

Environmental design guidelines for circular building components: the case of the circular building structure

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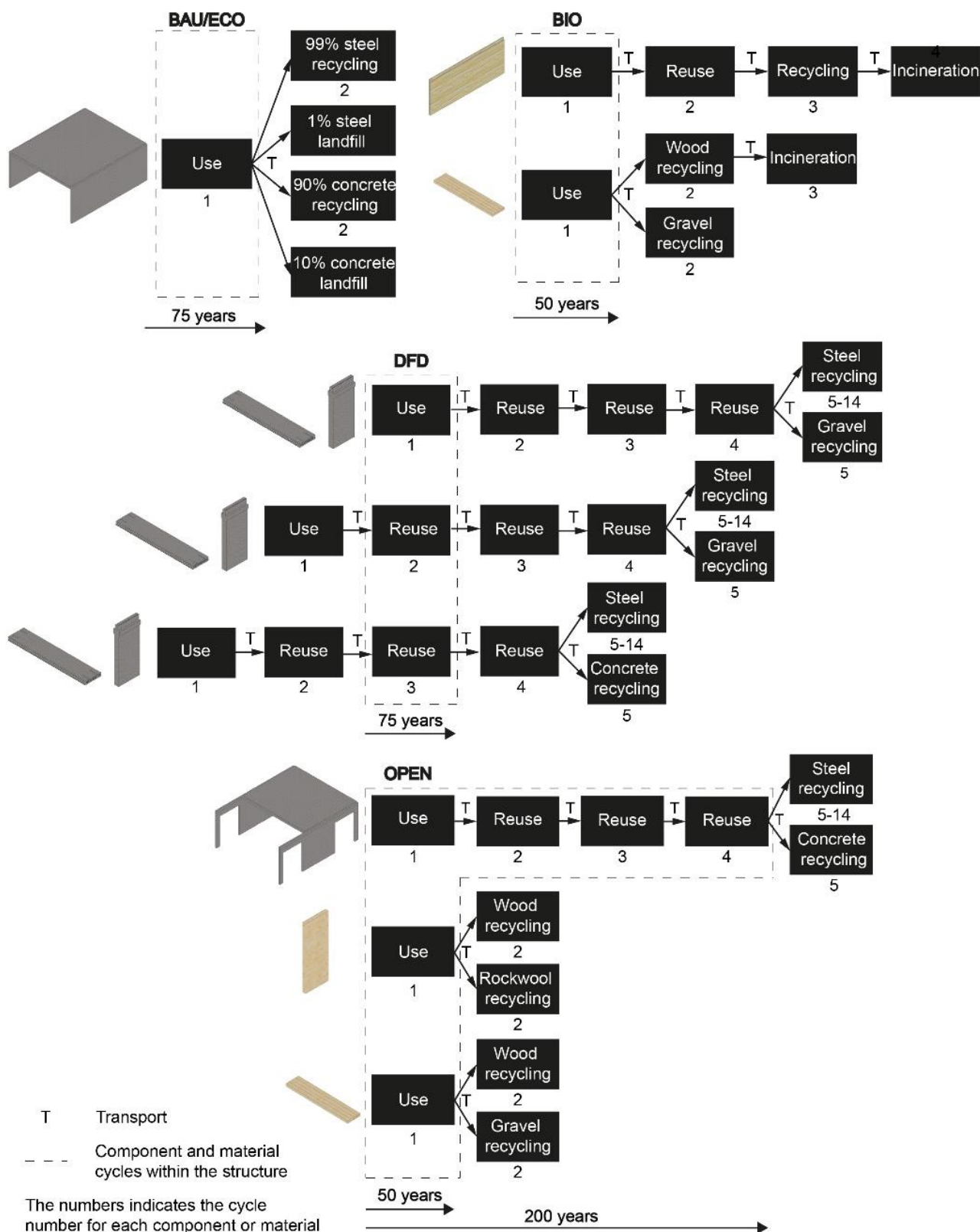
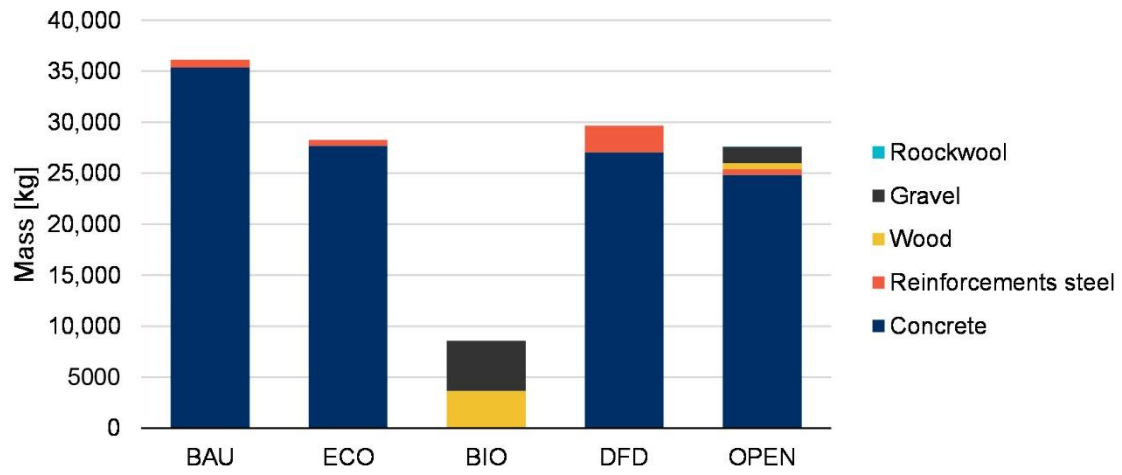
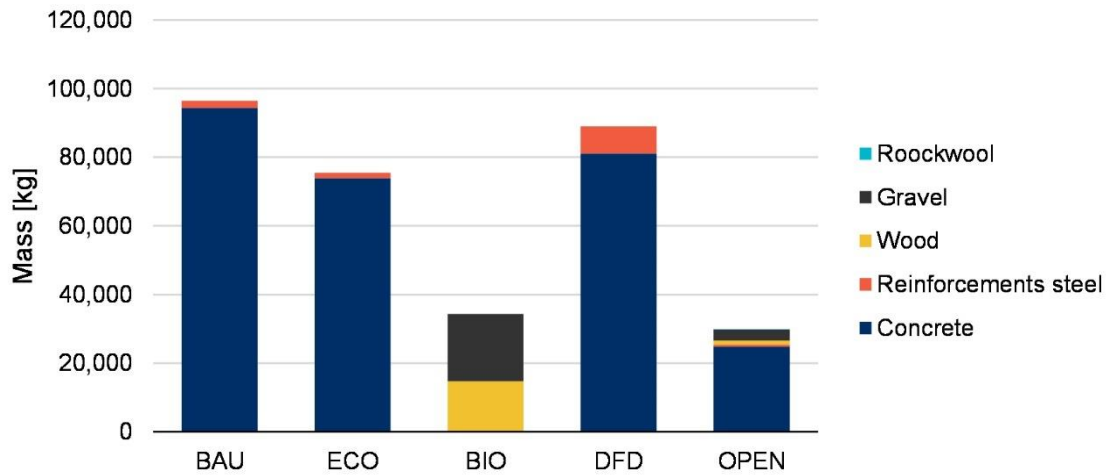


Figure S1. Flow diagrams of the design variants. Component and material cycles that are contained within the punctured line indicates the primary use cycles within the structure after which the components and materials are used for other purposes outside of the structure.



(a) Initial material shares of the variants at year 0



(b) Material share of the variants over the 200-year reference study period

Figure S2. Material shares.

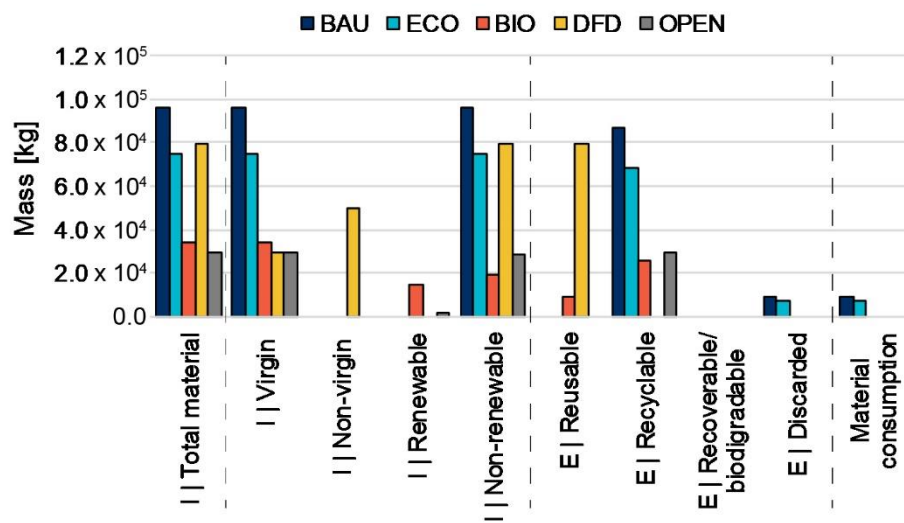


Figure S3. Material Flow Analysis.

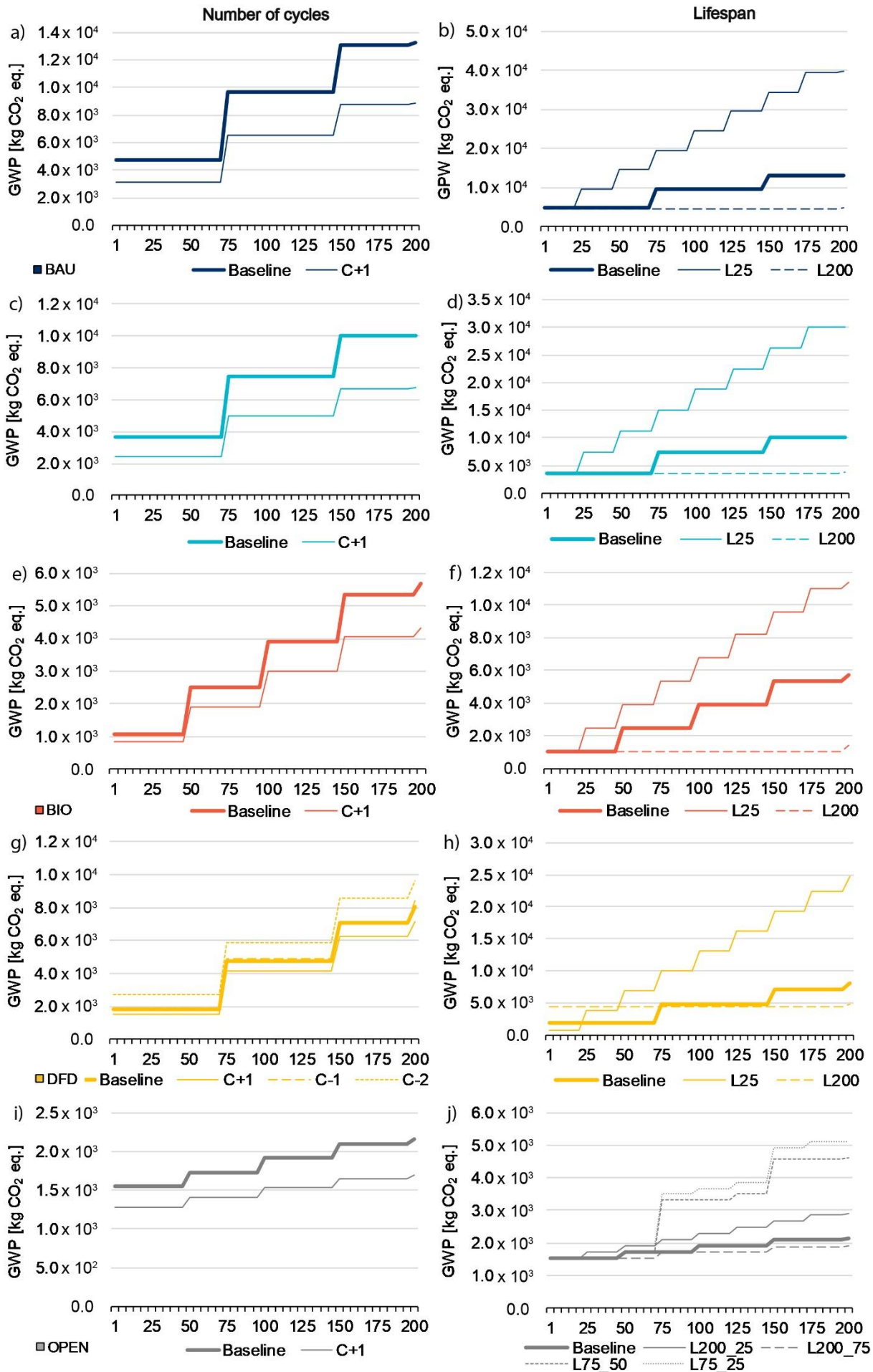


Figure S4. Cumulative GWP of the design variants over 200 years. *Note:* The y-axis of the different graphs are not harmonised i.e. they are individual for each graph to show further details on the variants' and scenarios' temporal GWP performance.

Table S1. Expert sessions. Expert session evaluation of the developed design guidelines. The results of the expert sessions are organised into three main categories: ‘guidelines are valid’, ‘guidelines are not valid’ and ‘improvements’. The percentage of expert sessions in which each issue under each category was raised is shown.

Category	Remarks	Percentage of expert sessions in which issue was raised	Times issue was raised
Guidelines are valid	The guidelines align with existing assumptions and/or circular design strategies	57%	15
	The guidelines are based and relevant CE design variants	14%	1
	The design guidelines are clear	14%	2
	The guidelines are based on, and distinguish between components with different lifespans	14%	3
	Validity		
	The guidelines are vital to transition to a CE in the built environment	14%	1
	Urgency		
	The guidelines stimulate more circular thinking	14%	1
Guidelines are not valid	The design guidelines are useful for practitioners	14%	1
	The guidelines show the complexity of true circularity in the built environment	14%	1
	Relevancy		
	The guidelines can vary depending on the methodology applied to calculate the LCA and MFA, and derive the design guidelines	14%	2
	The design variants are not fully comparable as they have different functionalities, clouding the LCA and MFA results	14%	1
	Some of the guidelines are not valid in all cases (e.g., guideline 9), contradict previous knowledge (e.g., guideline 4) or expectations (e.g., guideline 6)	43%	4
	Some variants and guidelines propose opposite or unlikely combinations of design principles (e.g., modular and material efficiency, long lifespan and re-used materials)	57%	4
	Validity		
Guidelines are not valid	The results of the guidelines are highly dependant on uncertain future cycles	43%	4
	The circularity of the guidelines depends if future cycles can be determined, documented and realised by industry in the long term	43%	13
	Uncertainty		
	The guidelines remain too abstract and general	86%	7
	The guidelines are complex	14%	1
	Guidelines are not sufficient to make truly circular designs, circular assessment (and developing EPD's) of developed designs is necessary	29%	2
	Usability		

Improvements	Relevancy	The guidelines do not provide novel information (are reduced to high level of abstraction where they merely confirm previous guidelines)	29%	2
	Implementability	Industry focusses on current cycles; it does not consider or organise multiple cycles as suggested in the guidelines	57%	5
		In design industry focusses on 'best value' for low initial costs in decision making; including environmental design guidelines will be challenging	14%	1
		Current regulations prevent following guidelines (e.g., legislation on non-virgin materials)	14%	1
		Difficult to use materials from innovative suppliers: they might not be able to prove they conform to the guidelines (i.e., too expensive)	14%	1
		The guidelines ask for many simultaneous changes by industry: priorities need to be identified	14%	1
		In practice it is very complex to 'determine' many of the circular design parameters (e.g., leading lifespan) mentioned in the guidelines	14%	0
	Clarification	Clarify what the guidelines provide 'advice on'	29%	3
		Provide a clear explanation with each guideline	43%	3
		Clarify, simplify and distinguish the terminology in the design guidelines (e.g., lean, open-loop, reloop, bio-based and biodegradable, leading lifespan)	57%	9
	Increasing validity guidelines	Quantify the design guidelines (e.g., scorecard of each design principles)	29%	2
		Curtail the scope of variations between the design variants to improve the clarity of results (and usefulness of the guidelines)	57%	6
		Consider chances of cycles according to design variant (e.g., when glue is applied there is 0% chance of re-use)	14%	1
		Perform additional sensitivity analysis (e.g., future cycles, transport, materials)	14%	3
		Test the guidelines with stakeholders to improve validity and/or implementability	29%	2
	Transparency	Present the LCA and MFA data in parallel with the design guidelines	14%	2
		Describe the applied assessment methods and the method to derive the design guidelines from the LCA and MFA	43%	5
		Visualise the LCA and MFA results more transparent (e.g., visualise impacts per time, impacts per cycle)	29%	2

Ease of use	Provide non-abstract guidelines (e.g., practical advice, concrete rules of thumb, dos and don'ts, visualise the building component)	71%	8
	Provide concrete examples for guidelines	71%	7
	Provide insight in relative contributions of building components to the building over time to determine priorities	14%	1
	Adapt the guidelines into a synthesis tool	43%	3
	Include guidelines based on single design parameters (e.g., choices of materials)	43%	5
	Provide instructions to designers on how and when to use the design guidelines (and/or additional assessment methods) during the design process	14%	1
	Relate the guidelines to other sustainability guidelines (e.g., operational energy efficiency)	14%	1
	Reduce the amount of guidelines to core principles; provide extra background document for further information	29%	4
Implementability	Include guidelines into legislation to incentivise their uptake	14%	1