø as far as possible, says the Project Manager. However, the decision is also significant for the climate footprint, and not least for the budget if recycled bricks have to be purchased from an external supplier.

Concrete floors have a costly carbon footprint

As described in the 2022 publication *Life cycle assessment for historic buildings*, a recycled brick emits about 56 times less carbon than a new brick, and if climate and aesthetics were the only factors, it would just be a matter of getting cracking with old bricks. However, there is no denying that a recycled brick is much more expensive to buy than a new brick – around DKK 18 compared with around DKK 3, says the project manager.

"So you do the math. The conclusion is that if you have two existing bricks on top of each other, then leave them there. And if you have to remove them because of the bad state of the wall, use the same old bricks to build up the wall again," says Anders Brüel.

However, in one important place in the old foundries, LCA calculations made no difference. Beneath the old concrete floors of the buildings was the result of a century of industrial pollution – first from the old foundry, and later from a motor repair shop that took over the buildings after the foundry closed down.

Realdania By & Byg therefore had to remove the old concrete floors, dig out the contaminated soil layer beneath the floors and transport it all to landfill.

"From an LCA perspective, this is a disaster because there's nothing wrong with the concrete

floors. But there was nothing to do about it. The concrete floors had to be removed, and the soil had to be dug out," says Anders Brüel.

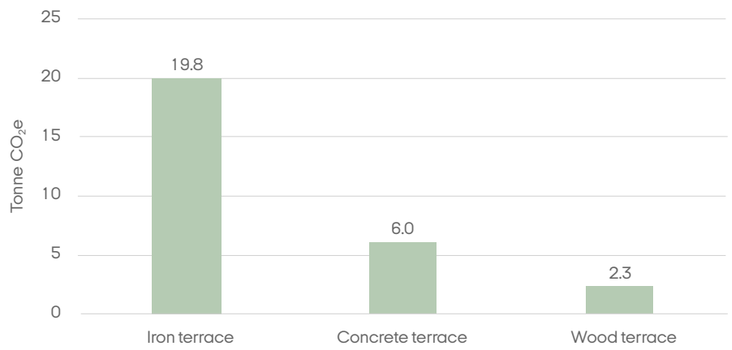
Concrete beat iron

At the back of the old industrial plant facing towards Tubæk Å watercourse, the plan is to build a terrace that will link the foundries in Præstø with an adjacent car park via a bridge. The terrace will also serve as a dam for when the watercourse overflows. The terrace will thus have a dual role for recreation, with a direct connection to the surrounding nature, and for protection against nature when it is more aggressive.

Therefore, there has been much to think about with regard to choice of materials for the terrace, which will have a great impact on the citizens' use of the building both functionally and aesthetically. The first impulse was – with a nod to the industrial history of the building – to produce the terrace out of cast iron. But LCA calculations turned out to be crucial for decisions about the materials for the future terrace. In terms of climate footprint, the most obvious architectural solution unfortunately turned out to be a dead end.

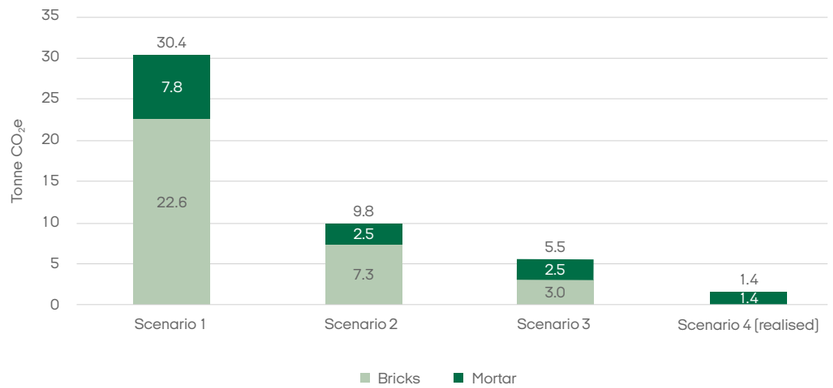
"Having a cast-iron terrace manufactured by a supplier that can cast up to 10-metre-long iron elements was hopeless in terms of LCA. The calculations showed that it would actually be much better to build the terrace out of concrete," says Anders Brüel.

Carbon emissions linked to different types of terrace



The difference in estimated carbon emissions from the new terrace using three different materials. The choice of concrete over wood was not least because the terrace will also serve as protection against rising water levels from the watercourse in Præstø.

Carbon emissions linked to different solutions for restoring the brick facade in Hall 5



The difference in carbon emissions using four different solutions for restoring the brick facade in Hall 5 in the foundries in Præstø.
Scenario 1 is to demolish all bricks and rebuild using new bricks.
Scenario 2 is to preserve what can be preserved and build new using new bricks.
Scenario 3 is to preserve what can be preserved and build new using "LESS" bricks.
Scenario 4 (the actually realised scenario) is to preserve what can be preserved and build new using recycled bricks cleaned on site.

INTERVIEW

“Everything went quiet when we saw the figures. The LCA calculations were a real aha! experience for us”

Carbon benefits required innovation on Als

INTERVIEW
with Per Troelsen, Project Manager, Realdania By & Byg

In the town of Augustenborg on the island of Als, Sønderborg Municipality and Realdania By & Byg are converting a 1970s town hall building to a new health centre for the town's residents. The future health centre is an example of how carbon savings from preserving existing buildings can make a transformation much more attractive in climate terms than demolishing and building new. However, creative architectural solutions were required to reach the goal.

At a time with global focus on climate change, it may be difficult to say “no” to cutting more than 50% off the carbon footprint of a building. This applies not least for Sønderborg Municipality, which has been a first mover in the climate area in Denmark, and since 2007 has been working with its *ProjectZero* vision to make the area's energy consumption carbon-neutral by 2029.

It can be divulged here that the municipality has decided to garner climate-footprint benefits during establishment of a new health centre in a former town hall building owned by the municipality in the town of Augustenborg.

The decision is entirely in line with the municipality's sustainability work, and the choice was made on the basis of an LCA by Realdania By & Byg that documents the significant climate benefits from preserving the shell of the former town hall building instead of tearing it down and building new. But there was a lot of thinking behind this apparently easy decision, including an architectural dilemma, which we will return to later in this article.

For Per Troelsen, a project manager at Realdania By & Byg, the future health centre in Augustenborg is a concrete example of how LCA calculations can help put documentation in place to create clarity for decisions on whether to preserve or build new. The advantages were so great in Augustenborg that there was no doubt.

“Everything went quiet when we saw the figures. The LCA calculations were a real aha! experience for us,” says Per Troelsen.

LCA as a fixed element
The figure on page 43 shows the calculated carbon difference between demolishing the town hall and building new, compared to preserving and transforming the existing building. As mentioned, the saving is more than 50%

The calculations were performed using Realdania By & Byg's LCA model, which contains data on restorations and transformations of almost 70 historical properties in the company's portfolio. Since 2022, the model has been extended to include operation and maintenance of the buildings. The calculations therefore give a more complete and accurate presentation of a property's lifecycle.

The health centre in Augustenborg is being built in the wake of the new health centres at Gråsten and Nordborg, also on the island of Als. In a budget agreement in 2023, Sønderborg Municipality earmarked DKK 20 mill. for

→ Realdania By & Byg is transforming the 1970s town hall building in Augustenborg into a new health centre. The building is owned by Sønderborg Municipality.

the health centre in Augustenborg, among other things with a medical and dental clinic, as well as physiotherapy and a chiropractor, to provide citizens with new health services. The former town hall building is approx. 1,800 m2 and is owned by Sønderborg Municipality. Therefore, it was basically easy for the municipality to decide to exploit the centrally located building for a new health centre.

Any thoughts about demolition were therefore quickly discarded after the LCA calculations arrived. Considerations then focused strongly on transforming the existing building.

Dropped full environmental clean-up

The first obstacle was an environmental survey of the building, which revealed high amounts of PCB, lead and asbestos, for example, in the internal elements of the building such as walls and ceilings. Therefore, it was decided that only the building's exterior was to be preserved in the new health centre.

"We talked ourselves further and further away from the notion of a full environmental clean-up, and towards brutally removing all the interior. This was also easier to plan," says Per Troelsen.

But there was also an architectural challenge in the decision to preserve the former town hall building from the 1970s as the basis for the new health centre. The building is surrounded by a number of historical buildings from the 1700s, including the listed school building, Gamle Drengeskole, and a former fire station. Part of the transformation is to make the area between the buildings more inviting and accessible for the residents of Augustenborg. But the style of the other buildings is from the Baroque period, and therefore the town hall building is architecturally completely out of line with the historical buildings around it.

This difference is not insignificant, as Sønderborg Municipality has ambitions to have the historical city centre in Hertugbyen Augustenborg included on the UNESCO World Heritage List. The Baroque buildings in Augustenborg are unique testimony to Denmark's historical relation with the border region, and a building from the 1970s undeniably stands out from the crowd.

The town hall tells its own story

However, the fact is that the 1970s building stands where it stands. Demolishing it and building new with something reminiscent of the old style would not be the right solution, according to the director of technical, environmental and sustainability services in Sønderborg Municipality: Sille Marcussen Dall. The result would be a building that on the surface reminds the viewer stylistically of the adjacent historical buildings, but nevertheless is a new building.

"It may be that the town hall building doesn't fit into the cultural environment architecturally. But on the other hand, the building is part of the narrative of its time. And from this perspective, and with the sustainability agenda, it would be wrong to just tear down the building," says Sille Marcussen Dall.

Initially, a new tiled roof for the town hall building was considered as a possibility to make the building more stylistically in line with its neighbouring buildings, but this idea was discarded.

"You could justify this, but no matter what, a new tiled roof would add a lot of carbon to the accounts, just for the sake of appearance," says Per Troelsen.

According to Sille Marcussen Dall, the LCA calculations were the final nails in the coffin for any thoughts of a new-build health centre.

"The LCA calculations have actually been an eye opener. The calculations we've seen have caused much reflection. And LCA is thought-provoking in a wider context, considering that many people today buy a plot with an old house, which they then tear down to build a new one," says Sille Marcussen Dall.

Architectural nod to the 1970s

As mentioned, the architectural solution to the differences between the 1970s building and the surrounding buildings from the 1700s is not to make the modern building reflect the old. Instead, the plan is to make the 1970s building more attractive with a pergola, i.e a structure with a tower and roof to function as an outdoor cover for the area in front of the health centre. The pergola in itself is a stylistic nod back to the 1970s, but it is also planned to construct the pergola in materials that lead thoughts in the direction of the historical Hertugbyen Augustenborg.

"This will give the health centre an expression characteristic of the period in which the building was originally erected. So it is true to the original architecture, but it is also an attempt to make the existing building more attractive. This and the carbon accounts are the argument for transforming the town hall instead of building new," says Per Troelsen.

For Per Troelsen, the transformation of the old town hall building into a new health centre is ultimately about doing things right in a climate context, and about finding the best possible solution to an architectural problem.

"I acknowledge that the town hall building is a challenge for the urban environment it's a part of. But if we can cut the carbon footprint by more than half by transforming instead of building new, then we have to give the building another chance," says Per Troelsen.

Hopes of scalability

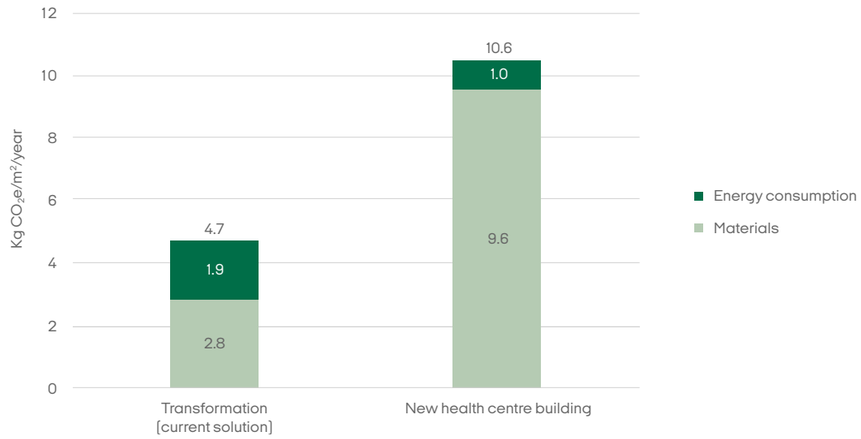
The final plans for the health centre in Augustenborg are expected to be finalised during 2024, and in the process, LCA will be applied regularly as a management tool," says Sille Marcussen Dall. The new health centre should be ready for the residents of Augustenborg by the end of 2027.

"I hope that this will be a good project and demonstrate that you *can* make sustainable transformations of existing buildings," the director concludes.

In a broader perspective, Realdania By & Byg hopes that the experience with the transformation in Augustenborg can be used in other municipalities throughout Denmark.

"Many municipalities own buildings that are now empty because their original function is no longer relevant. It'd be fantastic if the project in Augustenborg and the knowledge we have acquired with LCA calculations are scalable, and can be made available to other municipalities," says Per Troelsen.

Expected carbon emissions from transformation of the town hall compared with a new health centre building



← The low 1970s building is clearly distinct from the surrounding cultural environment in Augustenborg.

Theme 2

LCA in operation and maintenance

When assessing the climate impacts of a historical building, it is important to look at what it takes to heat up the building for its present use and at the carbon footprint of maintaining the building. The past years' data collection has enabled Realdania By & Byg to incorporate LCA in both operation and maintenance of the company's property portfolio.

Today, Realdania By & Byg measures the carbon footprint from heating by tenants and from the occasional maintenance measures on the buildings. In the following articles, employees from Realdania By & Byg's operations department talk about the use of LCA, both in the department's own work and in interaction with the project department, which is responsible for restoration of newly acquired buildings.

INTERVIEW

“LCA has given us a new way of viewing our properties”

The operations department's carbon experience enhances restoration projects

INTERVIEW
with Mikael Vikkelsø Nielsen, Team Leader, Realdania By & Byg

With LCA, the operations department at Realdania By & Byg can now assess how operation and maintenance of the company's historical properties impacts carbon emissions. Among other things, LCA gives valuable feedback to the project department, which is responsible for restoration of newly acquired properties, before they are released for ongoing operation. However, LCA has also provided people in operations with new insight into when, in climate terms, it is best to maintain the historical and often listed properties and, not least, when it is best not to.

How far can you go in efforts to reduce a building's carbon footprint, without spoiling the historical and architectural characteristics of the building? How much can you afford to change a building through renovation, and where can you efficiently cut the carbon footprint with a minimal blot on the aesthetics?

These considerations are constantly in play in the operations department at Realdania By & Byg, along with other considerations regarding durability and lifetime. Operation and maintenance of the company's almost 70 historical properties (many are also listed) must become greener over time. However, climate considerations must never push the original purpose of the portfolio off course: to preserve the historical properties for posterity through restorations or transformations.

LCA has become the tool to make it possible to keep a balance between preservation and climate initiatives.

“LCA has given us a new way of viewing our properties,” says Mikael Vikkelsø Nielsen, a team leader in the operations department at Realdania By & Byg.

“One the one hand, we don't want to spend millions on very small carbon measures, and on the other hand, we can find the low-hanging fruit with no cost in terms of the preservation value, but which also generate a rapid carbon benefit. This is where LCA is our most important tool to assess the effect of the changes we make to properties,” he says.

Early involvement in LCA

Today, the operations department works with LCA as a permanent part of operating and maintaining the historical buildings. Operation and maintenance were not included until the second phase of development and implementation of the LCA model in the organisation at Realdania By & Byg, while the first phase was based on a retrospective view of material consumption in restorations and transformations of the historical properties back to 2003. This means that, in the first phase, neither heating and electricity consumption nor maintenance

When team leader, Mikael Vikkelsø Nielsen, is not driving around Denmark and inspecting properties, he works at the Maternal House of Oluf Bager in Odense.

of the property in the future were taken into account.

However, even though operation and maintenance were not included in the first phase, the operations department was always closely involved in decisions relating to development of the LCA model. According to Mikael Vikkelsø Nielsen, this has helped create solid support for implementation of LCA as a tool in the operations department.

"A decision to perform LCA on your properties will often entail a new way of working for the operations department. It can be very resource-demanding and perhaps lead to resistance at first. But I think that we're different because we've been involved in the decision-making processes regarding introducing LCA from the start. I believe this is an important factor in getting LCA fully cemented in an organisation," says Mikael Vikkelsø Nielsen.

Revisiting properties with LCA

Since 2003, Realdania By & Byg has acquired almost 70 historical properties, all of which are part of Danish cultural and architectural heritage. Today the portfolio includes Skagen's Grey Lighthouse from 1858, the foundries in Præstø from 1898, and engineer Jørgen Varming's family home in Gentofte from 1952.

The age and nature of the properties, and in many cases their status as listed buildings, is very important for how the project department and operations department have worked, and continue to work, on restoration and maintenance of the properties. They cannot just do as they like. Everything has to be done with respect for the building practices, original materials, architectural expression and listed status of the individual property.

This still applies, but LCA gives the operations department a new perspective on the properties," says Mikael Vikkelsø Nielsen. For example, thermal windows in a historical property would not previously be replaced until they punctured or broke in some other way. This view is partly linked to a financial principle to retain individual building elements for as long as they are functioning properly. From a climate perspective too, there are obvious good arguments for delaying replacement for as long as possible. Initially, it seems just common sense. However, the assessment can easily change if the impact is calculated in an LCA in terms of greenhouse gases.

"Previously, it was good practice not to throw anything out which was still fully functional. But looking at the carbon footprint through LCA glasses, it's very likely that the improved carbon footprint in operation of the property pays back very quickly if something is replaced with a more modern product, even though it actually works perfectly well. We've started to revisit our properties in this way since LCA became part of the operations department," says Mikael Vikkelsø Nielsen.

Shares experience with the project department

Maintenance takes up most time for Mikael Vikkelsø Nielsen and his colleagues in the operating organisation. Every year, his department completes evaluations of maintenance activities on each historical property, and in this context, an LCA is prepared on the activities actually completed during the year. This means that the climate footprint of operations and maintenance is monitored regularly.

An important part of these tasks entails evaluating decisions made by the project department during the original restoration or transformation of the specific historical property. The operations department uses LCA calculations to determine whether the solutions selected also make sense in a climate context in the long term. This feedback for the project department can contribute important knowledge for Realdania By & Byg's new restorations.

"If we have to do a lot of carbon-intensive maintenance on a solution, we can report to the project department that, although the solution looked good during the procurement phase, it has since turned out to be a poor solution in terms of operation," says Mikael Vikkelsø Nielsen.

The team leader describes his department as an "experience generator", at which the experience collected is shared with people in projects.

"Our multidisciplinary skills and rapid action in new restoration projects means that we can make sure that the project department gets feedback on their decisions and can use the experience in new projects. This is where the role of LCA is now equally as important as ordinary, hard core building technology," says Mikael Vikkelsø Nielsen.

Preservation values versus carbon

Although the operations department has fully incorporated LCA, it is important for the team leader to make sure that the increased focus on climate impact does not impede on the basic objective of Realdania By & Byg to acquire and restore historical properties. As mentioned earlier in this article, there is a new debate on how far you can go with LCA-driven decisions in the maintenance of listed buildings.

"For example, are you sacrificing preservation values if you increase the thickness of the glass in a window a little? In future, we'll still have to make sure that we don't compromise the preservation values of a building. Here, the new focus on LCA presents some fascinating considerations," says Mikael Vikkelsø Nielsen.

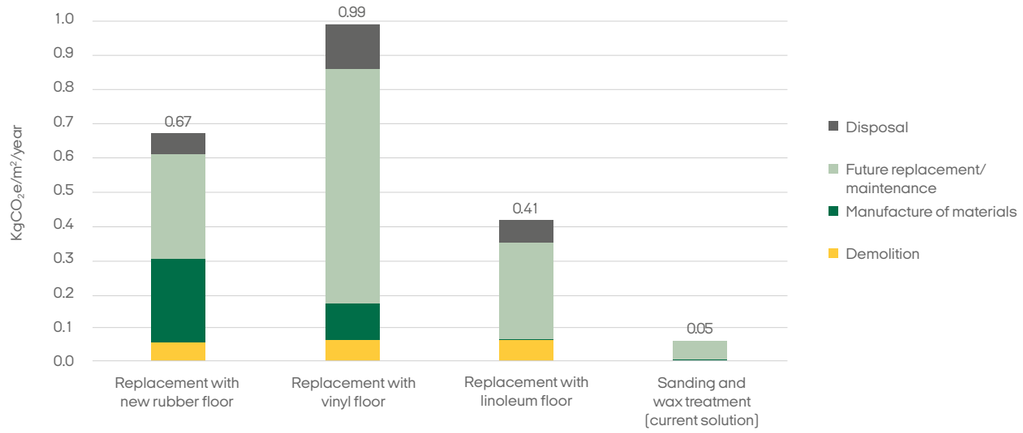
A specific example of the dilemma between preservation values and carbon is Varming's family home in Gentofte. Here, the operations department at Realdania By & Byg had to consider several solutions for the rubber-covered flooring which, after many years' use, had become worn and cracked. Was a new rubber covering best, what about an alternative material, or was it better to try to extend the lifetime of the existing rubber covering?

There was no clear answer at first, so the operations department had to take a systematic approach and assess each solution based on parameters such as cost, durability, climate footprint and aesthetics. Rubber has a large carbon footprint in production, and therefore the obvious choice was not to replace the existing rubber covering with a new rubber covering. The operations department considered linoleum as a more climate-friendly alternative to rubber, but this was rejected because of the preservation values: aesthetically, linoleum did not fit in with the history of the house. Instead, the solution was to repair the existing rubber covering by sanding it down and treating it with wax. This choice was made through trial and error, and the operations department still does not know how well the wax surface treatment will protect the rubber covering in the long term.

"It's a good example of how the climate considerations we want to incorporate sometimes conflict with preservation. Although we've introduced LCA, the values we have to keep intact in our portfolio of historical properties still take priority," says the team leader.

→ At the engineer Jørgen Varming's family home in Gentofte, LCA has been an important tool in a process that led to a decision to sand the existing rubber floor.

Comparison of different floor solutions



The differences in carbon emissions for different solutions for the floor in Jørgen Varming's family home. The light green parts of the first three columns show the carbon emissions from future replacement of the floor with different solutions, and in the fourth column, carbon emissions from regular sanding and waxing.

Energy sources and emission factors in LCA

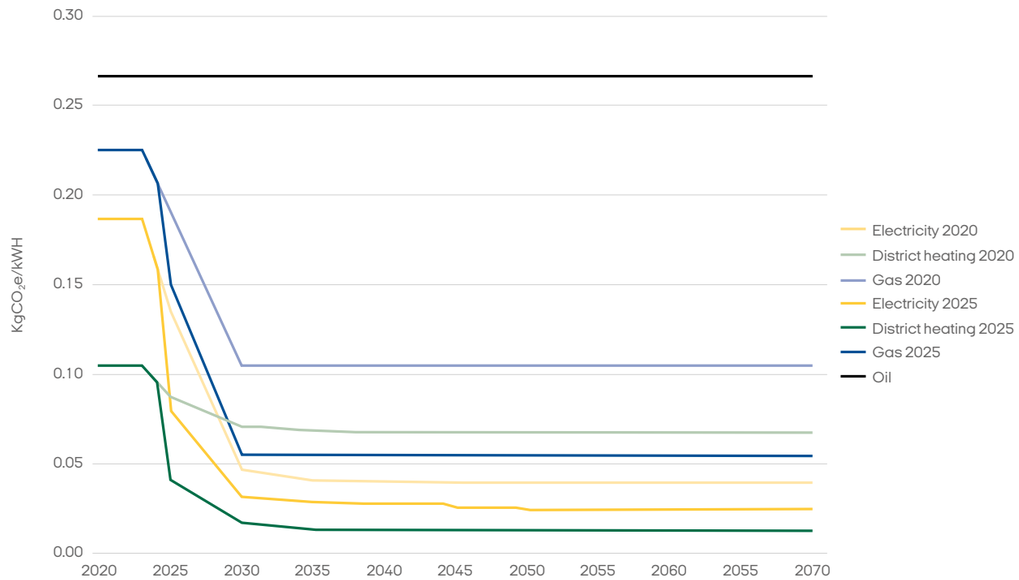
The type of energy source used to heat up a building has a major impact on the building's long-term carbon emissions. When climate considerations yield a recommendation to restore an old building instead of building new, it is important that it is possible to heat the old building using an energy source that produces the lowest carbon emissions. For example, if the building has an oil-fired boiler, the restoration should include replacing the boiler with district heating, geothermal heating or air-to-water heat pumps.

Actually, the carbon accounts of restoration look better and better as energy becomes greener and greener. Carbon emissions from operations fill less in the total calculation, as a new building typically require less carbon to heat than an old, restored building.

The official emission factors for carbon emissions per unit from the Danish Authority of Social Services and Housing are used in a Danish LCA to calculate future carbon emissions from heating a building. Here, emission factors from 2020 have been replaced by new downwards-adjusted factors from 2025 and onwards. The new emission factors reflect that electricity is expected to become greener, resulting in lower carbon emissions from heating in the future.

The change from 2025 speaks further in favour of restoring rather than building new. This is because there is less carbon advantage from lower energy consumption in new building compared with restoration. However, the emission factors are subject to some uncertainty with regard to actual carbon emissions from the energy sources. This can change in both directions in the future.

Differences in emissions projections from 2020 and 2025



The graph shows the official Danish emission factors for different sources of energy, applicable for 2020 and 2025, respectively. Note that carbon emissions from electricity are for just the actual power. Therefore, the curve cannot be used to compare carbon emissions from district heating with emissions from electricity-based heating with heat pumps, for example, which depends entirely on the efficiency of the individual heat pump.

INTERVIEW

"Developments in green energy have made the heat pump case even better than expected"

Large carbon savings by changing to a heat pump at Skagen's Grey Lighthouse

INTERVIEW
with Casper Clement Nielsen, Project Manager, Realdania By & Byg

At an old lighthouse in Skagen, which today functions as an ornithological information centre, Realdania By & Byg has replaced an otherwise perfectly operational oil-fired boiler with a heat pump. LCA calculations reveal a significantly reduced carbon footprint and they have been pivotal in the decision to change the heating system.

At the very tip of Jutland, Skagen's Grey Lighthouse rises 46 meters above the surrounding dunes, sandy beaches and sea. The lighthouse shined its beam across the sea from 1858 until 1994, but since 2017, the lighthouse and its associated buildings have functioned as an ornithological information centre for the many tourists who visit every year.

Realdania By & Byg acquired Skagen's Grey Lighthouse in 2014, and after much deliberation, and not least many LCA calculations, has now replaced the existing oil-fired boiler on the property. It is a good example of how LCA has moved into the operating organisation and is now applied actively to decide on future operation of the company's historical properties.

"LCA has been applied as a decision tool in the process of replacing the oil-fired boiler with a heat pump. Basic common sense would lead you to guess that the change would reduce the carbon footprint. But I was astounded when the LCA calculations showed the size of the reduction. The change makes a huge difference," says Casper Clement Nielsen, project manager in the operations department at Realdania By & Byg.

Lighthouse converted into an ornithological information centre

Both Skagen's Grey Lighthouse and the surrounding area are listed, and this has presented a number of practical challenges and considerations, outside and inside, with regard to changing the oil-fired boiler. These include the choice of an air-water heat pump instead of a geoexchange heating installation. We will return to this later.

Skagen's Grey Lighthouse was designed by the architect N.S. Nebelong, and besides the 46-metre-tall lighthouse, Denmark's second highest, it comprises a house for the lighthouse keeper, which today contains exhibitions, as well as two buildings which were formerly a stable and storehouse. Besides the approximate two million tourists and visitors, millions of birds pass through the area every year on their migration to and from breeding grounds in Scandinavia. Therefore, it was obvious to convert the old lighthouse into a bird experience centre, and today the Danish Nature Agency rents the buildings and runs the centre for migratory birds. The Agency also works with the Danish Ornithological Society - BirdLife Denmark.

Skagen's Grey Lighthouse is thus an example of a transformation in Realdania By & Byg's portfolio of almost 70 historical properties from the past 500 years: a building whose original function has been replaced by a new in connection with a restoration.

➔ Project manager Casper Clement Nielsen at the top of one of Denmark's most iconic lighthouses - Skagen's Grey Lighthouse built in 1858. The lighthouse was listed in 1977.

Even when Skagen's Grey Lighthouse was acquired in 2014, it was clear that the heating technology in the building was out of date. There was nothing wrong with the oil-fired boiler in the property and it could no doubt have continued to work and heat the buildings for many years, provided carbon footprint could be ignored, and the running costs too for that matter, although in this case they were not the decisive factor for Realdania By & Byg's decisions.

"An oil-fired boiler becomes less efficient after a number of years, but this boiler was still around 90 per cent efficient. So there was nothing wrong with it. But oil as a source of energy has a high carbon footprint, and the property had a relatively high energy consumption, so there was good reason to look more closely at whether savings could be made with another energy source," says Casper Clement Nielsen.

District heating rejected

Skagen is in Frederikshavn Municipality, which, like many other Danish municipalities, has developed its district heating grid in recent years, but district heating has not been in play as a heating technology for Skagen's Grey Lighthouse. Quite simply, the lighthouse is too far away and too remote from other properties for it to make any sense to lay district-heating pipes out to the building. Therefore, Casper Clement Nielsen had to look at alternatives to achieve the cuts he wanted in the carbon footprint from operating the building, and LCA was applied as a tool to compare the various heat sources.

The point of departure was an oil-fired boiler with a consumption of around DKK 180,000 and carbon emissions of around 39 tonnes a year. Converted to kilowatt-hours, the oil-fired boiler had an annual consumption corresponding to approximately 140,000 kWh. This is about 31-times more than an average Danish family's annual electricity consumption. Looking at the costs, changing to a heat pump entailed annual savings of 60 per cent, giving a payback time of three years.

"In purely financial terms it was a really good case, and even though, as the owners, we don't benefit from the savings, it made a positive difference for the tenant. For us, it was more important to look at the carbon savings from the replacement. This is where the LCA calculations gave us a good decision basis," says Casper Clement Nielsen.

Listed landscape presented challenges

A wood pellet boiler was also among the alternatives to an oil-fired boiler, but the heat pump was the most practical solution and, as mentioned above, the listing of Skagen's Grey Lighthouse was very significant in the choice of final solution: an air-water heat pump.

"Had the landscape around the lighthouse not been listed, we would probably have chosen geoexchange heating, because of the more stable temperature in the ground over a whole year. But the listed landscape means that we couldn't just excavate and lay the piping to the geoexchange heating installation.

The old oil-fired boiler has now been replaced with a buffer tank with a water heater inside. The location of the air-water heat pump also demanded careful consideration because of the listing. Realdania By & Byg had to apply to the Agency for Culture and Palaces for permission to dig pipes into the ground to link the inside and outside parts of the installation. Although the air-water solution also required some excavation work on the listed landscape, much less was required than for geoexchange heating. Therefore, the application was approved, taking into account the

listing. Besides this, Casper Clement Nielsen has spent a lot of time on finding the optimal location for the outside part of the heat pump to minimise noise nuisance and hide the installation from visitors to the centre.

"The outside part is about as large as a Fiat 500 car, and the location was carefully planned to fit in with nature as much as possible. It's a compromise between concealing it in a corner of the garden behind a fence and bush but not locating it so far away that it needs a long pipeline," says Casper Clement Nielsen.

↓ Casper Clement Nielsen by the outside part of the air-water heat pump, which now provides heating for Skagen's Grey Lighthouse and the adjacent buildings.

LCA showed a clear climate effect

The LCA calculations very quickly documented a large climate benefit from changing to a heat pump. If it had continued heating the lighthouse, the oil-fired boiler would have emitted approximately 39 tonnes CO2 a year, and that figure would not change. Realdania By & Byg's initial LCA calculations showed that the heat pump would cut emissions to about eight tonnes CO2 a year, and that the emissions would fall further as the electricity supply became increasingly based on renewable sources. The first calculations were based on emission factors calculated from the Danish electricity-mix in 2020, and this mix soon proved to be out of date. This concealed a positive surprise for the heat-pump option.

"New emission factors have been published since the heat pump was installed. We had calculated emissions of 6.5 tonnes CO2 for 2025, and we can already see that these will be down to four tonnes. Developments in green energy have made the heat pump case even better than expected," says Casper Clement Nielsen.

In practice, the electricity meter shows that since its installation, the heat pump has had an annual consumption of around 90,000 kWh. Compared with the calculated equivalent consumption for the oil-fired boiler, there is a reduction of approximately 36 per cent, due in part to insulation of the ceilings with wood fibre insulation. The insulation was fitted to optimise the building for use with a heat pump that supplies lower temperature inflow water than an oil-fired boiler. However, even if the heat pump required just as many kilowatt-hours as the oil-fired boiler, the carbon calculations would still have favoured the heat pump solution.

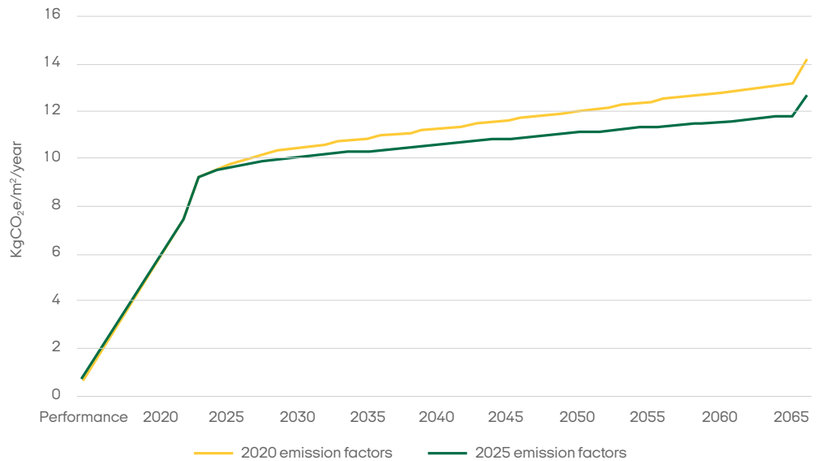
"The oil-fired boiler wouldn't have seen any positive development in carbon emissions. Even though we couldn't get district heating up here, establishing the heat pump means we've been able to couple up to a public resource [electricity, ed.], that is constantly developing in a green direction," says Casper Clement Nielsen.

LCA has weighed heavily

The LCA calculations have helped Realdania By & Byg make decisions based on concrete figures instead of gut feeling. Furthermore, the calculations have illustrated how establishment of the heat pump is likely to further improve the carbon accounts for operating Skagen's Grey Lighthouse in the future.

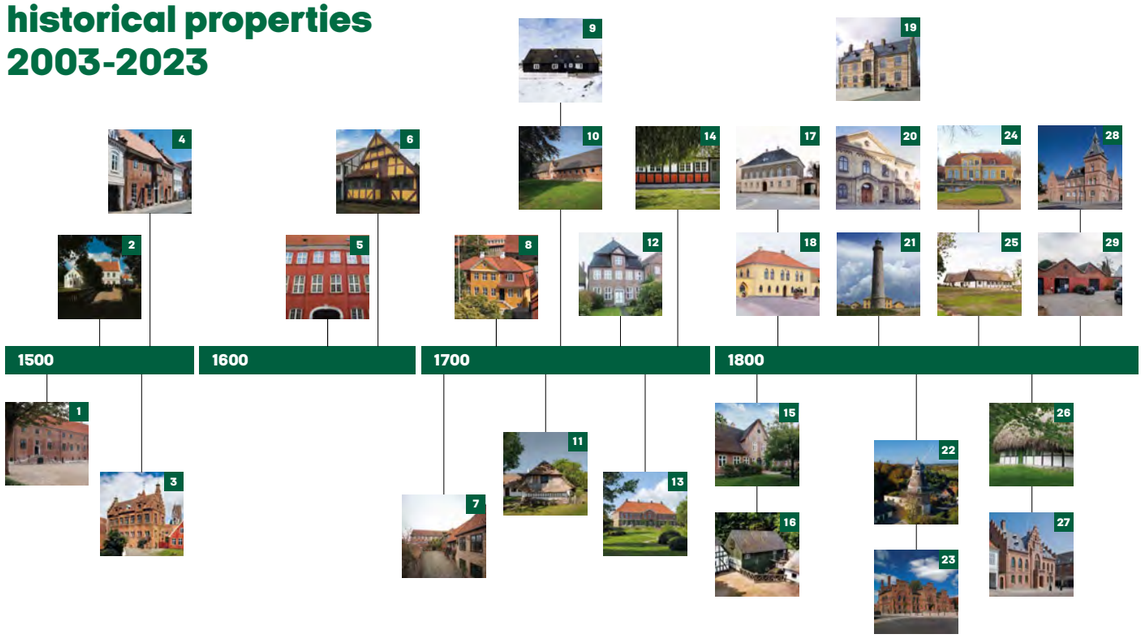
"Would we have replaced the oil-fired boiler if there hadn't been a financial benefit from doing so? Given that the LCA calculations have shown such large carbon savings, the answer is 'yes'. So the LCA has weighed heavily in our decisions."

Carbon emissions for Skagen's Grey Lighthouse



The graph shows the carbon emissions from restoration of Skagen's Grey Lighthouse and subsequent heating. The bend in the curve is due to establishment of the heat pump, and the continuation into the future shows the difference in carbon emissions based on current emission factors and the emission factors applying from 2025. Developments in green electricity thus make the LCA better.

Realdania By & Byg's historical properties 2003-2023



1504 and later
1 Odense Secular Convent for Noblewomen

1542 and later
2 Nørre Vosborg, Vemb

1580
3 Taarnborg, Ribe

1586 and later
4 The Maternal House of Oluf Bager, Odense

1663-1669
5 The Harboe Widow's Convent, Copenhagen

1690
6 Prior's House, Ærøskøbing

1723 and later
7 Marcussen's Yard, Aabenraa

1742 and later
8 The Fortification Depot, Copenhagen

1757-1770
9 Poul Egede's Home, Ilimanaq, Greenland

1764
10 Nørre Sødam Farm, Møgeltønder

1775
11 Stines House, Lolland

1777-1779
12 Digegreven's House, Tønder

1784-1785
13 Hindsgavl Castle, Middelfart

1795
14 Bent Madsen's Farmhouse, Dreslette

1823
15 Højergård, Højer

1827
16 Gammelby Mill, Fredericia

1838
17 Koch's Courthouse, Store Heddinge

1843-1845
18 Kornerup's Town Hall, Vordingborg

1853
19 Bindesbøll's Town Hall, Thisted

1858
20 Naval School for Girls, Copenhagen

1858
21 Skagen's Grey Lighthouse, Skagen

1858
22 Dyrehave Mill, Nyborg

1860
23 Meldahl's Town Hall, Fredericia

1860
24 Riise's Country House, Frederiksberg

1864/1873
25 Højgården, Sejerø

1865
26 Kalines House, Læsø

1880
27 Tvede's Town Hall, Sorø

1892
28 Amberg's Town Hall, Esbjerg

1898
29 The Foundries, Præstø

1901
30 The Jensen Family Farm, Korup

1905
31 The Harbour Master's House, Skagen

1906
32 The German-Inspired House, Højer

1907-1908
33 J.F. Willumsen's Family Home, Hellerup

1908
34 Gelsted Station, Gelsted

1910
35 The County Governor's Residence, Hjørring

1913
36 The Rosen House, Hellerup

1917
37 Bakkekammen 40, Holbæk

1917
38 The Balloon Hangar, Copenhagen

1918
39 Ejnar Ørnsholt's Private House, Nakskov

1918
40 Country House designed by Kay Fisker, Snekkersten

1924
41 Edvard Heiberg's Family Home, Virum

1929/1931
42 Arne Jacobsen's Private Home, Charlottenlund

1934
43 State-Guaranteed Smallholding, Skovbølling

1936
44 Kay Fisker's Private Flat, Copenhagen

1936
45 Arne Jacobsens Private Holiday Cottage, Gudmindrup

1937
46 Poul Henningsen's Family Home, Gentofte

1939
47 Viggo Møller-Jensen's Family Home, Kgs. Lyngby

1951
48 Arne Jacobsen's Private Home, Klampenborg

1952
49 Varming's Family Home, Gentofte

1953
50 Clemmensen's Family Home, Gentofte

1954
51 Esken, Fårevejle

1955
52 Erik Christian Sørensen's Private Home, Charlottenlund

1956
53 Bertel Udsen's Private Residence, Kgs. Lyngby

1956-1959
54 Jarmers Plads 2, Copenhagen

1958
55 Gunnløgsson's Private Residence, Rungsted Kyst

1958
56 Knud Friis' Family Home, Brabrand

1958
57 Vilhelm Lauritzen's Private Residence, Hellerup

1960
58 The Roman House, Helsingør

1963
59 Exner's Family Home, Skodsborg

1966
60 Glasalstrup, Hasselager

1969/1971
61 Poul Erik Thyrring's House, Herning

Photos

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New experience with LCA for historical properties – in restoration, operation and maintenance

Realdania By & Byg A/S, 2024

ISBN: 978-87-93746-90-9

Author/journalist - interview articles: Mikkel Meister

Other text: Realdania By & Byg

Translation: GlobalDenmark A/S

Layout and illustrations: OAB-Tryk ApS, Odense

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In 2022, Realdania By & Byg published its *Life cycle assessment for historic buildings,* which presented experience with mapping carbon emissions from completed restorations and transformations of buildings in the company's portfolio of properties.

Subsequently, all the data from the restorations has been supplemented by data on the carbon footprint of heating and maintenance of the buildings. Today, LCA is used to support decisions on the restoration of newly acquired properties and on ongoing operation and maintenance.

In most cases, restoring or transforming an existing building is usually better, in terms of climate impact, than building new. However, there is good reason to apply LCA in order to look critically at the consequences of the options – including in the long-term operation and maintenance of existing building stock.

Readers of this publication will meet some of the key people at Realdania By & Byg who work to preserve, operate or maintain the historical buildings: now with LCA as a permanent element.

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