

A future-proof built environment through regenerative and circular lenses – Delphi approach for criteria selection

S1. Supplementary file S1. Tables with final list of criteria and results

Table S1. List of ‘flows and stocks’ categories and criteria, with main results.

	Criteria	Score	Std.dev.	Median
1.1 Greenhouse gases (GHG)				
1.1.1	Achieve net zero or climate positive embodied emissions for new buildings	93.75%	0.61	5
1.1.2	Achieve net zero or climate positive embodied emissions for new infrastructure	81.25%	0.78	5
1.1.3	Achieve climate positive emissions in operation of new/existing infrastructure	81.25%	0.86	4
1.1.4	Achieve climate positive emissions in operation of new/existing buildings	81.25%	0.9	4.5
1.1.5	Provide urban and non-urban greenhouse gases sinks (storage)	93.75%	0.56	4
1.2 Energy				
1.2.1	Maximise operational energy performance of buildings and infrastructure	96.78%	0.56	6
1.2.2	Positive renewable energy production	90.32%	0.87	6
1.2.3	Grid connectivity providing renewable energy beyond project boundaries	81.25%	0.77	4.5
1.2.4	Reduce the embodied energy content of new and retrofitted infrastructure	81.25%	0.77	4.5
1.2.5	Smart energy systems (monitor and manage)	80.65%	0.82	5
1.2.8	Reduce the embodied energy content of new and retrofitted buildings	75.00%	0.85	5
1.3 Water				
1.3.1	Protect and regenerate natural water systems	100.00%	0.4	6
1.3.2	Assess and prioritise, when adequate, local water autonomy and recirculation (sourcing, treatment, and reuse)	93.75%	0.61	4.5
1.3.3	Maximise operational water performance of buildings and infrastructure	90.32%	0.76	6
1.3.4	Manage stormwater: quantity and quality	83.87%	0.82	6
1.3.5	Enhance supply water quality	77.42%	1.14	5
1.3.6	Reduce embodied water in the built environment	75.00%	0.78	4
1.4 Food system				
1.4.1	Infrastructure/ measures to reduce, reuse and recycle food waste	96.78%	0.55	5
1.4.2	Provide infrastructure and enable local synergies for on-site food waste recycling/ composting linked to local farming and food growing initiatives.	81.25%	0.73	4
1.4.3	Provide spaces for local and diverse food production	70.97%	0.91	5
1.4.4	Facilitate distribution or physical access to local healthy organic food	62.50%	1	4
1.5 Built environment stocks and flows (construction materials)				
1.5.1	Improve lifespan, flexibility, adaptability, repairability, and shared use of buildings and public spaces	100.00%	0.46	5
1.5.2	Increase circularity/ renewal potential of built environment stock	96.77%	0.56	6
1.5.3	Optimise built environment materials inflows and outflows	87.10%	0.67	5
1.5.4	Provide digital/ physical infrastructure (depots/ marketplaces) to enable construction material loops	80.65%	0.78	5
1.5.5	Life cycle sustainability assessment (LCSA) to assess various scenarios (cradle to cradle)	80.64%	0.79	6
1.6 Resource sourcing				
1.6.1	(E) Prioritise reusable resources	100.00%	0.43	5
1.6.2	Eliminate toxic and contaminating resources	93.55%	0.61	5
1.6.3	(E) Prioritise recyclable resources	87.50%	0.68	4

1.6.4	Prioritise biobased materials and inputs	83.87%	0.67	5
1.6.5	Prioritise recovered resources	83.87%	0.68	6
1.6.6.	(N) Implement track and trace measures for resources in the value chain	81.25%	0.78	5
1.6.7	Prioritise sustainability labelled products and transparent supply chains	80.64%	0.76	5
1.6.8	Prioritise local resources	77.42%	0.85	5
1.6.9	(N) Prioritise easily assembled construction components	75.00%	0.93	4
1.7 Material loops in operation				
1.7.1	(E) Circularity requirements in design, operation, deconstruction and waste contracts	93.75%	0.61	5
1.7.2	Track and reduce or eliminate non-recoverable waste	87.10%	0.78	5
1.7.3	Provide digital/ physical infrastructure (depots/ marketplaces) to enable operational material loops	80.65%	0.74	5
1.7.4	Track and increase operational waste recovery and looping rates	77.42%	0.81	6
<i>Note: the median range varies from round 1 (*, 1-6) to round 2 (**, 1-5):</i>				

Table S2. List of ‘urban systems’ categories and criteria, with main results.

	Criteria	Score	Std.dev.	Median
2.1 Adaptive resilience				
2.1.1	Increase the adaptive resilience of critical infrastructure	96.78%	0.56	5
2.1.2	Design, build and adapt urban systems and buildings for future conditions and risk mitigation	93.55%	0.61	5
2.1.3	Identify and assess scenarios for potential geophysical hazards and future climatic conditions	87.10%	0.79	6
2.1.4	Develop and implement contingency, emergency, and recovery plans	87.10%	0.67	5
2.2 Access and diversity				
2.2.1	Increase affordability, socioeconomic plurality and diversity of housing	96.77%	0.64	6
2.2.2	Universal and barrier-free design of all public spaces	90.32%	0.67	6
2.2.3	Improve wayfinding and visual communication	87.10%	0.61	5
2.2.4	Provide accessible, non-fenced or privatized green spaces and parks	87.10%	0.91	5
2.2.5	Access to drinking water and sanitary facilities in public spaces	87.10%	1.15	5
2.2.6	Eliminate energy poverty	87.09%	0.79	6
2.2.7	Facilitate access to amenities and services based on local needs	83.87%	1.06	5
2.2.8	Eliminate water poverty	80.64%	1.03	6
2.3 Mobility infrastructure				
2.3.1	(NC) Charging stations for electric vehicles	93.75%	0.61	5
2.3.2	(E) Integrate electric mobility as a support system to support an energy positive neighbourhood	93.75%	0.61	4.5
2.3.3	Increase transportation availability, affordability, diversity, connection, and access	90.32%	1.09	5
2.3.4	Improve pedestrian mobility network	87.09%	1.04	5
2.3.5	Improve cycling network and support infrastructure	83.87%	1.36	5
2.3.6	Improve quality of transit infrastructure	77.41%	0.99	5
2.3.7	(NC) Provide access to real-time transportation information	75.00%	0.81	4
2.3.8	Provide zero-emission mobility share systems	74.19%	1.15	5
2.3.9	Plan urban freight for effective reverse logistics and resource flows	70.97%	1.47	5
2.4 Smart and digital systems				
2.4.1	Smart infrastructure systems to monitor, optimise, and manage urban systems	80.64%	0.72	5
2.4.2	Ensure private data protection and security	77.42%	1.28	5
2.4.3	(N) Ensure interoperability, resilience and adaptability of smart and digital systems	75.00%	0.93	4
2.4.4	Enhance digital connectivity infrastructure	70.97%	0.83	5
2.4.5	Ensure open access to local public data	64.52%	1.08	5
2.5 Urban fabric				
2.5.1	Improve, when possible, street network connectivity and permeability	93.55%	0.59	5
2.5.2	Prioritise compact, mixed-used and transit-oriented development	83.87%	1.03	5
2.5.3	Optimise urban density (land use efficiency)	80.64%	1.12	6
<i>Note: the median range varies from round 1 (*, 1-6) to round 2 (**, 1-5):</i>				

Table S3. List of ‘outdoor environmental quality’ categories and criteria, with main results.

Criteria		Score	Std.dev.	Median
3.1 Thermal comfort				
3.1.1	Provide extreme weather warnings	83.87%	0.74	6
3.1.2	Preserve/improve the right to solar access on building facades	80.65%	0.81	5
3.1.3	Improve local microclimate and outdoor thermal comfort	70.96%	0.75	5
3.1.4	Provide outdoor spaces for different weather conditions throughout the year	67.74%	0.96	5
3.1.1	Provide extreme weather warnings	83.87%	0.74	6
3.2 Air quality				
3.2.1	Eliminate local sources of air contamination	96.78%	0.65	6
3.2.2	Protect air quality during construction activities and landscape maintenance	93.55%	0.7	5
3.2.3	Actively improve air quality/ clean the air	93.55%	0.71	6
3.2.4	Provide extreme air pollution warnings	83.87%	0.83	6
3.2.5	Monitor/ exhibit real-time air quality levels to citizens	61.29%	0.98	5
3.3 Soundscape				
3.3.1	Measures to control noise	80.65%	1	5
3.3.2	Measures to control vibration	74.20%	1.04	5
3.3.3	Develop and implement a soundscape plan to improve the overall acoustic performance of the area	68.75%	0.99	4
3.4 Visual comfort				
3.4.1	Reduce/ eliminate outdoor light pollution and intrusion	70.97%	0.91	5
3.4.2	Improve outdoor lighting quality (visibility facilitation)	61.29%	0.87	5
3.4.3	Treat outdoor surfaces to minimise glare and discomfort	61.29%	0.93	5
3.5 Beauty and sense of place				
3.5.1	Adopt a people-centred approach for the management of local heritage and cultural goods and references	87.50%	0.7	4.5
3.5.2	Reintegrate and honour local and traditional knowledge and cultures	87.10%	0.8	6
3.5.3	Design to enhance local history, materiality, and ecological & social characteristics	83.88%	0.72	5
3.5.4	Design to promote emotional and sensorial responses	75.00%	0.78	4
3.5.5	Preserve, promote, and highlight sights, landmarks, and public art	64.52%	0.81	5
3.6 Safety and security				
3.6.1	Adopt an urban 'safety and security' approach based on women, children, and older adults	93.75%	0.61	5
3.6.2	Implement crime prevention through environmental design	83.87%	0.74	6
3.6.3	Implement traffic calming and pedestrian safety measures	83.87%	0.91	5
3.7 Public use space (proxemics)				
3.7.1	Variety of restorative open spaces for physical and mental health	93.55%	0.62	6
3.7.2	Variety of possible uses and activities in open public spaces	77.42%	0.74	5
3.7.3	Provide public spaces for events and placemaking interventions	74.19%	0.69	5
3.7.4	Variety of open public spaces that allow for isolation and interaction	67.74%	0.98	5

Table S4. List of ‘bioconnectivity’ categories and criteria, with main results.

	Criteria	Score	Std.dev.	Median
4.1 Biosphere conservation and regeneration				
4.1.1	Restore/renature water bodies	100.00%	0.47	5
4.1.2	Increase and regenerate green areas and corridors within and around the urban fabric	93.75%	0.6	5
4.1.3	Prioritise infill, greyfield and brownfield retrofit and remediation	93.75%	0.6	5
4.1.4	Provide ecological buffers around sensitive areas	90.33%	0.66	5
4.1.5	Regenerate and protect green areas outside the project	90.33%	0.99	5
4.1.6	Conserve and regenerate habitats for threatened and endangered species	90.32%	0.67	6
4.2 Impacts to biosphere and human health				
4.2.1	Assess conditions and implement actions to eliminate and reverse impacts	83.88%	1.07	5
4.2.2	Control construction activity pollution	83.87%	0.87	5
4.2.3	Use only flora adequate for the local context: non-invasive and adapted	77.42%	1.13	5
4.2.4	Reduce earthworks and restore soils previously disturbed	67.75%	1.05	5
4.2.5	(NC/E) Implement bird-safe design guidelines for outdoor glazed surfaces	62.50%	0.78	4
4.3 Ecosystem services				
4.3.1	(Re)design open spaces, infrastructure, and building surfaces for optimal ecosystem services provision	83.87%	0.73	5
4.3.2	Prioritise biomimicry and nature-based solutions for built environment regeneration	77.42%	0.75	5
4.3.3	Conduct an ecosystem services assessment and valuation	67.74%	1.04	5
4.4 Green infrastructure maintenance				
4.4.1	Implement long-term monitoring and maintenance of urban biodiversity and green infrastructure	87.09%	0.91	6
4.4.2	Implement a soil management plan	70.97%	0.76	5
4.4.3	Implement integrated pest management	61.29%	0.86	5

Table S5. List of ‘governance, community, and local economy’ categories and criteria, with main results.

	Criteria	Score	Std.dev.	Median
5.1 Local governance and participation				
5.1.1	Regenerative and circular policies and guidelines for buildings and infrastructure	90.32%	0.67	6
5.1.2	Ensure inclusive, equitable, and collaborative participation of urban stakeholders	90.32%	0.94	6
5.1.3	Support regenerative and circular initiatives developed by the community	87.10%	0.69	5
5.1.4	Monitor and report performance/ satisfaction (pre, during and post transition)	83.87%	0.73	5
5.1.5	Implement regenerative/ circular procurement and contract practices	83.87%	0.76	6
5.1.6	Enhance community governance structures	77.42%	0.78	5
5.1.7	Implement community management system to support transition/ regeneration and operation	77.42%	1.03	5
5.1.8	Support community volunteer initiatives	74.19%	1.01	5
5.2 Education and awareness				
5.2.1	Provide community learning and training spaces (physical and digital)	80.65%	0.84	5
5.2.2	Provide information and training in regenerative and circular solutions for the built environment	77.42%	0.89	6
5.2.3	Ensure wide access to sustainability information	74.19%	0.8	5
5.2.4	Provide information and training in regenerative and circular solutions for the daily life	74.19%	0.98	5
5.3 Local economies and businesses ecosystem				
5.3.1	Enable local and cross-sectoral resource loops	80.65%	0.84	5
5.3.2	Prioritise 'built environment' businesses with regenerative/ circular practices	80.64%	0.85	6
5.3.3	Support/ reward transition of local businesses to regenerative/ circular practices	80.64%	1.06	5
5.3.4	Support and reward businesses with fair trade and socioenvironmental practices	77.42%	0.85	5
5.3.5	Foster transparency and corporate responsibility of local businesses	74.20%	0.82	5
5.3.6	Prioritise local waste management cooperatives	70.97%	0.95	5
5.3.7	Promote repair shops, cafes, and events	64.52%	1.07	5
5.3.8	Enable local 'banks of talents' for the community	64.51%	0.96	5
5.3.9	Prioritise community-owned/ controlled business	62.50%	1.16	4