What is the effect of the skin on the global warming potential of a membrane structure?

The following research has been done in the context of the PhD of Zehra Eryuruk, under the supervision of Marijke Mollaert , Danny Van Hemelrijck and Lars De Laet. The PhD research concerns the environmental impact of membrane structures.

General description

Typically, membrane structures have a different function, are different in design and architectural form, and vary in the ratio of structural material weight to skin.

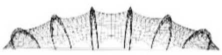
Four case studies are analysed using OneClickLCA. To allow easy comparison of the skin contribution, the models are simplified to some extent:

- Only the data for the skin and supporting structure are taken into account, while the foundation materials are excluded from this study.
- Transport is not considered.
- The end-of-life scenario is set to recycling for steel, recycling for plastics and landfill for wood.
- The Global Warming Potential (GWP) values for steel can vary between 0,7 and 3,2 kgCO_2e/kg (A1-A3 construction materials, EN 15804). The same steel data is used for the case studies considered. *Steel hot rolled, I, H, U, L, T and wide flats, S235-S960* for steel component, *Prestressed steel for concrete reinforcement (strands)* for cables, and generic data for stainless steel bolts, with a GWP value of 4.1 CO_2e/kg.
- The amount of cut-off varies according to the architectural shape. The membrane waste is set to 10% for all case studies. In the absence of data on fabrication (cutting and welding), this is not included in the simulations.

Two Life Cycle Assessments (LCA) are performed for each case study:

1. A LCA with a service life of 50 years for all materials (scenario 1).
2. A LCA with the skin's service life set at 25 years, necessitating replacement once within the 50-year project service life, while the primary structure and steel components maintain a 50-year service life (scenario 2).

Table 1. General data for the four case studies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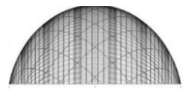
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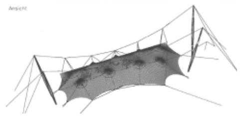
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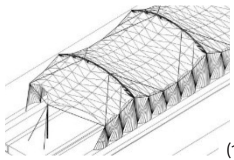
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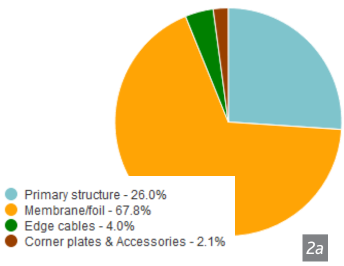
	M&G Research	Comptoir Forestier	Elspe Grandstand	Erasmus metro station
Installation	1990	1995	1978 (renewed 2015)	2003
Covered area (m²)	2400	1144	2200	2700
Type	enclosed	enclosed	open	membrane roof
Structure	arches	grid shell	masts + cables	'Candelabra'
Self-weight kg/m²	5,89	53,79	16,88	22,73
Skin kg/m²	2,76 (47%)	2,24 (4%)	3,24 (19%)	1,58 (7%)
Structure kg/m²	3,13 (53%)	51,55 (96%)	13,64 (81%)	21,15 (93%)

(1): © Philippe SAMYN and PARTNERS architects & engineers. / (2): © teschner Ingenieure

1. Case study M&G Research (Italy)

M&G Research project is really a lightweight structure with steel arches supporting the skin. The LCA simulations consider PVC-coated polyester (1,55 kg/m²) and PVC foil (data for PVC board) for the skin, and steel for the primary structure, edge cables and corner plates.

Comparing the two simulations, the contribution of the membrane to the total GWP is **67,8%** in the first scenario and **80,1%** in the second. For this type of construction, the contribution of the membrane to the total GWP is high.



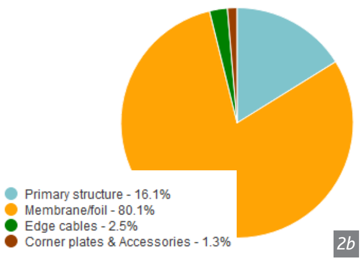
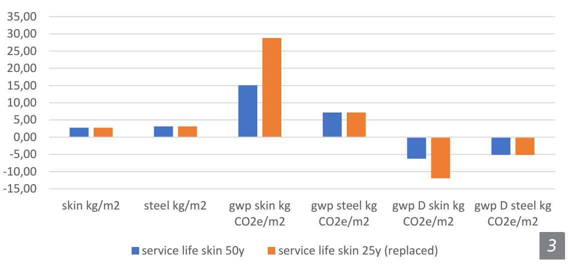


Table 2. GWP results for M&G Research depending on the service life (SL) of the skin

	SL skin 50y	SL skin 25y (replaced)
Skin kg/m²	2,76	2,76
Steel kg/m²	3,13	3,13
GWP skin kg CO_2e/m²	15,07	28,80
GWP steel kg CO_2e/m²	7,16	7,16
Total GWP/m²	22,23	35,96
GWP D(*) skin kg CO_2e/m²	-6,26	-11,95
GWP D steel kg CO_2e/m²	-5,15	-5,15

(*) D are the benefits and loads beyond the system boundary related to the reuse, recovery and recycling potential (EN 15804)

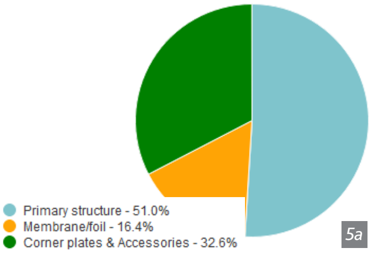


As shown in Figure 3, the GWP/m² is higher for the skin than for the steel parts (3rd and 4th group of bars).

Figure 1. M&G Research project, Philippe SAMYN and PARTNERS architects & engineers, ©photo: Carol Montecelli
Figure 2a/b. GWP for the 2 scenarios for M&G Research
Figure 3. GWP results for M&G Research

The project Le Comptoir Forestier is a heavier structure with a wooden grid shell supporting the skin. The initial concept was designed with a membrane cover, but it was revised with glass following the mayors' suggestion. In the LCA simulation, the skin material considered is **PVC-coated polyester (1,35kg/m²)**, while the primary structure is wood and stainless steel. For wood, the end-of-life scenario considered involves landfill disposal. Comparing the two simulations, the contribution of the membrane to the total GWP is **16,4%** in the first scenario and is **27,2%** in the second, which is lower than for the M&G Research project. It corresponds to a lower weight fraction..

2. Case study Comptoir Forestier (Belgium)



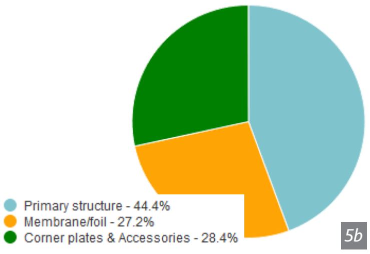
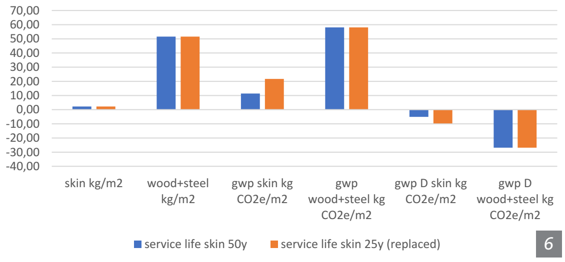


Table 3. GWP results for Le Comptoir Forestier

	SL skIn 50y	SL skin 25y (replaced)
Skin kg/m²	2,24	2,24
Wood + steel kg/m²	51,55	51,55
GWP skin kg CO_2e/m²	11,39	21,71
GWP wood + steel kg CO_2e/m²	58,10	58,10
Total GWP/m²	69,49	79,81
GWP D skin kg CO_2e/m²	-5,09	-9,70
GWP D wood + steel kg CO_2e/m²	-26,81	-26,81



As shown in Figure 6, the GWP/m² is lower for the skin than for the wood and steel parts (3rd and 4th group of bars). Although this structure is 10 times heavier than the structure of M&G Research, the GWP/m² for the scenario with membrane replacement is only twice as high.

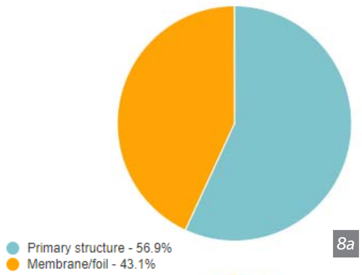
Figure 4. Le Comptoir Forestier © Philippe SAMYN and PARTNERS architects & engineers.
Figure 5a/b. GWP for the 2 scenarios for Le Comptoir Forestier
Figure 6. GWP results for Le Comptoir Forestier

The Elspe Grandstand structure is a free span canopy, supported by steel cables and 4 high masts. The LCA simulation considers **PVC-coated polyester (1,55kg/m²)** for the skin and steel for the primary structure, including the connections.

Comparing the two simulations, the contribution of the membrane to the total GWP is **43,1%** in the first scenario and is **59,1%** in the second.

As shown in Figure 9, the GWP/m² is of the same order of magnitude for the skin and for the steel parts (3rd and 4th group of bars).

3. Case study Elspe Grandstand (Germany)



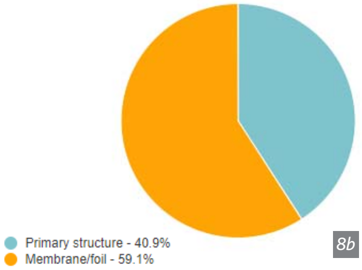


Table 4. GWP results for Elspe Grandstand

	SL skIn 50y	SL skIn 25y (replaced)
Skin kg/m²	3,24	3,24
Steel kg/m²	13,64	13,64
GWP skin kg CO_2e/m²	19,27	36,82
GWP steel kg CO_2e/m²	25,45	25,45
Total GWP/m²	44,72	62,27
GWP D skin kg CO_2e/m²	-7,36	-14,05
GWP D steel kg CO_2e/m²	-20,18	-20,18

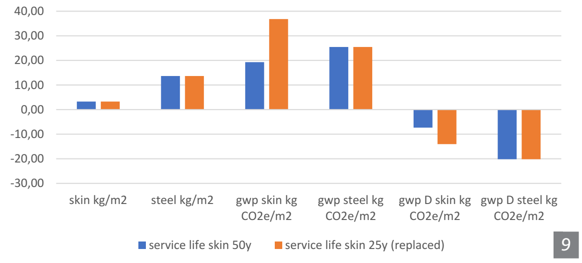


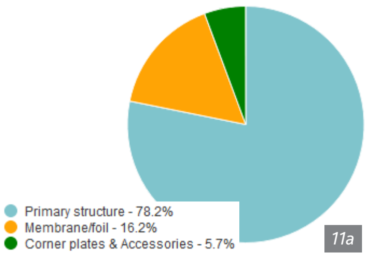
Figure 7. Elspe Grandstand ©Mehler Texnologies
Figure 8a/b. GWP for the 2 scenarios for Elspe Grandstand
Figure 9. GWP results for Elspe Grandstand

4.Case study Erasmus metro station (Belgium)

The Erasmus metro station project is a canopy supported by steel 'candelabra' structures placed every 15m. The rectangular roof is achieved through the integration of diagonal compression trusses.

The LCA simulation considers **PVC-coated polyester (1,35kg/m²)** for the skin due to the unavailability of an EPD for glass-PTFE. Meanwhile, steel is used for the primary structure, including the cables and the connections.

Comparing the two simulations, the contribution of the membrane to the total GWP is **16,2%** in the first scenario and is **26,9%** in the second.



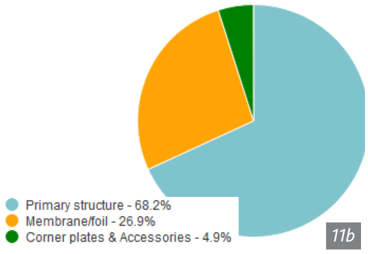
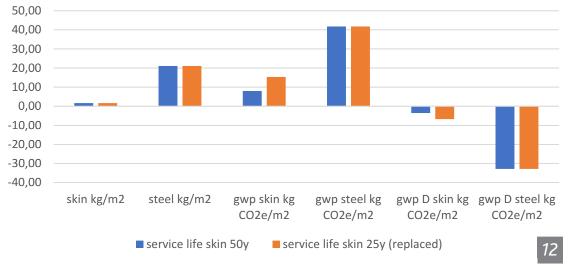


Table 5. GWP results for Erasmus metro station

	SL skIn 50y	SL skin 25y (replaced)
Skin kg/m²	1,58	1,58
Steel kg/m²	21,15	21,15
GWP skin kg CO_2e/m²	8,06	15,39
GWP steel kg CO_2e/m²	41,75	41,75
Total GWP/m²	49,81	57,14
GWP D skin kg CO_2e/m²	-3,60	-6,85
GWP D steel kg CO_2e/m²	-32,81	-32,81



As shown in Figure 12, the GWP/m² is smaller for the skin than for the steel parts (3rd and 4th group of bars).

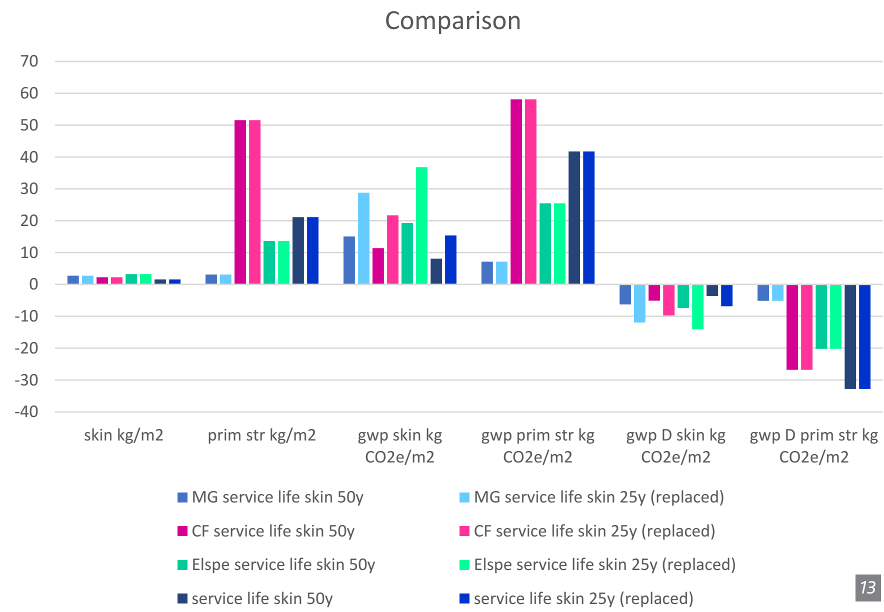
Figure 10. Erasmus metro station © Philippe SAMYN and PARTNERS architects & engineers.
Figure 11. GWP for the 2 scenarios for Erasmus metro station
Figure 12. GWP results for Erasmus metro station

Comparison and discussion

First a few comments on the results of OneClickLCA:

- If a replacement of the skin is done, the result for the waste for the replacement is lower than for the 1st installation (where a 10% waste fraction is specified, but apparently this value is not applied for the replacement). So, the total GWP for the 2nd skin is lower.
- The impact of the end-of-life treatment in module end-of-life (C1-C4) does only consider one fabric incineration. The incineration impact of the second fabric is considered in module replacement and refurbishment (B4-B5).

Considering the validity of the results, certain approximations were necessary due to the absence of data for certain materials, such as steel cables and PTFE-coated fabrics. Resolving these data gaps is essential for ensuring accurate and complete assessments.



As previously highlighted, the assessed designs are very different; however, several logical observations can be made:

- The GWP/m² of the skin is almost doubled in the second scenario (see the 3rd group of bars).
- The GWP for the benefit and loads beyond the system boundary (Module D) of the skin is almost doubled in the second scenario (5th group of bars).
- The GWP/m² for the skin shows proportional relation to the self-weight of the skin (comparing the 1st and 3rd group of bars):
  - approximately a factor of 5 for the 50-year scenario.
  - approximately a factor of 10 for the 25-year scenario concerning the skin, which includes a replacement.
- The impact of the membrane's effect varies based on the structure type. For instance, in the case of Le Comptoir Forestier, characterised by a relatively heavy wooden grid shell, the membrane's contribution is low. Conversely, in the M&G Research project, which is a very lightweight structure, the membrane impact is high.

The general conclusion is that to make appropriate decisions about the environmental performance of a design, it is crucial to integrate Life Cycle Assessment from the initial design stage.

Figure 13. GWP results for the four considered case studies

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