

# Reconstruction Site

Re-designing the disposable Expo

by

A. Scott Proudfoot

A thesis

presented to the University Of Waterloo

in fulfilment of the

thesis requirement for the degree of

Master of Architecture

Waterloo, Ontario, Canada, 2017

© A. Scott Proudfoot 2017

*Author’s Declaration*

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.



# Abstract

Building, supported by the practice of architecture, is churning resources into waste at an alarming rate. Our method of construction has its inevitable conclusion in a pile of rubble. Lamentably, the natural resources we build with are finite, and our exploitation of these has nearly reached its peak. As humanity strives for a renewable energy future, architecture must engage in the renewable use of materials.

In the long term future, architects need to design buildings so their materials can be recovered, refurbished and reused. Principles for designing in circular life cycles were laid out by McDonough and Braungart in their 2002 book, *Cradle to Cradle*.<sup>1</sup> In more than a decade since the book was published, there is little evidence that the process of architecture has changed to support design for disassembly and the reuse of materials. This thesis aims to outline a method of design for material reuse that supports a healthy circular flow of material life, death and rebirth.

World Expositions have become the epitome of disposable architecture, with renowned architects designing pavilions with an intended life span of six months. This thesis proposes a transformation of the Expo type from an endgame of waste to one of reuse. A contemplated Expo Toronto in 2025 provides the opportunity to reclaim a reputation for showcasing the future. The proposed brief for such an Expo challenges countries to exhibit stories of regeneration in an event built on the theme of reuse and recycling. The Expo is an ideal venue for the design of prototype pavilions assembled out of renewable and reusable materials. This thesis proposes two pavilion types, which at the Expo's conclusion will be immediately reused in communities across Canada. The first type is designed to be entirely recycled when it is no longer needed. The second pavilion type is assembled of material which can be composted, returning nutrients to the soil. The resulting buildings will be adaptable to change, reusable in parts, and return their materials to circular flows at end of life.

---

1. William McDonough and Michael Braungart, *Cradle to Cradle : Remaking the Way We Make Things* (New York: North Point Press, 2002), 166.

# Acknowledgements

Thank you to Terri Meyer Boake, my supervisor, for guidance and inspiration throughout the adventure of writing a thesis. Your keen interest and strong opinions helped me sharpen the argument. I appreciate the time and energy you gave to support my work.

Thank you to Jane Hutton for broadening my academic perspective through readings and our discussions. I appreciate the time you spent reading early thesis drafts and your ever-accurate comments.

Thank you to Val Rynnimeri for mentoring me in the early stages of a thesis idea, and for returning at the end to lend your knowledge and criticism.

Thank you to my friends for making the whole process fun, for your honest critiques and for entertaining distractions.

And finally, thank you to my family, for steady support and invaluable proofreading of the thesis.

Table of Contents

Author’s Declaration	iii
Abstract	v
Acknowledgements	vii
Table of Contents	viii
List of Figures	x
<b>1. Introduction</b>	<b>2</b>
Architecture becomes waste	3
Finite resources and scarcity	5
Material sustainability only matters if we fix climate change.	6
In the wider discourse on sustainability	7
Resources and waste in the building industry	10
<b>2. The challenges of circular material streams</b>	<b>14</b>
Waste is worth much more than we care to think about.	15
Recycling buildings	18
Composting buildings	20
Adapt!	21
Preserving material value	22
Design for disassembly	23
Uncertainty and limits to Modernist optimization.	25
Reusable will mean local	27
Conclusion	28
<b>3. Designing material flows</b>	<b>32</b>
Beginning with good chemistries	34
White-listing building materials	36
Material flow diagrams	38
Conclusion	46
<b>4. Precedents</b>	<b>50</b>
Learning from impermanence	50
<b>5. Design for Expo Toronto 2030</b>	<b>60</b>
Learning from Milan	62
Designing a regenerative Expo	64
The opportunity	66

Toronto rejects Expo waste	68
A proposal for Expo 2030 in Toronto	70
Regenerative Stories	72
Pavilion design	76
<b>6. Design Proposal for a Leased Expo Pavilion</b>	<b>82</b>
The story of a building’s whole life cycle	82
Program flexibility	87
A second user community	88
Client and Program	90
Adaptability and module sizing	96
<b>6.2 Compostable Pavilion</b>	<b>98</b>
Building material flow diagram	104
Assembly and disassembly	110
At the conclusion of the Expo	114
Beginning a second life	116
<b>6.3 Recycleable Pavilion</b>	<b>118</b>
Building material flow diagram	124
Building services	130
At the conclusion of the Expo	134
Beginning a second life	136
<b>7. Conclusion</b>	<b>140</b>
Epilogue	142
<b>Bibliography</b>	<b>146</b>
<b>Appendix A</b>	<b>154</b>
<b>Appendix B</b>	<b>156</b>

List of Figures

1. Introduction

- 1
- Figure 1.1 Mixed wood, metal and plaster waste in a residential dumpster. These valuable materials will be forever lost in a landfill.  
Photograph by author
- 2
- Figure 1.2 Demolition of the Swiss pavilion at Expo 2010 in Shanghai.  
Photograph by Bartosz Kolonko, August 21, 2015. <http://bartoszkolonko.ch/blog/2015/8/demolishing>
- 4
- Figure 1.4 The relationship between resources and waste  
Redrawn by author from: Choppin, Julien, and Nicola Delon. *Matière grise: matériaux réemploi architecture*. Paris: Pavillon de l’Arsenal, 2014.
- 4
- Figure 1.3 The conversion of buildings into waste.  
Photograph by Helena Normark, “Demolition.” <https://www.flickr.com/photos/helenanormark/7723709822/>
- 7
- Figure 1.5 Spray foam insulation is very effective at reducing energy use in buildings, but by gluing everything together, material reclamation will be impossible for an entire generation of buildings.  
Source: <http://www.biggamereptiles.com/media/37bffb5-78f7-4a58-b5bc-6ae0a458c5e9.JPG>
- 7
- Figure 1.6 Circular flows of material through manufacturing, use, recovery and recycling.  
Source: Altanova, <http://www.altanova-energy.com/wp-content/uploads/2015/06/LCA.png>
- 9
- Figure 1.7 Recycling has been a symbol of the environmental movement since the first earth day in 1970.  
Source: clker, <http://www.clker.com/cliparts/K/Y/4/Y/F/K/green-recycle-symbol-md.png>
- 10
- Figure 1.8 Most of our buildings are waiting for a trip to the landfill.  
Photograph by Jack Landau. Source: <http://urbantoronto.ca/news/2014/05/demolition-work-begins-phase-three-regent-park>

2. The challenges of circular material streams

- 13
- Figure 2.1 Interlocking concrete blocks junked at the Cambridge landfill. Even the most durable modular systems can be made obsolete by changes of fashion.  
Photograph by author
- 14
- Figure 2.2 Biological and technical life cycles from *Cradle to Cradle*.  
Source: <http://wp.auburn.edu/sustainability/wp-content/uploads/2016/04/Cradle-to-Cradle.jpg>
- 16
- Figure 2.3 Weight of materials in Canada’s buildings by decade and projected into the future. (millions of tons)  
Data was derived from Statistics Canada historical construction expenditures, see Appendix A. for sources.  
By author

- 16
- Figure 2.4 Weight of consumer products in Canada, by decade and projected into the future. (millions of tons)  
See Appendix A. for data sources.  
By author
- 17
- Figure 2.5 Canadian landfill waste projected into the future assuming flat growth. Construction and demolition waste will overtake all other waste sources combined.  
By author
- 18
- Figure 2.6 Scrap Metal is reliably valuable and dense, encouraging recycling.  
Source: <https://ichemepresident.files.wordpress.com/2014/07/scrap-metal.jpg>
- 19
- Figure 2.7 Sorting of recycling can be partially automated but the process is still labour intensive.  
Source: <https://i1.wp.com/diversified-recycling.com/wp-content/uploads/2013/05/New-Recycle-Center-078.jpg>
- 20
- Figure 2.8 Current composting methods use industrial machinery to turn heaps of organic materials.  
By Author
- 21
- Figure 2.9 Composting in place would more closely resemble a forest floor.  
Source: <http://chanmanthechinaman.deviantart.com/art/forest-floor-293038028>
- 22
- Figure 2.10 Shearing building layers by Stewart Brand. A building should accommodate renewal of layers at different paces.  
Brand, Stewart. *How Buildings Learn : What Happens after They’re Built*. New York, NY: Viking, 1994.
- 22
- Figure 2.11 Adaptive reuse takes forms never imagined by the original users, such as this hosiery factory converted into the Waterloo School of Architecture.  
Source: Photograph by Fred Hunsberger, <https://www.flickr.com/photos/waterlooarchitecture/29524656523>
- 24
- Figure 2.12 Scaffolding connections are reusable many times, as they can be easily disassembled without damage.  
By Author
- 25
- Figure 2.13 Efficient and fragile. Imagine trying to weld another mounting point onto this structural steel connection, it would be impossible.  
Source: Anna Winston, Arup unveils its first 3D-printed structural steel building components. *Dezeen.com*. [http://static.dezeen.com/uploads/2014/06/Arup-3d-print-ed-steel\\_dezeen\\_784\\_3.jpg](http://static.dezeen.com/uploads/2014/06/Arup-3d-print-ed-steel_dezeen_784_3.jpg)
- 26
- Figure 2.15 Advice for low maintenance architecture in 1975 seems hopelessly out of date.  
Source: Feldman, Edwin B. *Building Design for Maintainability*. New York: McGraw-Hill, 1975. 115.

List of Figures

- 26
- Figure 2.14 Nakagin capsule tower, the poster child of reconfigurable metabolist buildings, was never renovated. It now awaits demolition.  
Source: <http://www.inspirationde.com/wp-content/uploads/2015/04/all-sizes-tokyo-nakagin-capsule-tower-flickr-photo-sharing-1429938095nkg48.jpg>
- 27
- Figure 2.16 Ikea has changed their kitchen cabinet module size, rendering twenty years of kitchens obsolete.  
Source: <http://www.baedaily.com/wp-content/uploads/2015/09/ikea1.jpg>

3. Designing material flows

- 31
- Figure 3.1 Discarded bricks at the Cambridge landfill. North Americans seldom reuse bricks because the labour cost of cleaning and storing masonry is too costly.  
Photograph by author
- 34
- Figure 3.2 Interface carpet tiles declare their product as intended for recycling, but the bulky backing is a composite of polyester, vinyl acetate, toxic PVC, and glass fibres. Post consumer carpet tiles make up only 23% of recycled products, and that is unlikely to increase because polymer degradation in recycling requires a substantial fraction of new material to maintain desired properties.<sup>7</sup>  
Source: Reclaimed Carpet Tiles, Interface.com. [http://interfaceinc.scene7.com/is/image/InterfaceInc/wc\\_reclaimedtile-gal?\\$960x540\\$](http://interfaceinc.scene7.com/is/image/InterfaceInc/wc_reclaimedtile-gal?$960x540$)
- 35
- Figure 3.3 Red list of chemicals for which there is no safe level of exposure.  
“The Red List,” *International Living Future Institute*, accessed December 13, 2016, <https://living-future.org/declare/about/red-list/> Formatting by Author.
- 37
- Figure 3.4 Common construction materials separated by life cycle.  
By Author
- 39
- Figure 3.5 Diagram identifying components of the vinyl edging profile  
By Author
- 39
- Figure 3.6 Material life cycle diagram of a polyvinyl chloride edging profile.  
By Author
- 41
- Figure 3.7 Material flow diagram for wood treatments  
By Author
- 42
- Figure 3.8 Material flow diagram for cellulose insulation  
By Author
- 43
- Figure 3.9 Material flow diagram for rock wool insulation  
By Author
- 44
- Figure 3.10 Material flow diagram for wood adhesives  
By Author
- 45
- Figure 3.11 Material flow diagram for polyethylene  
By Author

4. Precedents

- 49
- Figure 4.1 Used doors for sale at Kitchener’s Habitat for Humanity ReStore. Recovery and storage of reusable materials is expensive.  
Photograph by author
- 51
- Figure 4.2 The Crystal Palace, Joseph Paxton (1851)  
Source: [https://upload.wikimedia.org/wikipedia/commons/a/ad/Steel\\_engraving%3B\\_Crystal\\_Palace%2C\\_1851\\_exhibition\\_Wellcome\\_L0023919.jpg](https://upload.wikimedia.org/wikipedia/commons/a/ad/Steel_engraving%3B_Crystal_Palace%2C_1851_exhibition_Wellcome_L0023919.jpg)
- 52
- Figure 4.3 Eiffel Tower (1889)  
Source: <http://www.eiffeltowerguide.com/images/Stages%20of%20Eiffel%20Tower.jpg>
- 53
- Figure 4.4 Swiss Sound Box, by Peter Zumthor (2000)  
Source: [https://carolinaverdial.files.wordpress.com/2011/08/peter-zumthor\\_swiss-sound-box-3.jpg](https://carolinaverdial.files.wordpress.com/2011/08/peter-zumthor_swiss-sound-box-3.jpg)
- 53
- Figure 4.5 Cellophane house, KieranTimberlake (2008)  
Source: <http://www.kierantimberlake.com/pages/view/14/cellophane-house/parent:3>
- 55
- Figure 4.6 Holding Pattern at MoMA Interboro (2011)  
Source: Interboro Partners, [http://www.interboropartners.com/upload/2015-12-28/holding\\_pattern\\_51.xl.jpg](http://www.interboropartners.com/upload/2015-12-28/holding_pattern_51.xl.jpg)
- 55
- Figure 4.7 Hy-Fi by The Living (2014)  
Source: The Living, [http://www.thelivingnewyork.com/images/hyfi\\_01.jpg](http://www.thelivingnewyork.com/images/hyfi_01.jpg)
- 56
- Figure 4.8 Toyo Ito Serpentine gallery pavilion (2002)  
Source: <http://www.archdaily.com/344319/serpentine-gallery-pavilion-2002-toyo-ito-cecil-balmond-arup/51423db8b3fc4bae2c00004e-serpentine-gallery-pavilion-2002-toyo-ito-cecil-balmond-arup-photo>
- 56
- Figure 4.9 The Toyo Ito pavilion is now a beach-side cafe (2015)  
Source: <https://www.theguardian.com/artanddesign/2015/jun/16/serpentine-pavilion-second-lives-zaha-hadid-toyo-ito-frank-gehry#img-2>
- 57
- Figure 4.10 ICEHouse by William McDonough (2016)  
Source: <http://assets.inhabitat.com/wp-content/blogs.dir/1/files/2016/01/william-mc-donough-partners-icehouse-4.jpg>

5. Design for Expo Toronto 2030

- 59
- Figure 5.1 Shattered acrylic rods during demolition of the British Seed Cathedral at Expo 2010 represent the waste that follows temporary buildings.  
Source: Adam Minter, 2010. <http://shanghaiscrap.com/wp-content/uploads/2010/12/DSC00054.jpg>
- 60
- Figure 5.2 After Expo ‘67, demolition of Man the Explorer pavilion with Buckminster Fuller’s dome in the background.  
Source: Phillip Buehler, [http://www.dchillier.com/expo\\_ruins/expo-16.jpg](http://www.dchillier.com/expo_ruins/expo-16.jpg)
- 61
- Figure 5.3 Demolition of the Yukon Pavilion at Expo ‘86 in Vancouver.  
Source: Gregory Melle, November 30, 1986, <https://www.flickr.com/photos/can-adagood/3068761279>

List of Figures

61      Figure 5.4 Destructive demolition of the Thai Pavilion after Expo 2015. How can we end this pattern of waste?  
Source: [http://milano.corriere.it/notizie/cronaca/16\\_gennaio\\_25/Expo-dismantling-smantellamento-padiglioni-smontati-bc248e30-c333-11e5-b326-365a9a1e3b10.shtml](http://milano.corriere.it/notizie/cronaca/16_gennaio_25/Expo-dismantling-smantellamento-padiglioni-smontati-bc248e30-c333-11e5-b326-365a9a1e3b10.shtml)

63      Figure 5.5 Herzog and De Meuron’s masterplan for Expo 2015, featuring mostly farmland, with shelter canopies by the organisers.  
Source: [https://arkhitekton.files.wordpress.com/2009/09/hdm\\_milan2015\\_006.jpg](https://arkhitekton.files.wordpress.com/2009/09/hdm_milan2015_006.jpg)

64      Figure 5.6 Site remediation after Expo Milan 2015  
Source: [http://www.askanews.it/regioni/lombardia/Expo-congelamento-invernale-albero-della-vita-costa-360000-euro\\_711674161.htm](http://www.askanews.it/regioni/lombardia/Expo-congelamento-invernale-albero-della-vita-costa-360000-euro_711674161.htm)

65      Figure 5.7 Expo architecture can learn from the low impact inhabitation of fields during a music festival. After the event the land will be returned to productive use.  
Source: [https://abcnews.go.com/images/International/EPA\\_week\\_in\\_pictures\\_tents\\_jef\\_160819.jpg](https://abcnews.go.com/images/International/EPA_week_in_pictures_tents_jef_160819.jpg)

66      Figure 5.8 Newspaper article on the Toronto Expo debate.  
Screen capture of <http://www.theglobeandmail.com/news/toronto/toronto-exploring-potential-bid-to-host-2025-world-Expo/article28367594/>

68      Figure 5.9 One year later the debate is over “for now” (John Tory)  
Screen capture of <http://www.theglobeandmail.com/news/toronto/toronto-mayor-calls-for-end-to-expo-2025-bid-prioritizing-transit-and-public-housing/article32541876/>

70      Figure 5.10 Schematic masterplan for Expo 2030. The Expo grounds are populated with recyclable and compostable pavilions developed in the following chapter.  
By author

72      Figure 5.11 Proposed Expo 2030 poster representing the beautiful diversity of inviting the world in.  
By author

74      Figure 5.12 Time lapse of expo site from construction through use and regeneration.  
By Author

78      Figure 5.13 High tech leased pavilions at Expo ‘86, Vancouver  
Source: [https://upload.wikimedia.org/wikipedia/commons/4/4e/WEST\\_GERMAN\\_PAVILION\\_AT\\_EXPO\\_86,\\_VANCOUVER,\\_B.C..jpg](https://upload.wikimedia.org/wikipedia/commons/4/4e/WEST_GERMAN_PAVILION_AT_EXPO_86,_VANCOUVER,_B.C..jpg)

79      Figure 5.14 Lebanon Pavilion, 2010  
Source: <http://www.evolo.us/architecture/all-the-pavilions-at-the-2010-shanghai-world-Expo/>

79      Figure 5.15 Brunei Pavilion, 2010  
Source: <http://www.evolo.us/architecture/all-the-pavilions-at-the-2010-shanghai-world-Expo/>

79      Figure 5.16 Sri Lanka Pavilion, 2010  
Source: <http://www.evolo.us/architecture/all-the-pavilions-at-the-2010-shanghai-world-Expo/>

79      Figure 5.17 Colombia Pavilion, 2010  
Source: <http://www.evolo.us/architecture/all-the-pavilions-at-the-2010-shanghai-world-Expo/>

79      Figure 5.18 Vietnam Pavilion, 2010  
Source: [https://lh4.ggpht.com/\\_vqAAFYgeDm8/THuz\\_f4P\\_QI/AAAAAAAAAEsI/wRaow1cOdYE/world\\_Expo\\_post\\_pic30.jpg?imgmax=1280](https://lh4.ggpht.com/_vqAAFYgeDm8/THuz_f4P_QI/AAAAAAAAAEsI/wRaow1cOdYE/world_Expo_post_pic30.jpg?imgmax=1280)

79      Figure 5.19 Iceland Pavilion, 2010  
Source: [https://upload.wikimedia.org/wikipedia/commons/d/d2/Iceland\\_Pavilion\\_of\\_Shanghai\\_Expo.jpg](https://upload.wikimedia.org/wikipedia/commons/d/d2/Iceland_Pavilion_of_Shanghai_Expo.jpg)

6. Design Proposal for a Leased Expo Pavilion

81      Figure 6.1 Leaves returning their nutrients to the soil through decomposition. Buildings should strive to fade away as gracefully as leaves.  
Photograph by author.

83      Figure 6.2 Compostable pavilion (top) and recyclable pavilion  
By Author

85      Figure 6.3 Exterior view of Expo pavilions in their first life  
By Author

87      Figure 6.4 Life cycle overview of the pavilion design.  
By Author

88      Figure 6.5 Northern destination communities for the regeneration of Expo pavilions.  
Map by author. Data sources: <http://www.diva-gis.org/gdata> and <http://www.arcgis.com/home/item.html?id=0549fcf91a47426ab423ea0f36ccc3d4>

89      Figure 6.6 Attawapiskat First Nation youth poster from Idle No More protests in Ottawa. 2016  
Source: <https://tworowtimes.com/wp-content/uploads/2016/04/Helping-hands-initiative.jpg>

91      Figure 6.7 Open span space in the Expo pavilions hosting an exhibit  
By Author

91      Figure 6.8 The Expo pavilion reused as a small town community centre.  
By Author

93      Figure 6.9 Three possible buildings from the Expo pavilion kit of parts.  
By Author

95      Figure 6.10 Exterior view of an Expo pavilion transformed into a northern community centre.  
By Author

97      Figure 6.11 Module size diagrams  
By Author



List of Figures

6.2 Compostable Pavilion

99	Figure 6.12 Interior perspective of the compostable pavilion By Author
101	Figure 6.13 Exterior axonometric of compostable pavilion By Author
101	Figure 6.14 Alternate configurations of the compostable pavilion. By Author
103	Figure 6.15 View of a basketball game in the new northern recreation centres. By Author
109	Figure 6.16 Material flow diagram for the compostable pavilion. By Author
110	Figure 6.17 Exploded section assembly diagram By Author
113	Figure 6.18 Orthographic drawings of compostable pavilion By Author
114	Figure 6.19 Detail of compostable pavilion during the Expo By Author
116	Figure 6.20 Detail of compostable pavilion as a community centre By Author

6.3 Recycleable Pavilion

119	Figure 6.21 Interior perspective of recyclable pavilion By Author
121	Figure 6.22 Exterior axonometric of recyclable pavilion By Author
121	Figure 6.23 Alternate configurations of the recyclable pavilion By Author
123	Figure 6.24 View of an Expo installation in the leased pavilion By Author
129	Figure 6.25 Material flow diagram for recyclable pavilion By Author
131	Figure 6.27 Detail section of building services. During the Expo building services are exposed for easy installation of exhibits. By Author
131	Figure 6.26 Detail section of building services. For longer term use a continuous access panel conceals services in a chase. By Author

133	Figure 6.28 Orthographic drawings of recyclable pavilion By Author
134	Figure 6.29 Detail of recyclable pavilion during the Expo By Author
136	Figure 6.30 Detail of recyclable pavilion as a community centre By Author

7. Conclusion

139	Figure 7.1 Reclaimed sinks and toilets at the Cambridge waste transfer station Photograph by author
-----	--

Appendix A

155	Figure 7.2 Weight of materials in Canada’s buildings by decade and projected into the future. (millions of tons) By author
155	Figure 7.3 Weight of consumer products in Canada, by decade and projected into the future. (millions of tons) By author
155	Figure 7.4 Canadian landfill waste projected into the future assuming flat growth. Construction and demolition waste will overtake all other waste sources combined. By author



# 1.

## *Introduction*

**Figure 1.1** Mixed wood, metal and plaster waste in a residential dumpster. These valuable materials will be forever lost in a landfill.



## 1. Introduction

The twentieth century was a period of exploration and extraction. Humans settled the most remote locations on earth and expanded cities to capture more than half the world's population. But society's wasteful consumption habits are nearing ecological limits.<sup>1</sup> Environmental historian John Robert McNeil asserts that the past hundred years of rapid growth have been so ecologically disruptive that natural feedback cycles will guarantee perpetual disturbances.<sup>2</sup> The building industry has ignored the cyclical character of nature for too long, preferring a linear model of extraction, use and disposal. Architecture can flourish in the future by embracing a more ecological model of life-cycle thinking. The short lives of temporary architecture offer the biggest opportunity for improvement from circular strategies of recycling and reuse.

World Expos are the epitome of waste today but could offer a hope for the future. The problem of churning scarce materials into waste is uniquely urgent at temporary events. Expos were intended to exhibit progress, but lately they have lost substance. Demonstrations of new technologies to the world have receded in importance as pavilions focus on public relations and national image.<sup>3</sup> The massive volumes of waste resulting from disposal of temporary buildings and exhibits used only six months overshadows the benefits of an international event. While attempting to display a vision of the future, world expositions have become acute case studies in waste creation.

Expos have traditionally looked to the future, but they are currently pointing in a troubling direction. Shanghai Expo 2010 was a showcase for speedy, disposable development.<sup>4</sup> Dubai's plans for Expo 2020 describe a wildly expensive desert city of questionable sustainability.<sup>5</sup> The cost of



Figure 1.2 Demolition of the Swiss pavilion at Expo 2010 in Shanghai.

1. Ken Geiser, *Materials Matter : toward a Sustainable Materials Policy* (Cambridge, MA: MIT Press, 2001), 2.
2. John Robert McNeill, *Something New under the Sun : An Environmental History of the Twentieth-century World* (New York: W.W. Norton & Company, 2000), xxiv.
3. Florian Heilmeyer, "Putting an End to the Vanity Fair," *Uncube Magazine* no. 32 (2015), 54, <http://www.uncubemagazine.com/magazine-32-15358283.html#!/page54>
4. Juliet Song, "The Phenomena of China's Disposable Buildings," *Epoch Times*, January 3, 2016, <http://www.theepochtimes.com/n3/1932144-the-phenomena-of-chinas-disposable-buildings/>
5. Dubai's Expo will be located 40km out of the city, in the desert. Organizers plan to spend heavily on show-stopper pavilions and technology to make the site habitable. When the United Arab Emirates oil money runs out the cost of high tech desert living will be unsustainable. "Site and Legacy," Expo 2020 Dubai, accessed December 11, 2016, <http://expo2020dubai.ae/content/legacy.aspx>

hosting a world exposition is hard to justify in responsible countries, who have surrendered hosting to developing countries as a marketing event. If Expos are seen as advertisements by their organizers, then there is no expectation that the money being spent returns value. Expo architecture loses purpose when it is reduced to ephemeral marketing. The developed world needs to reclaim the Expo and re-conceive it as a responsibly executed event for cultural exchange.

In 2016 Toronto had a unique opportunity to bid on a World Expo in 2025.<sup>6</sup> The event could have been a catalyst for regeneration of industrial lands and new infrastructure, but Toronto's recent decision not to host was an explicit rejection of financial and material waste.

This thesis reconsiders the missed opportunity by designing a waste-free Expo through material reuse and recycling. It outlines a plan for Toronto to host a sustainable world's fair as a role model for the world. Through the design of prototype generic pavilions for an Expo, the thesis develops the eventual recycling and composting of buildings at end of life to prevent generating waste. Instead of designing a bespoke national pavilion, generic pavilions are more adaptable to reuse and the lessons learned are widely applicable in architecture.<sup>7</sup> The goal is to transform the designed waste of architecture to circular flows of material reuse and recycling.

Hosting a world exposition is a unique chance to learn from the flexibility and disassembly of temporary buildings. Architecture's most iconic adaptable buildings, the Pompidou Centre and Nakagin Capsule Tower, have never been altered as they were intended to be. A temporary exposition provides the chance to practice design for disassembly, reuse, and recycling.

### Architecture becomes waste

Engineering professor Peter Guthrie eloquently describes the inevitable destination of buildings in a pithy phrase: "all architecture is but waste in transit"<sup>8</sup> Contemporary buildings are consigned to landfill by choices made in design and construction. The building industry creates a

6. Allison Ridgway, "Toronto exploring potential bid to host 2025 World Expo," *Globe and Mail*, January 24, 2016.
7. Kiel Moe, *Convergence : An Architectural Agenda for Energy* (London: Routledge, 2013), 246.
8. Jeremy Till, *Architecture Depends* (Cambridge, MA: MIT Press, 2009), 67.

disproportionate share of landfill waste due to a bulky product. Buildings have not always been disposable however; in the past, scarcity of material encouraged the reuse of bricks across generations of structures. Subsistence farmers and indigenous peoples still build closed life cycle shelters out of local materials.<sup>9</sup> However, contemporary architecture has abandoned the practice. Cost and time pressures discourage the understanding and use of local materials when commodities are available. Modern migration for education, work or retirement removes designers from a long term connection to the land. Decisions made will not affect them or their descendants. Even when local materials are plentiful, their uniqueness may not be accepted by a regulatory framework that values uniformity and safety.<sup>10</sup> Our search for ever more modern ways of building has left behind recovery and reuse of material.

Modernity feverishly worked to bring everyone plenty, but in doing so increased the scarcity of resources. Everything we touch is designed, and with a few exceptions will one day become landfill.

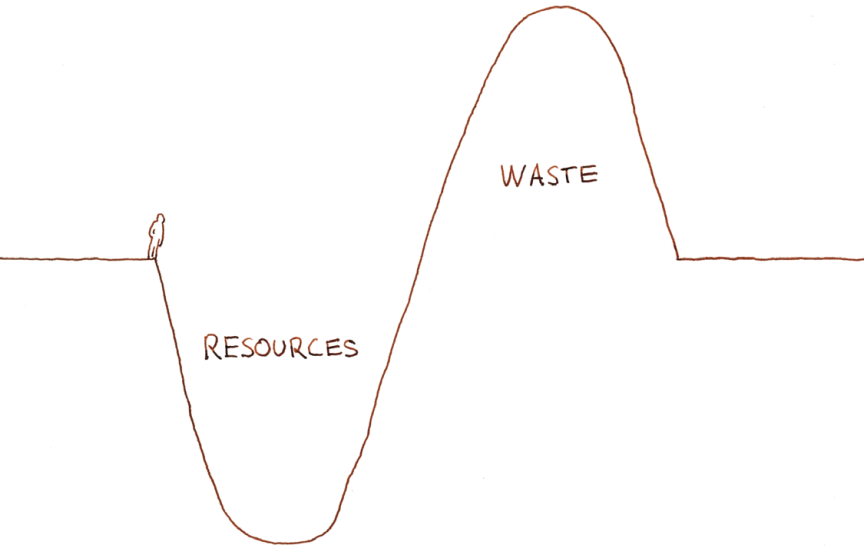


Figure 1.4 The relationship between resources and waste

9. Bjørn Berge, *The Ecology of Building Materials* (Oxford ; Boston: Architectural Press, 2000), 121.

10. Sebastian El khouli and Viola John and Martin Zeumer, *Sustainable Construction Techniques : From Structural Design to Interior Fit-out : Assessing and Improving the Environmental Impact of Buildings* (Munich: DETAIL, Institut Für Internationale Architektur-Dokumentation, 2015), 56.

It will be challenging to disassemble and recycle the staggering volume of resources locked into buildings. Designers have a responsibility to redesign products for a better fate than disposal.

Finite resources and scarcity

Earth's finite nature was most poetically described by visionary engineer Buckminster Fuller in his 1969 book, *Operating Manual for Spaceship Earth*.<sup>11</sup> Our planet is likened to a ship flying through space, with finite resources and no possibility of resupply. Limitations are hard to accept though, as humans feel uncomfortable with a restricted future. In a much debated 1972 report, *Limits to Growth*, international think tank the Club of Rome predicted that the economy would run up against hard limits in the earth's systems.<sup>12</sup> The slowly accumulating effects of climate change are troublesome evidence that we are reaching those limits.

Some distance further into the future, limits on material extraction exist. The concept of peak oil may be familiar to many, but challenges also lie ahead for the extraction of other minerals. Peak copper, cobalt, phosphorus and even water are driving exploration and economic shifts.<sup>13</sup> Humanity will not run out of copper all at once, but further extraction is increasingly costly and environmentally damaging. Every new mine chases ore of lower and lower purity, requiring more excavation, disruption and increased cost. The cost of extracting additional resources should drive us to be more careful with what we already have. Unfortunately, humanity is breezily converting resources into a blended waste stream. Once landfilled, only metals and some plastics can be recovered by mining.<sup>14</sup> Construction and demolition waste is of particularly low value to landfill miners, who depend on selling power from the incineration organic materials. The

11. Richard Buckminster Fuller, *Operating Manual for Spaceship Earth* (New York: Simon and Schuster, 1969), 49.

12. Donella H. Meadows et al., *The Limits to Growth : A Report for the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books, 1972), 23.

13. Michael T Klare, *The Race for What's Left : The Global Scramble for the World's Last Resources* (New York: Metropolitan Books, 2012), 39.

14. Kathryn Warren and Adam Read, "Landfill Mining: Goldmine or Minefield?" *Waste Management World*, November 2, 2014, <https://waste-management-world.com/al/landfill-mining-goldmine-or-minefield>

In addition, the risk of exposing asbestos or another toxic material is an impediment to opening old landfills. Current landfill mining is conducted primarily for power generation and to open up space, material recovery is a side benefit.

bulk of waste created by architecture is not recoverable: those resources are forever lost. This results in an impoverishing of the earth. The wealth of future generations is irretrievably ruined because we choose to ignore the finite nature of our spaceship earth.

Capitalism is frenetically working to overcome limits, but we must acknowledge scarcity in order to return to sustainability. Architecture, in shaping consumption of the biggest piece of property people own, plays an important role in creating scarcity. Successful design stimulates demand for itself, generating a scarcity of that design in the market, which prompts more extraction of the resources required to manufacture it.<sup>15</sup> Design has an active role to play in returning to sustainability. We must, in the words of the Bruntland Commission, design “without compromising the ability of future generations to meet their own needs.”<sup>16</sup>

**Material sustainability only matters if we fix climate change.**

Humanity’s most pressing threat is anthropogenic climate change from carbon emissions. Warming and ocean acidification will have severe and irreversible impacts.<sup>17</sup> Like a frog in boiling water, the slow change has gone unnoticed too long. Our short political and business cycles have difficulty tackling such a long term problem. If carbon emissions continue, civilization will diminish as drought and migration stress humanity.<sup>18</sup> Finite material resources will not be a pressing concern if the population drops significantly and wealth dissipates. Existing resources will last longer and be less exploited. However, since designing for the collapse of society is defeatist, this thesis chooses to be optimistic that a solution will be found. It will take a century of hard work to roll back carbon emissions, but the alternative is bleak and not worth designing for.

While the world is working to claw back carbon, the energy efficiency

15. Jon Goodbun et al., *The Design of Scarcity* (Moscow: Strelka Institute for Media, Architecture and Design, 2013), Ebook, 20.

16. G.H. Brundtland and World Commission on Environment and Development, *Our Common Future: Report of the World Commission On Environment and Development* (Oxford: Oxford University Press, 1987), Part I.3.27.

17. IPCC “Summary for policymakers.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B. et al. (eds.)] (Cambridge ; New York: Cambridge University Press, 2014), 14.

18. Ibid, 13.



**Figure 1.5** Spray foam insulation is very effective at reducing energy use in buildings, but by gluing everything together, material reclamation will be impossible for an entire generation of buildings.



**Figure 1.6** Circular flows of material through manufacturing, use, recovery and recycling.

obsession that began with the 1973 oil crisis will reach a fever pitch.<sup>19</sup> Unfortunately, worries about resource scarcity get comparative little attention. Once we stop emitting carbon, our energy infatuation will lapse, revealing some ugly decisions made in the name of energy efficiency.

Lightweight, hermetically sealed buildings are the most efficient and also the most disposable, but disposability is troubling in the long term. Energy is inexhaustible: every day the sun delivers new energy through light and wind. However, no new matter is delivered to earth, with the exception of rare and disruptive asteroid impacts. We can afford to waste energy, but not material, and wasted material will become an important limit on our future. The date upon which we start designing in closed life cycles will determine what portion of Earth’s finite supply is preserved for future generations.

**In the wider discourse on sustainability**

We expect the life cycle of buildings to be cradle to grave, beginning with extraction of materials and ending entombed in a landfill forever, but design can change this paradigm by enabling buildings to be reborn. This thesis strives to improve the long term sustainability of materials by designing circular flows of use, recycling and new use.

*Cradle to Cradle* by architect William McDonough and chemist Michael Braungart forms the starting point for this thesis.<sup>20</sup> They challenge designers to create products with circular material flows, where materials are designed to be recovered after use for regeneration into new products.

Their challenge has been embraced by the sustainability community with mixed results. Bringing a product to market is complex and messy, entailing compromises along the way. A manufacturer’s best effort for recycling may be negated by subsequent decisions of the client in use or disposal.

Separating material flows into a form of technical or biological life cycles is the most beneficial guidance in the *Cradle to Cradle*. McDonough and Braungart refer to ideal materials as nutrients, indicating their potential to feed another life cycle. Technical nutrients are metals and plastics

19. Giovanna Borasi and Mirko Zardini, *Sorry, out of gas : Architecture’s response to the 1973 oil crisis* (Montréal: Canadian Centre for Architecture, 2007), 44.

20. William McDonough and Michael Braungart, *Cradle to Cradle : Remaking the Way We Make Things* (New York: North Point Press, 2002), 166.



that can be reformulated endlessly in an industrial process. Biological nutrients, such as wood, come from the earth and can be composted at end of life. By designing with only those material types, buildings can be endlessly renewable. McDonough and Braungart warn that outside of circular ecologies, increasing the efficiency of wasteful methods only reduces harm, eliminating waste will require redesigning the process.

In an extensive survey of worldwide material flows, Professor Vaclav Smil concludes that increasing efficiency in manufacturing will not be sufficient to meet the rising human demand for materials.<sup>21</sup> While Smil discounts recycling as only applicable to a few materials, he does not propose another solution for material scarcity beyond the hope that human ingenuity will solve eventual problems when they become acute.<sup>22</sup> This thesis chooses to develop recycling of suitable materials in the design of buildings to eliminate waste, and so divorce standard of life from continued material extraction. Architects play an especially large role in designing material flows, in 2006 construction materials accounted for 77% of all material flows in the United States.<sup>23</sup>

North American sustainability initiatives have a varied track record of tackling material waste. Straightforward rating systems such as LEED are popular but have failed to create significant change.<sup>24</sup> On the other side, the onerous Living Building Challenge requires design for disassembly, though it only reaches a handful of buildings per year.<sup>25</sup> A more universal

21. Vaclav Smil, *Making the Modern World: Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), xi.

22. Ibid. 180.

23. Ibid. 84.

24. *LEED Canada for New Construction 1.0 Credit Distribution as of February 2016*, PDF, Canadian Green building Council, February 2016 [https://www.cagbc.org/cagbcdocs/LEED\\_Canada\\_NC\\_v1-Average\\_Scorecard-Feb\\_2016-EN.pdf](https://www.cagbc.org/cagbcdocs/LEED_Canada_NC_v1-Average_Scorecard-Feb_2016-EN.pdf)  
Only three percent of Canadian LEED new construction projects achieved either of two material reuse credits. The LEED ratings system does not reward waste reduction during demolition, or incentivise design for disassembly, though points could be awarded through innovation credits. The Construction Waste Management credit avoids landfill, but the diverted materials have to be downcycled as good recycling facilities do not exist.

25. ILFI staff, "ILFI Announcing certification of 18 new living buildings," *Trimtab* (blog), International Living Futures Institute, May 23, 2016, <http://trimtab.living-future.org/blog/ilfi-announcing-certification-of-18-new-living-buildings/>  
The Living Building Challenge is a stringent building certification which aims to encourage buildings with positive energy, environment, and social impacts As of May 2016 the total number of certified living buildings worldwide is 44.

approach is required to effect a significant reduction in construction and demolition waste.

Industry has embraced environmental product declarations as a method for quantifying the harms of building materials. A typical declaration report is a dense catalogue of product ingredients, ecological damage during manufacturing and a suggested end of life.<sup>26</sup> These declarations are commissioned by manufacturers, so they present products favourably while omitting proprietary information. Environmental product declarations are useful only in selecting products.

Architects should aspire to do more in designing life cycles. By questioning the sources of building material, design can be selective and influence production processes by removing toxins. Asking about the end of life plan for a product stimulates discussion in the present and will one day determine eligibility for use in sustainable buildings.

The design project in this thesis is an application of the principles "Reduce, Reuse, Recycle." A deeper examination of these three terms uncovers more complex definitions than are evident in public sloganeering. In practice the triplet is often interpreted as Reduce, then Reuse, and finally Recycle. In this thesis the primacy of reduction needs to be reconsidered. Improvements to quality of life often come from plenty, not reduction. While the advantage of reducing extra building floor area or packaging might be obvious, arguing for the reduction of housing is difficult. As well, in designing buildings for disassembly additional material must be used to make connections between components reversible.

Championing 'reduction' above all else leads to the narrow minded optimization of existing processes and a diminishing quality of life.

Reuse is the ideal mode for recirculation in material life cycles, requiring no energy beyond that for transportation. In industry, reuse is defined loosely as any matter re-purposed in new construction, an example is granite counter-tops ground up for aggregate in concrete. This thesis chooses a more limited definition of reuse as use again in the same manner as before. Some cleaning or refurbishment may be necessary between uses, but the material should be substantially unaltered.

Recycling is proposed as the solution to material scarcity, but in



**Figure 1.7** Recycling has been a symbol of the environmental movement since the first earth day in 1970.

26. Peter J. Arsenault, "Full Transparency in Product Declarations: Specifying Products that are Consistent with Environmental Quality and Human Health," *Architectural Record* 201, no. 7, (2013), 137.

practice the process often amounts to downcycling: valuable materials are transformed into less useful objects because of contamination in the recovery system.<sup>27</sup> An example of this is the mulching of food grade containers into plastic lumber. If recycling can be made more effective, then the role of reduction and reuse in slowing waste creation becomes less critical. Recycling is capable of regenerating that waste into McDonought and Braungart’s material nutrients. The design portion of this thesis explores what will be necessary to make buildings fully recyclable.

Resources and waste in the building industry

The building industry has a huge role in waste creation because the volume of that waste is so vast. Outside the construction industry, most other manufactured goods are smaller because they are made inside other buildings, workshops and factories. With this size disparity, architecture has an opportunity to substantially reduce the world’s waste through design. Current efforts to reduce landfill waste often start with reducing the volume of manufactured goods. Miniaturization, which has worked so well in technology, is constrained from improving buildings by the minimum space demanded by people. A ongoing favourite reduction technique of modernity is dematerialization through lightweight design.<sup>28</sup> Technical improvements have steadily reduced material consumption from the days of stone frame buildings, but further weight reductions are regrettably limited by human comfort and durability concerns. Many recent techniques use composite material systems to shed weight, however, such composites are impossible to separate into component materials, and are relegated to landfill during demolition. Unfortunately, even typical buildings do not fare much better than wholesale demolition and land-filling. Canadian buildings are designed to last 50-100 years, and when demolished 88% of waste goes directly to landfill.<sup>29</sup> Of the remaining twelve percent only the metals are commonly recycled. The rest is downcycled



Figure 1.8 Most of our buildings are waiting for a trip to the landfill.

27. Vaclav Smil, *Making the Modern World : Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), 112.

28. Ibid, 119.

29. *The Private Sector IC&I Waste Management System in Ontario*, RIS International Ltd., January 2005, 7, <http://kelleherenvironmental.com/wp-content/uploads/2012/07/ICIPrivateSectorWasteStudy.pdf>  
Statistics Canada estimates the construction and demolition diversion rate to be 12% in Ontario, indicating that the remaining 88% is landfilled.

into a less valuable second use, typically in a bulk form such as the aggregate mentioned earlier. In some Canadian cities, programs for recovering lumber are becoming mandatory.<sup>30</sup> A significant proportion of housing demolition waste can then be diverted from landfill. These materials are still downcycled however, only delaying their inevitable disposal.

Construction and demolition generates 27% of Canadian landfill waste.<sup>31</sup> That percentage would be even greater if buildings were being demolished as fast as they are built. Due to the country’s speedy growth, Canada has a standing inventory of waste in the form of its present buildings. These were never designed for reuse or recycling. Creative downcycling is the only method of reducing the inevitable waste. By designing buildings from materials which are used and regenerated in circular streams, architecture can replace that problematic inventory of waste with a new inventory of valuable materials awaiting reuse in the distant future.

The inevitable solution to material waste is creating paths for good materials to recirculate. Architects need to take responsibility for waste flows built into their design. As a society overall, we need to come to see waste as a design problem. Our buildings, and every object within them, were summoned into existence by design. Design should also create a path for these objects to fade gracefully.

30. Albert Shames, *Green Demolition Program Update*, City of Vancouver, November 16, 2015, <http://council.vancouver.ca/20151216/documents/cfsc5.pdf>  
The city of Vancouver has enacted a green demolition bylaw targeting 90% waste diversion, and in 2015 banned the disposal of clean wood.

31. Muluken Yeheyis et al., “An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability” *Clean Technologies and Environmental Policy* 15 (February 2012), 81. DOI: 10.1007/s10098-012-0481-6,





## 2.

### *The challenges of circular material streams*

**Figure 2.1** Interlocking concrete blocks junked at the Cambridge landfill. Even the most durable modular systems can be made obsolete by changes of fashion.



2. The challenges of circular material streams

Significant challenges lie ahead in transforming production methods from a linear waste generating model to one of circular reuse. Instead of conceiving construction materials as products, thinking of materials in streams being transformed through use, recovery, and regeneration enables designers to close the loop with reuse. Building materials will have to participate in either a biological or technical life cycle of renewal.<sup>1</sup> Plants and microbes do the work of regenerating biological wastes into nutrients for new growth. By contrast, in a technical cycle human industry recaptures materials after use for recycling into fresh metals and plastics.

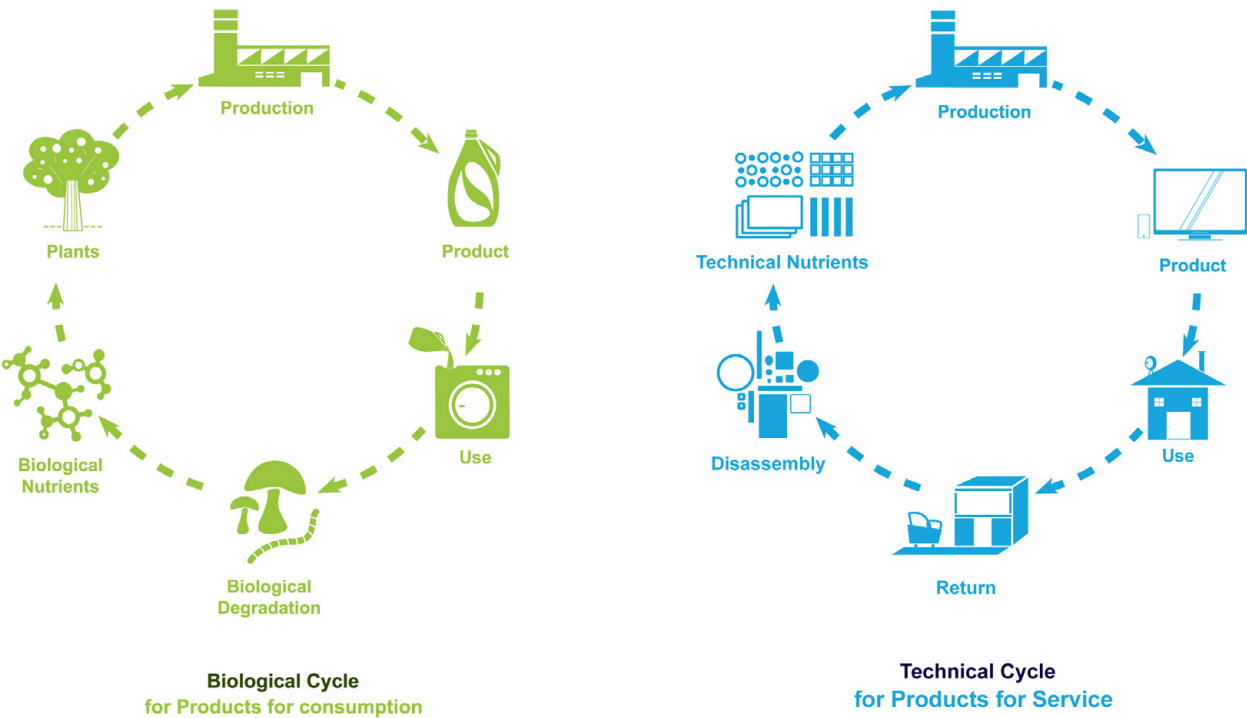


Figure 2.2 Biological and technical life cycles from *Cradle to Cradle*.

Adopting circular material flows will change the building industry by increasing the value in construction and demolition waste. Current processes for recycling and composting need expansion to handle the large volume of demolition waste. Architects will learn to design for the disassembly and reuse of buildings, but design and material selection are only a portion of the solution of circular material use. Market forces and

1. William McDonough and Michael Braungart, *Cradle to Cradle : Remaking the Way We Make Things* (New York: North Point Press, 2002), 105, 109.

occupant choices also influence when and how a building is dismantled. By designing architecture out of valuable materials which are easy to recover there will be an incentive in the future to close the circle with local reuse and recycling of materials. Topics in this chapter explore how the building industry and the profession of architecture will evolve as they close the loop on material use.

Waste is worth much more than we care to think about.

Waste management is one of the underlying material foundations of civilization. A disruption in indoor plumbing or garbage collection is a disconcerting reminder of our reliance on waste removal to maintain comfortable and healthy lives. Unobtrusive waste collection frees people from having to worry about the consequences of their consumption. We throw things ‘away’ without caring where ‘away’ is, as long as it is not here. But as humanity has settled the earth, there is less and less ‘away’ left to fill with garbage. Locations for disposal are becoming a scarce commodity. The stories we tell about our possessions stop at disposal. We seldom consider the space required, processes of decomposition, and the potential for retrieving key resources. Once materials are designed for disposal, recovery of their value becomes nearly impossible. Consumer products are difficult to separate, contaminated with toxins, and self-obsoleteing.<sup>2</sup>

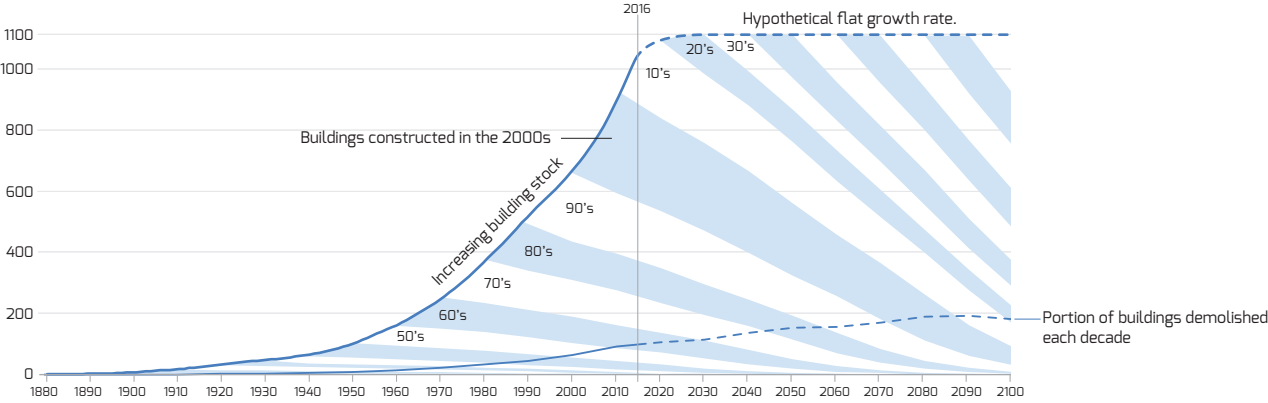
Construction and demolition waste deserves much more attention than it is given by society. While residential and commercial waste currently constitutes the majority of Canadian landfills, the share of demolition waste is bound to increase in coming years as buildings of the post Second World War boom years reach end of life.

Buildings last much longer on average than consumer goods,<sup>3</sup> so the volume of their waste creation has not yet become clear. Canada has been growing rapidly for the last hundred years, but when consumption inevitably slows and the hockey stick rate of growth bends over into an S curve, the long term effects of designed waste in buildings will be felt.

2. Ibid. 5.  
3. Vaclav Smil, *Making the Modern World : Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), 113.

To illustrate the inertia of architecture as “waste in transit”<sup>4</sup> it is worth comparing demolition wastes to all other wastes in a slow growth future.

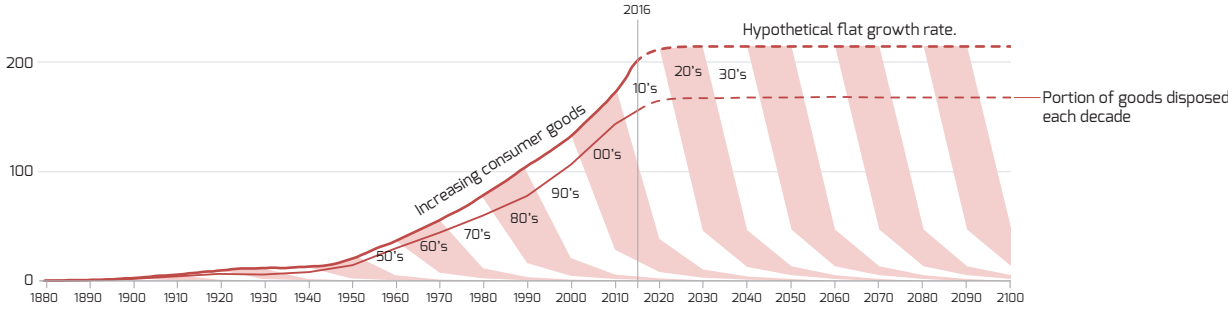
If the Canadian economy stopped growing in 2020, the glut of buildings constructed in the 2000s will remain in use for many decades, delaying the waste of demolition. The following graph of building stock maps what portion of all Canadian buildings were constructed in each decade, represented by a shaded bar which reduces in width as buildings reach end of life and are demolished.



**Figure 2.3** Weight of materials in Canada’s buildings by decade and projected into the future. (millions of tons)  
Data was derived from Statistics Canada historical construction expenditures, see Appendix A. for sources.

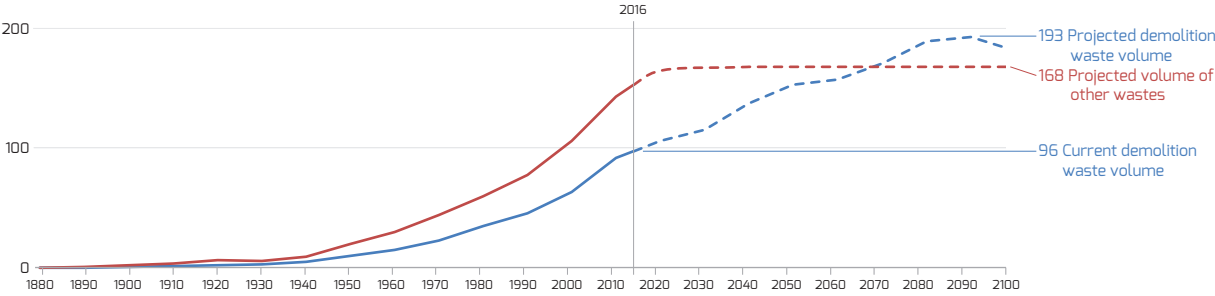
In this scenario, demolition of buildings will peak in 2080, eighty years after the construction boom of the 2000s.

By contrast, the consumer goods that create Canada’s non-demolition waste fade from use quickly, being replaced in a one to ten year time frame. In the following graph the portion of goods manufactured in each decade is quickly succeeded by new stock, returning to a regular pattern soon after 2020.



**Figure 2.4** Weight of consumer products in Canada, by decade and projected into the future. (millions of tons)  
See Appendix A. for data sources.

Currently construction and demolition waste makes up one third of landfill waste in Canada,<sup>5</sup> but that share will continue to increase for seventy years as the huge number of buildings constructed since the year 2000 reach end of life.



**Figure 2.5** Canadian landfill waste projected into the future assuming flat growth. Construction and demolition waste will overtake all other waste sources combined.

The massive volume of waste generated by society presents a huge opportunity. Before production, the mountain of waste consisted of valuable materials full of possibilities. The limited secondary uses of its new role as trash indicates that a massive erasure of value has occurred. Continuing disposal of such material represents a limit on the well-being of future generations by closing off possibilities and erasing value.

Reusing building materials

Reuse of material in modern construction is rare for a variety of reasons primarily relating to uncertainty about the reclaimed material:

- Recovered materials are of unknown quality so cannot be relied upon. Removing uncertainty by grading the strength of recovered wood and steel sections requires labour and paperwork, increasing cost beyond that of new material.<sup>6</sup>
- In older finish materials, toxins such as asbestos or lead paint may

4. Jeremy Till, *Architecture Depends*, Cambridge, MA: MIT Press, 2009, 67.  
5. Muluken Yeheyis et al., “An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability” *Clean Technologies and Environmental Policy* 15 (February 2012), 81. DOI: 10.1007/s10098-012-0481-6,  
6. Sebastian El khoulí and Viola John and Martin Zeumer, *Sustainable Construction Techniques : From Structural Design to Interior Fit-out : Assessing and Improving the Environmental Impact of Buildings* (Munich: DETAIL, Institut Für Internationale Architektur-Dokumentation, 2015), 56.



be present which constrain future uses.<sup>7</sup>

- The quantity of material also may not match a need, with no possibility of sourcing any more.
- The availability of materials is uncertain in advance: architects designing a year before construction have to guess at what will be available. If the reused materials are purchased in preparation for a job, storage for bulky materials will be required.

The additional cost of space, labour and capital negates the competitive advantage of reclaimed material. When designing with old material, a client has to appreciate the story of a material's provenance to value it over new.

In designing new buildings for reuse, architects cannot predict how their materials will be salvaged. Designers can mitigate some of the uncertainty of reuse by documenting the installed materials in as-built plans. Future reclaimers will appreciate labels on structural elements which record dimensions and strength. Difficulties in reusing construction materials reinforce the importance of recycling to capture anything that cannot be reused.

### Recycling buildings

The act of construction draws on a worldwide industrial production system to supply material. Financial incentives for optimizing production processes are much greater than those devoted to recovering low value wastes. There are some unexplored opportunities in the immature field of reclamation and recycling. Delving into current recycling processes reveals methods to increase their effectiveness by better designing buildings as inputs.

Recycling as currently practiced produces poor quality products at significant expense.<sup>8</sup> Reprocessed materials are typically low grade and contaminated with foreign material.<sup>9</sup> Better separation is required to make recycling effective in supporting circular material streams. Recycling

7. Barbara Knecht, "Designing for Disassembly and Deconstruction," (*Architectural Record* 192.10, October 2004), 188.

8. Vaclav Smil, *Making the Modern World: Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), 112.

9. Samantha MacBride, *Recycling Reconsidered: the Present Failure and Future Promise of Environmental Action in the United States* (Cambridge, MA: MIT Press, 2012), 478.



**Figure 2.6** Scrap Metal is reliably valuable and dense, encouraging recycling.

feed-stocks are bulky, so transporting waste to the proper recycling facility is more expensive than a nearby landfill. Unless recycling can produce a valuable output, economics favours disposal.<sup>10</sup>

Sophisticated technologies are now used to automate sorting of mixed recyclables. Complex feedstock such as buildings are typically crushed into particles for automated separation using magnets, lasers and air jets.<sup>11</sup> However, crushing produces a mix of small particles that cannot be fully separated.<sup>12</sup> Recycling is most effective when provided with a large, dependable flow of a single material, or mono-material.<sup>13</sup> Designing buildings for disassembly is key to producing high quality material streams which make recycling effective. Removing uncertainty enables the most efficient recycling infrastructure.

Despite improvements in control over material flows, contamination remains a huge concern for recycling. Circular material streams depend on clean flows of material to regenerate. Removing all contamination may be impossible though, as materials often depend on trace amounts of other elements for key properties. Nickel and chromium in steel alloys are one such example. But more troubling for architecture is that pigments which give colour are a potent source of contamination in recycling. In most cases colours mix together during remelting to generate a muddy grey product. Tiny amounts of pigment in a product are enough to provide colour while being sparse enough to make separation impossible. During recycling, heavy metals pigments such as lead oxide and cobalt blue found in older buildings can be released as toxins.<sup>14</sup> Modern replacements for these poisons may do no harm, but they too are unrecoverable. It will be challenging to design the colourful architecture demanded by society



**Figure 2.7** Sorting of recycling can be partially automated but the process is still labour intensive.

10. John Timmer, "Bikes, bowling balls, and the delicate balancing act that is modern recycling," *Ars Technica*, December 7, 2015, <http://arstechnica.com/science/2015/12/recycling-matching-high-tech-materials-science-with-economics-that-work/>

11. Ibid.

12. Kari Heiskanen, "Theory and tools of physical separation," in *Handbook of Recycling*, ed. Ernst Worrel and Markus A. Reuter (Amsterdam: Elsevier, 2014), 40, 57. Complex recycling streams are typically reduced to consistently sized particles for sorting. However, state of the art physical separation of small particles offers diminishing returns for separation rates above 90%. Therefore grinding materials up guarantees the creation of a waste fraction.

13. El khoul et al., *Sustainable Construction Techniques*, 59.

14. Bjørn Berge, *The Ecology of Building Materials* (Oxford ; Boston: Architectural Press, 2000), 409.

within circular material flows. Architecture will reject circular materials streams if they mean abandoning colour in design. While pigmentation will be a persistent problem for recycling, compostable material streams present an opportunity with biodegradable colours.

Composting buildings

Construction materials that originate from biological processes could be composted at end of life. Wood is the most common compostable material used in buildings, but paper, cellulose, straw and linoleum are other examples. By employing local soil microbes to do the work of decomposition, composting can occur anywhere, obviating the cost of transportation to dedicated facilities which makes recycling so expensive.

Municipal collection of compostable material is a good precedent for industrial scale decomposition applied to buildings. North American cities commonly accept yard clippings and kitchen waste for biodegradation into earth. Municipal composters use industrial methods with heavy human intervention in shredding, blending and turning the waste.<sup>15</sup> While biodegradation does not require any mechanical help, mixing accelerates the process, reducing the land required. At the municipal level, open air compost piles are simple to deploy with low tech stirring using construction equipment.<sup>16</sup> The cost of labour and land is paid for by diverting compostable waste from scarce landfill space.

While mechanical composting successfully reduces the waste volumes, the creation of circular material streams is less effective. Farmers are wary to accept compost with unknown contaminants and pesticides from kitchen scraps.<sup>17</sup> Soil of too poor quality for sale is commonly given away in the community.<sup>18</sup> A more successful composting program would be



Figure 2.8 Current composting methods use industrial machinery to turn heaps of organic materials.

15. Eliot Epstein, *Industrial Composting : Environmental Engineering and Facilities Management* (Boca Raton, FL: CRC Press, 2011), 32.

16. Ibid. 105.

17. “Clopyralid in Compost,” *Washington State University Organic Farming Systems and Nutrient Management*, accessed November 18, 2016, <https://puyallup.wsu.edu/soils/clopyralid/> Clopyralid is a persistent pesticide found in compost at doses high enough to kill vegetables.

18. Several cities in Ontario give compost away for free, including the local Cambridge landfill. “Compost and mulch is now available at the Cambridge and Waterloo landfill,” Region of Waterloo, Accessed December 11, 2016, <http://www.regionofwaterloo.ca/en/aboutTheEnvironment/waste.asp>

one which creates a valuable product. The trend is towards even more sophisticated processes for capturing methane produced during decomposition for power generation. However these facilities require complex infrastructure including massive airtight buildings and self contained breathing systems for workers.<sup>19</sup>

A widespread composting system for buildings would have to abandon current energy intensive methods. The labour required to actively decompose all the buildings being demolished would be cost prohibitive. With time, worms and bacteria can completely digest building materials designed for organic life cycles. Placing compostable matter directly where nutrients are needed would eliminate the necessity of transportation and dedicated land. In practice building composting might look like chipped lumber being spread on a woodlot several years after clear cut. In this method nutrients are returned to where they began their journey, ready for another circuit.

Since the first Earth Day in 1970 we have been told to reduce, reuse then recycle.<sup>20</sup> However, by observing successful biological life cycles the importance of recycling over reducing and reusing becomes apparent. A well designed life cycle is built on re-cycling of material and energy. Reuse is not common in the natural world. Living organisms are feverishly engaged in reproduction, not reduction. Successful natural systems are evaluated not by how well they reduce but by how much they proliferate. Building materials with positive life cycles would do best by flourishing, and displacing damaging products along the way.

Adapt!

The regeneration material streams into new nutrients may not create much waste, but damage to the environment still occurs during each cycle from production byproducts and from energy used.<sup>21</sup> Good life cycle



Figure 2.9 Composting in place would more closely resemble a forest floor.

19. Orgaworld Surrey anaerobic digestion and composting facility. British Columbia. <http://www.orgaworld.ca/default.action?itemid=57> A sophisticated biofuel production facility is being completed in Surrey, BC. Natural natural gas generated in digestion tanks will be burned in vehicles to offset the expense of complex oxygen-free composting chambers.

20. Rachele Gordon, “The History of the Three R’s,” *Recycle Nation*, May 11, 2015, <http://recyclenation.com/2015/05/-history-of-three-r-s>

21. Vaclav Smil, *Making the Modern World : Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), 166.



design should slow recycling by extending the life of buildings. A naive approach might seek to increase durability, making the building resistant to daily wear. Locking buildings into one use pattern, however, does not suit the rapid changes of society and economics. Too rigid a material framework leads to the obsolescence of a building before materials have reached their service lives. Designing structures to adapt will delay the inevitable demolition by better serving occupants. Buildings should be extended and enhanced by new occupants, getting better over time. Cities are enriched as old buildings are regenerated, both serving new uses while preserving history. An adaptable building maintains value through small renovations which would be too costly in a rigid structure. Flexibility has limits however, space which could serve any use has no character. Good adaptability makes small changes accessible to occupants by keeping infrastructure out of the way.

Architects can create adaptable buildings by rejecting rigid single-use planning in favour of more generic programming. An open ended program anticipates several next-uses for the building while accommodating the present.<sup>22</sup> The designed generic program can absorb change over time without the waste of renovations.<sup>23</sup> Specifically generic program does not mean the architecture has to appear generic, but the functions of space should be flexible to anticipate inevitable change. Tightly programmed buildings ignore a client's changing needs and desires, which are typically the reason to hire an architect in the first place.<sup>24</sup>

Preserving material value

Designers should create buildings that are worth something during disassembly. Safeguarding the wealth of today for future generations requires the preservation of value in materials through use and eventual demolition. Current building materials depreciate almost entirely by the time they are installed on a building. If any monetary value remains, it is erased through weathering, the wear and tear of daily use, or discounted by changes of design fashion. The value of a material is a good indicator of its potential for reuse and recycling. A good quality material with

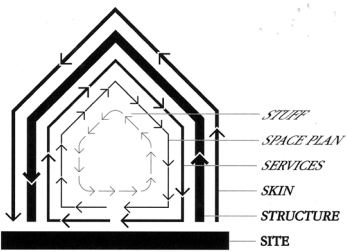


Figure 2.10 Shearing building layers by Stewart Brand. A building should accommodate renewal of layers at different paces.



Figure 2.11 Adaptive reuse takes forms never imagined by the original users, such as this hosiery factory converted into the Waterloo School of Architecture.

22. Kiel Moe, *Convergence : An Architectural Agenda for Energy* (London: Routledge, 2013), 247.  
23. Ibid. 260.  
24. Ibid. 249.

multiple possible uses will be worth more and by designing to preserve such value, architects achieve flexibility at end of building life.

While current materials are burdens to be knocked down and disposed of, valuable materials form an incentive to disassemble a building to recover them.<sup>25</sup> Disassembly instructions may be lost or obsolete by the end of a building's life, but economic self interest can be relied upon to recover materials that are valuable. In designing future valued buildings it is critical not to include materials with negative worth. Asbestos and lead paint, as examples, encumber demolition projects with delays and costly mitigation work. New projects should be precautionary in selecting materials which will not create future liabilities in disassembly. Finally, a pleasant side effect of using materials that hold value well is that occupants prize them. Valued materials are more likely to be maintained and appreciated.

Upcycling has become a fashionable term in sustainable discourse, denoting the reuse of material to create products of higher value than the original.<sup>26</sup> This concept is only applicable, however, to the social value attached to objects. Transforming an object into something else can only ever return a lower quality due to entropy and its arrow of destructive time. An increase in the social valuation of an existing object could be called upcycling. Old barn-board or stone can be 'upcycled' into interior finishes because we appreciate the history and patina embodied in these materials. They will never regain the same technical value as when they were new. In practice, upcycling amounts to a non-material creative recycling, one which only delays the inevitable landfilling of objects not designed for recovery.

Design for disassembly

Designing for disassembly is crucial to preserving the quality of resources for reuse or recycling. Instead of bulk demolition, the process of dismantling a building is considered at the design stage to make it easy, safe and rewarding.<sup>27</sup> All materials have some residual value, though when they are hard to separate for sale the cost of recovery makes reclamation

25. El khoul et al., *Sustainable Construction Techniques*, 55.  
26. William McDonough and Michael Braungart, *The Upcycle : Beyond Sustainability - Designing for Abundance* (New York: North Point Press, 2013), 34.  
27. Knecht, "Designing for..." 183.

unattractive. Contemporary demolition is a messy process where a building is pulverized into rubble that can be shipped to landfill. Recyclable materials recovered from a rubble pile are bound to be contaminated, discouraging recycling. Design for disassembly aims to reduce waste during demolition by easing the separation of materials. Buildings are also easier to adapt through renovation when elements can be separated. Clean disassembly may permit the dismantling and reuse of material in the same building, for example moving walls during re-planning. Even if materials are not directly reused, simpler demolition will save time and disruption.

Architecture's product and process will change when buildings are designed for disassembly.<sup>28</sup> The most obvious difference will be a flourishing of visible joints on buildings. Design for disassembly depends on accessible connections, both visually and ergonomically.<sup>29</sup> Seamless surfaces cannot be reduced to their components without damage, instead mechanically fastened panels offer reversible connections for renovation and deconstruction. Chemical joints, such as glues, caulking, tape, and curing materials like concrete should be minimized.<sup>30</sup> Separating two objects that are chemically bonded tears up the bond and often scars both surfaces. Removing glues from building materials will be a significant challenge. Construction materials have become less robust over time, as the large surface area of glued bonds stabilizes thin substrates. A return to mechanical fasteners will be accompanied by increased costs of sturdier materials. Chemical joints have also been instrumental in waterproofing and sealing buildings. The complete elimination of glues is unlikely, as that would return architecture to peaked roofs and drafty rooms.

When designing for disassembly, the person demolishing the building is considered along with building occupants. Providing safe manoeuvring areas and human scale components with easy access is important in disassembly as well as construction.<sup>31</sup> As more materials are made available for recovery, the work of former demolition contractors will expand to create new jobs in building deconstruction and material recovery. In the



**Figure 2.12** Scaffolding connections are reusable many times, as they can be easily disassembled without damage.



**Figure 2.13** Efficient and fragile. Imagine trying to weld another mounting point onto this structural steel connection, it would be impossible.

deconstruction process, good as-built drawings are crucial for organization. Architects can create deconstruction plans along with documentation of materials and connections to ease disassembly.

Design for disassembly has an important role to play in enabling the recirculation of materials through multiple life cycles. In practice, while the role architecture in disassembly is not yet fully defined, there is room for creativity as the field evolves.

### Uncertainty and limits to Modernist optimization.

When designing for disassembly and reuse it is necessary to anticipate the future to some degree. In addition to the current client, an architect must think about the individuals who will demolish and reclaim materials. Certainty about the future would be helpful in reducing waste by optimizing design for future renovations and demolition. Knowing which module or standard to use would make materials interchangeable with other buildings. However, selecting the wrong standard will orphan the building from support, requiring custom replacement parts. Too much confidence in predictions increases the risks taken and danger of failure. Highly specific scenarios of the future are more likely to be wrong than vague ones. A loose design is appropriate for more possible situations than a tightly optimized one. Design should aim to provide an avenue for reuse in as many futures as possible, without sacrificing performance in the present.

Modernity has been defined by the quest for efficiency. However, optimization can only be deployed against predictable eventualities.<sup>32</sup> While performance is increased for defined goals, extra flexibility which might help in unexpected situations is lost. A structurally efficient design is more fragile to unpredicted events than one with surplus capacity. In the hundred year timescale of a building the uses and abuses it will be subject to are unpredictable. A tightly space-efficient building will not have extra room to grow for new program or services. To avoid obsolescence and the accompanying waste of demolition, program should be designed with a loose fit for future change. Where change is likely, overbuilding parts of the building that are hard to access is beneficial in the future. This might take the form of structural overbuilding or extra

28. Vince Catalli and d'Esign consultants, *Designing for Disassembly* (Ontario: Canada Mortgage and Housing Corporation, 1998), 23

29. Brad Guy and Nicholas Ciarimboli, *Design for Disassembly in the built environment: a guide to closed-loop design and building* (Seattle, WA: City of Seattle 2006), 6.

30. Ibid. 8.

31. Ibid. 6.

32. Nassim Nicholas Taleb, *Antifragile : Things That Gain from Disorder* (New York: Random House, 2012), 8.



space in mechanical rooms.

Rigid buildings which are difficult to renovate do not fare well over time. There is also danger in flexibility however. Lightweight architecture promises to reduce material use and increase flexibility, but at the expense of resilience. The forces of wind and rain that lightweight structures must resist are no less for than regular buildings. Weight-optimized structures operate with less margin between forces and their breaking point. Dangerous levels of corrosion on a thin material might only be surface problems on a thicker member. Extra material provides robustness not achievable with lightweight structure.

Modular systems are also vulnerable to changes. A module is founded on the standardized dimensions which permit interlocking assembly. However, replacing damaged elements with non-modular parts is made difficult due to proprietary connections. When parts are no longer available, the modular building will be orphaned from support and easy maintenance. Successful modular systems have to be optimistic in assuming that they have a place of importance in the future, but they often fall victim to the churn of business and new product lines. Pre-cast concrete buildings of the 1960s are great examples of modules no longer in production because

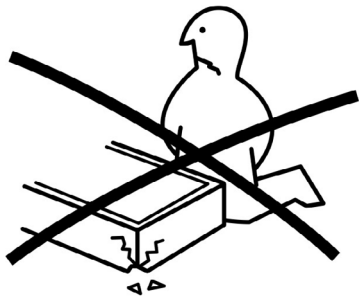


**Fig. 53.** Desirable features include minimum supports, vinyl upholstery, plastic laminate table, built-in ash tray.

*Figure 2.15* Advice for low maintenance architecture in 1975 seems hopelessly out of date.



*Figure 2.14* Nakagin capsule tower, the poster child of reconfigurable metabolist buildings, was never renovated. It now awaits demolition.



*Figure 2.16* Ikea has changed their kitchen cabinet module size, rendering twenty years of kitchens obsolete.

tastes have changed. Technological advancements have also left old modules orphaned as building codes shift to higher performance standards. Often corporations decide to introduce new models with the goal of out-dating old ones and stimulating demand.<sup>33</sup> Yearly vehicle updates are the most conspicuous example of this planned obsolescence. Fashion, technology and commerce contribute to obsoleting modules before they wear out. Even when repair is possible, the uniformity of modules will make a less weathered new repair stand out.

The easy disassembly of modular buildings does not make up for varied modes of failure. Custom buildings are more resilient to changes in fashion because aesthetic variation resists categorization into trends. Bespoke buildings are easier to repair when a failure inevitably occurs. Buildings designed with circular material streams should not be tied to a module's eventual obsolescence. Architecture should design buildings with loose fit program and sturdy construction.

### Reusable will mean local

Reuse has traditionally been a local enterprise. Small networks of distribution were effective in delivering milk and beer bottles, then returning them to the manufacturer. In the latter half of the twentieth century, globalization removed foreign trade controls and international distribution networks brought merchandise from all over the world. Consumer reuse networks in North America died out as the variety of containers proliferated. As distribution systems became more efficient and centralized, the distance traveled and cost of container recovery increased. While it may be economical to deliver products from abroad, shipping back bulky packaging for reuse is expensive. The energy entailed in returning beer bottles to Germany for refilling would not make environmental sense. Once reuse was abandoned, optimization worked to reduce the amount of packaging going to landfill. New containers are thinner, built only sturdy enough for one voyage.

The story of bottle reuse is a good metaphor for the abandonment of local networks in building. Raw materials and better manufacturing are available in other parts of the globe, so many construction materials are shipped in. The threat of climate change makes it imperative that we reduce the energy used to transport heavy building materials. It would be

33. Giles Slade, *Made to Break : Technology and Obsolescence in America* (Cambridge, MA: Harvard University Press, 2006), 29.

a shame, however, to forgo quality international products by mandating local consumption.

Local networks have more than an energy advantage, they are more resilient. In several cases, economic pressures have concentrated the global production of a product into a small region. Deliveries of solar panels from China or high performance windows from Germany could be interrupted by a natural disaster or political intervention. A Chinese restriction on rare earth metal exports in 2010 sent motor companies scrambling when key ingredients in their magnets were not available, as they were not mined elsewhere in the world.<sup>34</sup> Local networks of production are resistant to disasters, politics and currency fluctuations.

The challenge for local networks is that resources are often thousands of kilometres away from the project site. When buildings designed with circular material flows begin reaching end of life this will change as materials come available close to where they are needed. High transportation costs for scrap material will encourage smaller producers to open local recycling facilities. The mature North American steel market has seen this transformation with the decline of large smelters and rise of small arc furnace recyclers.<sup>35</sup> Global ecologies that supplied the first generation of materials will be supplanted by local circular ecologies.

Conclusion

Changing the building industry will be difficult, but there are many unexplored opportunities in the afterlife of buildings. Architects have so far developed highly refined methods of planning the birth of a building. Designers who will put even a portion of that energy into closing the loop for materials streams at end of life have the opportunity to make a mark in this as yet undeveloped field.

A world Expo would provide a unique venue for experimentation with circular material streams. Inviting the world to participate in sustainable material use will expose many of the difficulties in material recycling, with the positive impact of encouraging it worldwide by putting recycling on shared view. A short, six month expo pavilion lifetime increases the intensity of pressure to reuse and recycle, while concentrating diverse

34. Michael T Klare, *The Race for What's Left : The Global Scramble for the World's Last Resources* (New York: Metropolitan Books, 2012), 152.  
35. Robert P. Rogers, *An Economic History of the American Steel Industry* (London ; New York: Routledge, 2009), 131.

participants onto one expo site generates fertile conditions for creative collaboration and exchange.

The design of two expo pavilions addressed later in this thesis delves into the difficulties and opportunities of circular material streams. The buildings are a practical exploration of comprehensive design for disassembly. Components of the pavilions are modular enough for flexible reuse without custom parts. Every material which is assembled into exposition pavilions must be destined for biological or technical life cycles in order to enable the preservation of material value and future local cycles which are afforded by circular material streams. Communicating this flow of material to visitors will be essential to the Expo's success. Architects will be the key agents responsible for designing material flows and their representation.





# 3.

## *Designing material flows*

**Figure 3.1** Discarded bricks at the Cambridge landfill. North Americans seldom reuse bricks because the labour cost of cleaning and storing masonry is too costly.



3. Designing material flows

In this chapter the design of material flows lays the groundwork for architecture by assembling a palette of cradle to cradle materials for use in buildings. Currently architects work with manufacturers to select a material with the right aesthetic and technical qualities. Life cycle design extends the responsibility of the architect back to material extraction, and forward to end of life, recovery and regeneration. Selecting materials with healthy life cycles requires a new type of communication with manufacturers and clients to compare materials and reach decisions. Representing material flows allows them to be purposely designed.

This thesis proposes a material chemistry flow diagram as a method to communicate life cycles. Designers can compare the ingredients and wastes of materials when they are assembled in a clean diagram. Having the entire material stream laid out enables architects to fix problems in recycling or composting by proposing changes to material flows at the outset.

The life cycle story of building materials is illustrated here through arrows representing the flow of materials. These simplify the stories of materials into a series of processes from extraction to construction, reconstruction and recycling. Between steps, transformations and transportation are collapsed into arrows. This method has the benefit of making the diagram more general by eliminating local variations, but in doing so it obscures the externalities of transport and processing. Excluding quantitative information at this stage avoids the trap of blindly optimizing existing processes without examining alternate methods. The goal is to focus on closing the loop of material streams at the expense of current specific producers and geographies. Once materials recirculate in closed life cycles engineers can be engaged to optimize the process.

A key for material flow diagrams

In order to aid legibility, material flows are represented in this thesis with four different colours. Two of these are derived from Braungart and McDonough’s Cradle to Cradle concept of nutrients.<sup>1</sup> The remaining materials can be divided into toxic and non-toxic.

Recycled

McDonough and Braungart’s concept of technical nutrients, man-made substances that can be renewed by industry, is here termed recyclable. Effective recycling depends on the strict meaning of re-cycling, returning materials back to their original use.



Composted

Compostable materials emerge from the concept of biological nutrients. Plant matter is harvested, used, and left to decompose at end of life. Leveraging the environment for production and disposal creates a far smaller ecological footprint than mined materials.<sup>2</sup>



Disposed

Materials extracted for a single use encompass most of what we build with today. Many of these, like gravel, will not be exhausted any time soon. However they form the bulk of waste. Downcycled materials also appear here, as they are designed for only one use in their current form.



Toxic

A surprising number of building materials are toxic to their occupants or the environment. Removing these from use is a priority, as managing them in waste streams is a long term problem without immediately obvious or economically viable solutions.



1. William McDonough and Michael Braungart, *Cradle to Cradle : Remaking the Way We Make Things* (New York: North Point Press, 2002), 104.  
2. Vaclav Smil, *Making the Modern World : Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), 108.



Beginning with good chemistries

Choosing to build with recyclable or compostable materials creates the challenge of identifying these materials. Manufacturer’s product specifications generally enumerate strengths, durability and warranties. Seldom do they propose an end of life plan for the material. Several certification systems attempt to expose this information, to varying degrees of success.

Environmental product declarations are the most common life cycle assessment information attached to building materials in North America. Presenting the information is voluntary and self reported.<sup>3</sup> Life cycle analyses predominantly care about carbon emissions, not materials. Some product declarations list ingredients and end of life information, however, these are typically incomplete, with ‘proprietary ingredients’ hiding true chemical composition. Manufacturers are happy to list “recyclable” on a product which is only a quarter recyclable.

The Cradle to Cradle Institute was started by William McDonough and Michael Braungart to certify circular life cycle products for a fee.<sup>4</sup> In the decade since its inception, the program has strayed from its ideals to green-wash products such as drywall and polystyrene insulation.<sup>5</sup> Certification systems demanding thousands of dollars from manufacturers end up attracting only the largest producers who can afford to spend marketing money. Frustratingly, no ingredients are listed for approved products, leaving users to trust the vague rating criteria.

The Living Buildings Institute has a rigorous performance standard which certifies buildings and products against a wide list of criteria.<sup>6</sup> Design



Figure 3.2 Interface carpet tiles declare their product as intended for recycling, but the bulky backing is a composite of polyester, vinyl acetate, toxic PVC, and glass fibres. Post consumer carpet tiles make up only 23% of recycled products, and that is unlikely to increase because polymer degradation in recycling requires a substantial fraction of new material to maintain desired properties.<sup>7</sup>

3. Peter J. Arsenault, “Full Transparency in Product Declarations: Specifying Products that are Consistent with Environmental Quality and Human Health,” *Architectural Record* 201, no. 7, (2013), 137.

4. “Cradle to Cradle Certified Products Registry” *Cradle to Cradle Products Innovation Institute*, Accessed October 26, 2016, <http://www.c2ccertified.org/products/registry>

5. Tom Woolley, *Building materials, health and indoor air quality: no breathing space?* Abingdon, Oxon ; New York, NY: Routledge, 2016. “C2C provides greenwash approval of products that are bad for the environment.”

6. The Living Product Challenge evaluates materials by their impacts on place, water, energy, health, safety, equity and beauty. “Living Product Challenge,” International Living Future Institute, <http://living-future.org/lpc>

7. “Environmental Product Declaration: Modular Carpet - Interface Americas Glasbac Re - Type 66 Nylon,” Interface.com, PDF, October 2016. [http://interfaceinc.scene7.com/is/content/InterfaceInc/Interface/Americas/WebsiteContentAssets/Documents/Technical/EPDBriefs/GlasBacRENylon66/wc\\_am-epdglasbacrenylon66oct2016.pdf](http://interfaceinc.scene7.com/is/content/InterfaceInc/Interface/Americas/WebsiteContentAssets/Documents/Technical/EPDBriefs/GlasBacRENylon66/wc_am-epdglasbacrenylon66oct2016.pdf)

Living Building Red List of Harmful Chemicals

- Alkylphenols
- Asbestos
- Bisphenol A (BPA)
- Cadmium
- Chlorinated Polyethylene and Chlorosulfonated Polyethylene
- Chlorobenzenes
- Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs)
- Chloroprene (Neoprene)
- Chromium VI
- Chlorinated Polyvinyl Chloride (CPVC)
- Formaldehyde (added)
- Halogenated Flame Retardants (HFRs)
- Lead (added)
- Mercury
- Polychlorinated Biphenyls (PCBs) Perfluorinated Compounds (PFCs)
- Phthalates
- Polyvinyl Chloride (PVC)
- Polyvinylidene Chloride (PVDC)
- Short Chain Chlorinated Paraffin
- Wood treatments containing Creosote, Arsenic or Pentachlorophenol
- Volatile Organic Compounds (VOCs) in wet applied products

Figure 3.3 Red list of chemicals for which there is no safe level of exposure.

for disassembly and reuse are mandatory components of certification. The institute has the industry’s strictest list of toxic materials not safe at any level of exposure, their Red List. They also certify building products, listing every ingredient in a product, highlighting any toxic ones, and noting provenance. Ingredient lists prove extremely helpful in determining which materials are safe to use. However, The Living Building Institute’s niche market position has so far restricted the number of products certified.

Given the shortage of information that could be obtained from green certification systems on recyclable and compostable building materials, it was necessary to assemble material flow diagrams from first principles of mono-materials, mechanical fastening and ease of recovery. These principles had to be implemented with good chemistries to achieve sustainability.

For most building material flow diagrams, research began by selecting a monomaterial, then chasing down its ingredients through material safety data sheets. These information sheets are required by law for workplace safety with chemicals. While hard to parse, the sheets are mandatory, ensuring they can be found for any material. Sometimes manufacturers are able to hide behind proprietary ingredients but often all constituents are listed. By researching each ingredient the product can be evaluated for toxicity and ability to be recycled. In some cases, otherwise healthy products are subtly contaminated by a mould release agent or dye.

White-listing building materials

If we begin separating construction materials into the four different life cycle categories a grim picture emerges. The majority of materials are ineligible for use in recyclable or compostable buildings. This places a significant constraint on the design of cradle to cradle buildings. The following diagram separates North America’s most common building materials into four material categories, ordered by Masterformat division number.

Div.	Material	End of life	Legend
03	Concrete	Downcycled	Recyclable material
04	Mortared masonry	Reusable	Compostable material
	Glued masonry	Inseparable	Disposed material
	Toxic glazes, pigments	Toxic	Toxic material
05	Steel	Recyclable	
	Aluminum	Recyclable	
	Copper	Recyclable	
	Stainless steel	Recyclable	
	Galvanized steel	Recyclable	
	Lead	Toxic heavy metal	
	Mercury	Toxic heavy metal	
06	Wood	Compostable	
	Polyethylene	Recyclable	
	Polyvinyl chloride	Toxic chlorine	
	Pressure treated lumber	Toxic arsenic and creosote	
	Neoprene	Toxic chlorine	
	Chlorinated plastics	Toxic chlorine	
	Epoxy	Toxic bisphenol A	
	Formaldehyde glues	Toxic	
	Composites	Inseparable	
07	Tyvek (spun polyethylene)	Recyclable	
	Polyethylene film	Recyclable	
	Cellulose fibres	Compostable	
	Straw	Compostable	
	Rockwool	Recyclable	

Div.	Material	End of life
	Polystyrene foam	Landfilled
	Flat roofing products	Toxic, inseparable
	Painted metal roofs	inseparable
	Caulking	Inseparable
08	Aluminum and steel frames	Recyclable
	Vinyl frames	Toxic chlorine
	Glass	Recyclable
	Coated glass	Inseparable
	Laminated glass	Inseparable
	Tinted glass	inseparable, possibly toxic
	“Smart windows”	Inseparable, possibly toxic
09	Plaster	Downcycled
	Gypsum board	Downcycled
	Fastened panelling	Recyclable or compostable
	Tile	Downcycled
	Concrete flooring	Downcycled
	Wood flooring	Sometimes recyclable
	Vinyl flooring	Toxic
	Fluid applied flooring	Inseparable
	Carpet	Some are recyclable

The following finishes are only appropriate where the base material and finish can biodegrade together.

Most paints	Inseparable
Glued anything	Inseparable
Composites	Inseparable

A detailed list of citations for this diagram appears separately in Appendix B.

Figure 3.4 Common construction materials separated by life cycle.

Material flow diagrams

The life cycle diagrams in this thesis are the result of concerted effort to eliminate toxins and disposable materials. In order to illustrate the insidious entry of contaminants and their effects through to end of life, a worst case scenario material flow is useful. The analysis of a fibre-reinforced PVC extrusion reveals some ugly externalities. Many of the ingredients are toxic during production, during use, and in disposal. Nothing good can come of the material, the most appropriate disposal method would be sealing it away for thousands of years.

Legend

- Recyclable material
- Compostable material
- Disposed material
- Toxic material

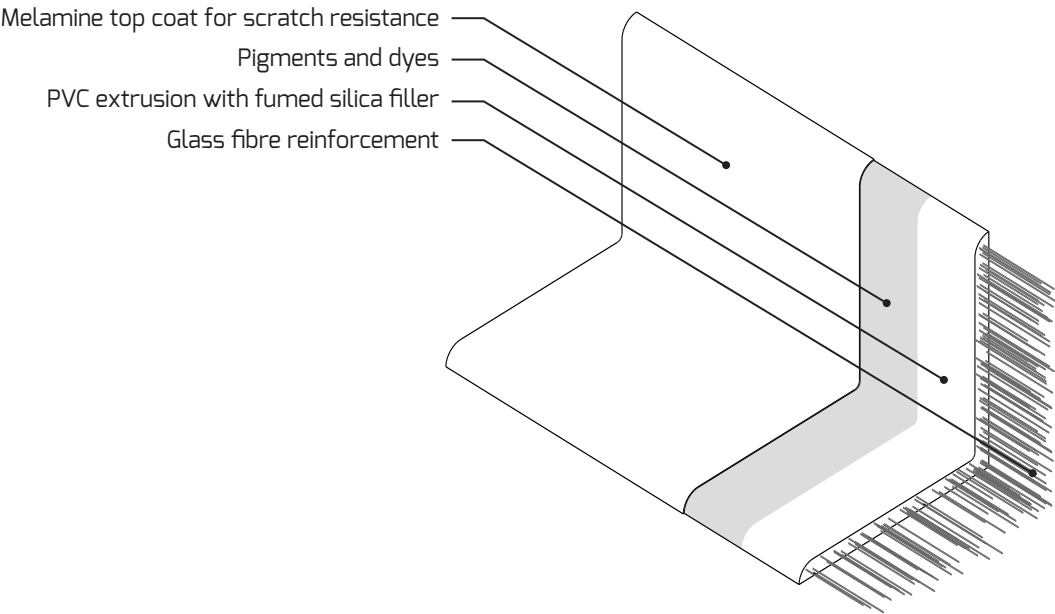
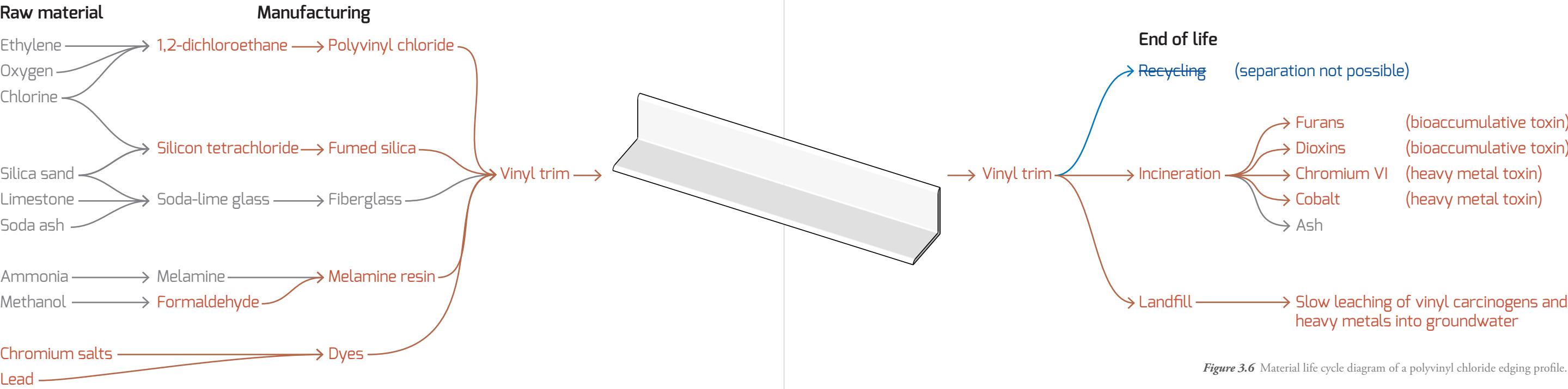


Figure 3.5 Diagram identifying components of the vinyl edging profile

Redesigned materials

When architects consider the life cycle of a building’s materials, they become engaged in production processes. Representing these processes through life cycle diagrams identifies hazardous methods and materials, revealing opportunities for improvement. While wading through research on harmful manufacturing methods sometimes a niche product without harms will emerge. In several cases, an entire category of products is unsuitable for recycling or composting. When such a product is necessary for high performance buildings, architects can work with manufacturers to modify ingredients or adapt assembly methods. The reduction of formaldehyde emissions from wood products has been a success story of architectural agency in reshaping material. Several proposed redesigns of material life cycles are examined in detail over the following pages.

Wood treatments

Increasing the longevity of wood has been a challenge for the entire duration of civilization. Methods for preserving wood range from charring, staining, painting, laminating to pressure impregnating.<sup>8</sup> Most of these methods include an anti biological component to stop mould and insects. These biocides become a problem at the end of life cycle, when wood should biodegrade. Heavy metal biocides persist in the environment, plastic varnishes degrade extremely slowly, and poisons leach from pressure treatments.<sup>9</sup> Searching for biodegradable wood treatments is in some ways futile; a good wood treatment would resist degradation. After eliminating

8. Bjørn Berge, *The Ecology of Building Materials* (Oxford ; Boston: Architectural Press, 2000), 433.  
9. Ibid. 437.

- Legend
- Recyclable material
  - Compostable material
  - Disposed material
  - Toxic material

all non-biodegradable treatments, only natural oils, waxes, charring and a new process called acetylisation remain.<sup>10</sup> Acetylisation holds promise because the treatment is non-toxic, it binds reactive elements in the wood to naturally occurring acetyl groups.<sup>11</sup> The reaction produces food grade vinegar as a byproduct. The resulting wood performs like pressure treated, removing the need to paint wood with toxic pigments.<sup>12</sup>

10. “End of Life,” *Accoya.com*, accessed December 13, 2016. <https://www.accoya.com/sustainability/end-of-life/>  
11. Roger M. Rowell et al. “Production of Dimensionally Stable and Decay Resistant Wood Components Based on Acetylation” (Paper presented at the 11DBMC International Conference on Durability of Building Materials and Components, Istanbul, May 11-14th, 2008), <https://www.accoya.com/wp-content/uploads/2015/06/Roger-Rowell.pdf>  
12. Ibid.

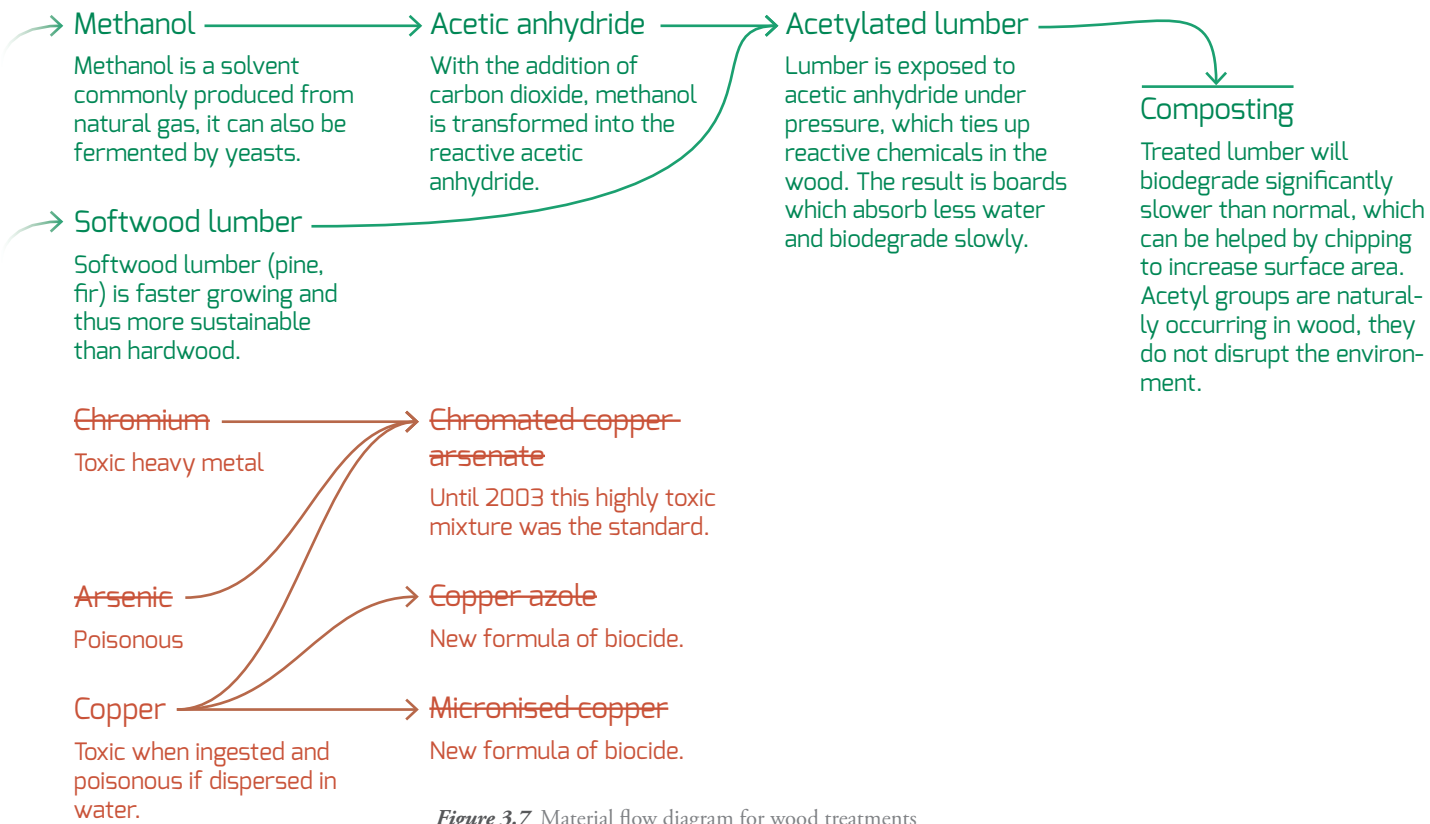


Figure 3.7 Material flow diagram for wood treatments



Cellulose Insulation

Cellulose insulation has the lowest environmental footprint of all insulation types.<sup>13</sup> To render the fluffy paper fibres fireproof however, boric acid (borax) and ammonium sulfate are added.<sup>14</sup> Borax is an environmental toxin, which relegates the eminently compostable paper fibres to landfill.<sup>15</sup> Ammonium sulfate, on the other hand, while not renewable is commonly used as fertilizer.<sup>16</sup> Substituting a greater quantity of ammonium sulfate for boric acid will produce cellulose insulation that can be safely composted.

13. Margit Pfundstein, *Insulating Materials : Principles, Materials, Applications* (Basel ; Munich: Birkhäuser ; Edition Detail, 2008), 96.  
14. Berge, *The Ecology...* 285.  
15. Pfundstein, *Insulating Materials...* 47.  
16. “Nutrient Source Specifics: Ammonium Sulfate.” *International Plant Nutrition Institute*. accessed October 14, 2016. <http://www.ipni.net/specifics-en>

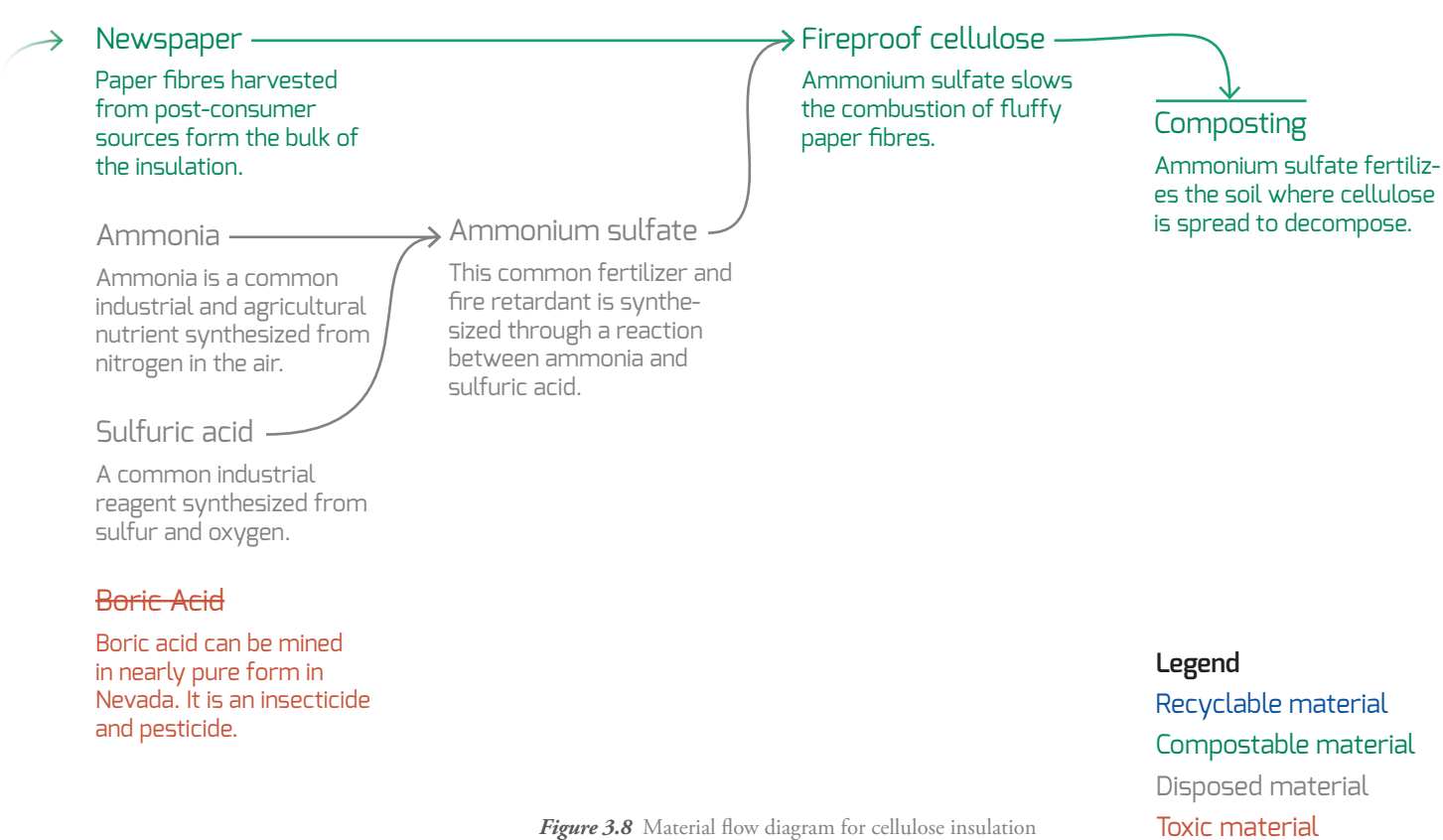


Figure 3.8 Material flow diagram for cellulose insulation

Rock Wool

Rockwool is growing more and more popular for building insulation. Marketing materials often tout its environmental friendliness, however, the rock fibres are held together by a toxic thermo-set phenol formaldehyde adhesive.<sup>17</sup> Post-industrial recycling of small quantities is practised, though there is no widespread collection system for post-consumer rock-wool.<sup>18</sup> By replacing the formaldehyde adhesive with a thermoplastic polymer such as nylon, the materials can be separated at end of life. Nylon can be recovered by solvent dissolution, and cleaned rock fibres can then be remelted into fresh wool.

17. Pfundstein, *Insulating Materials...* 21.  
18. Ibid. 23. and “ROCKWOOL Sustainability Report 2015,” *Roxul*, accessed December 13, 2016, 17. [http://www.roxul.com/files/RX-NA\\_EN/pdf/Corporate/ROCKWOOL\\_Sustainability-Report\\_2015\\_web.pdf](http://www.roxul.com/files/RX-NA_EN/pdf/Corporate/ROCKWOOL_Sustainability-Report_2015_web.pdf)

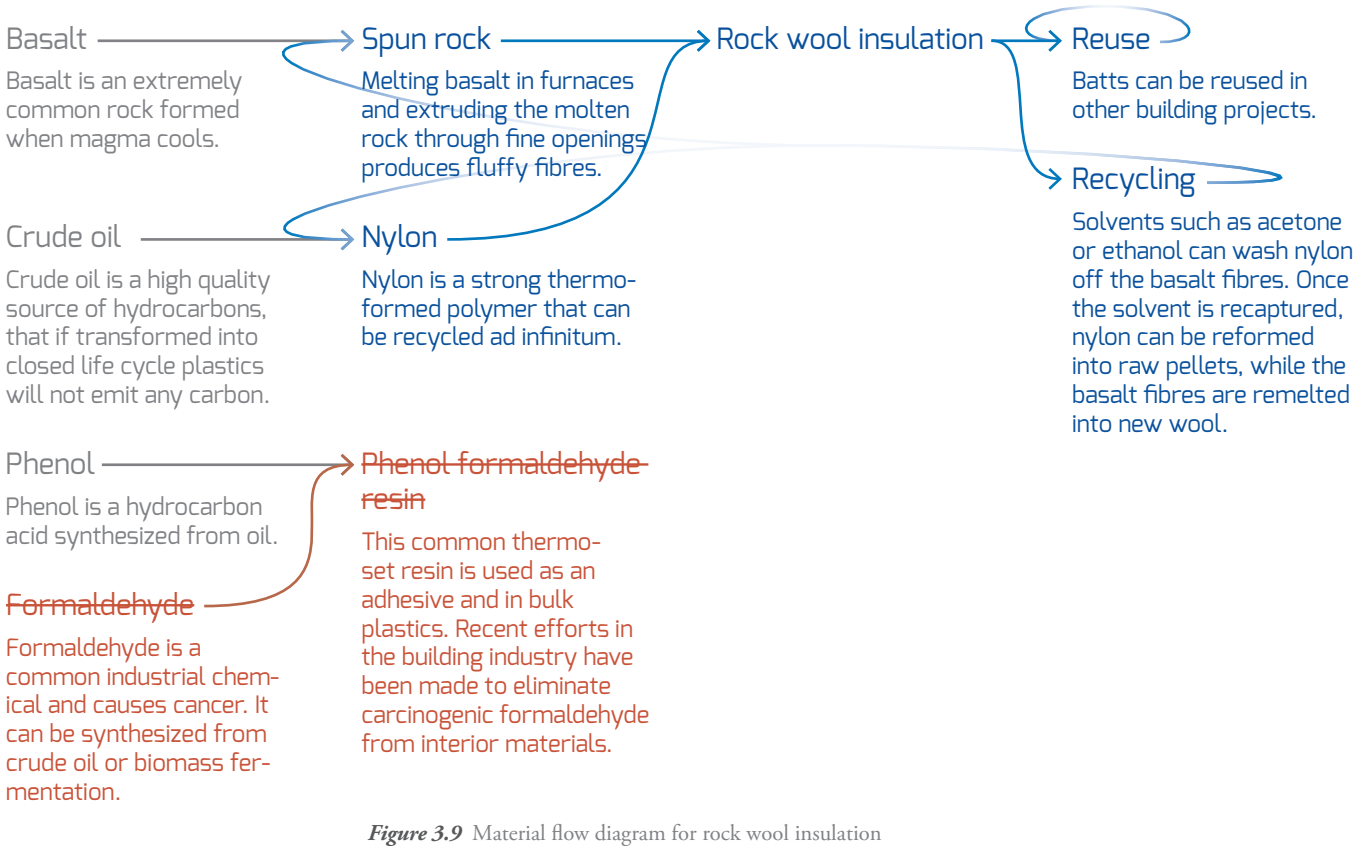


Figure 3.9 Material flow diagram for rock wool insulation

Wood Adhesive

Recent advances in soy glue promise to remove formaldehyde emissions from composite wood products.<sup>19</sup> However, a deeper dive into the chemistry of soy flour adhesives reveals that the new ingredient is a curing polymer blend called Kymene.<sup>20</sup> This chlorinated hydrocarbon does not emit formaldehyde but will produce the persistent toxins dioxin and furan when burned. Research into soy glue chemistries is ongoing, but there may be no good solution.<sup>21</sup> Any biodegradable glue will fail to be waterproof enough for structural use.

19. Lizanne Dirks and Pietro Galgani, "Soy Glue," *WoodGuide.org*, accessed September 23, 2016, <http://www.woodguide.org/guide/soy-glue/>

20. Kaichang Li, "Formaldehyde-free lignocellulosic adhesives and composites made from the adhesives," U.S. Patent No. 7,252,735, 2007.

21. Trina Ghosh Dastidara and Anil N. Netravali, "A soy flour based thermoset resin without the use of any external crosslinker," *Green Chem.* no. 15, 2013, 3243. DOI: 10.1039/c3gc40887f

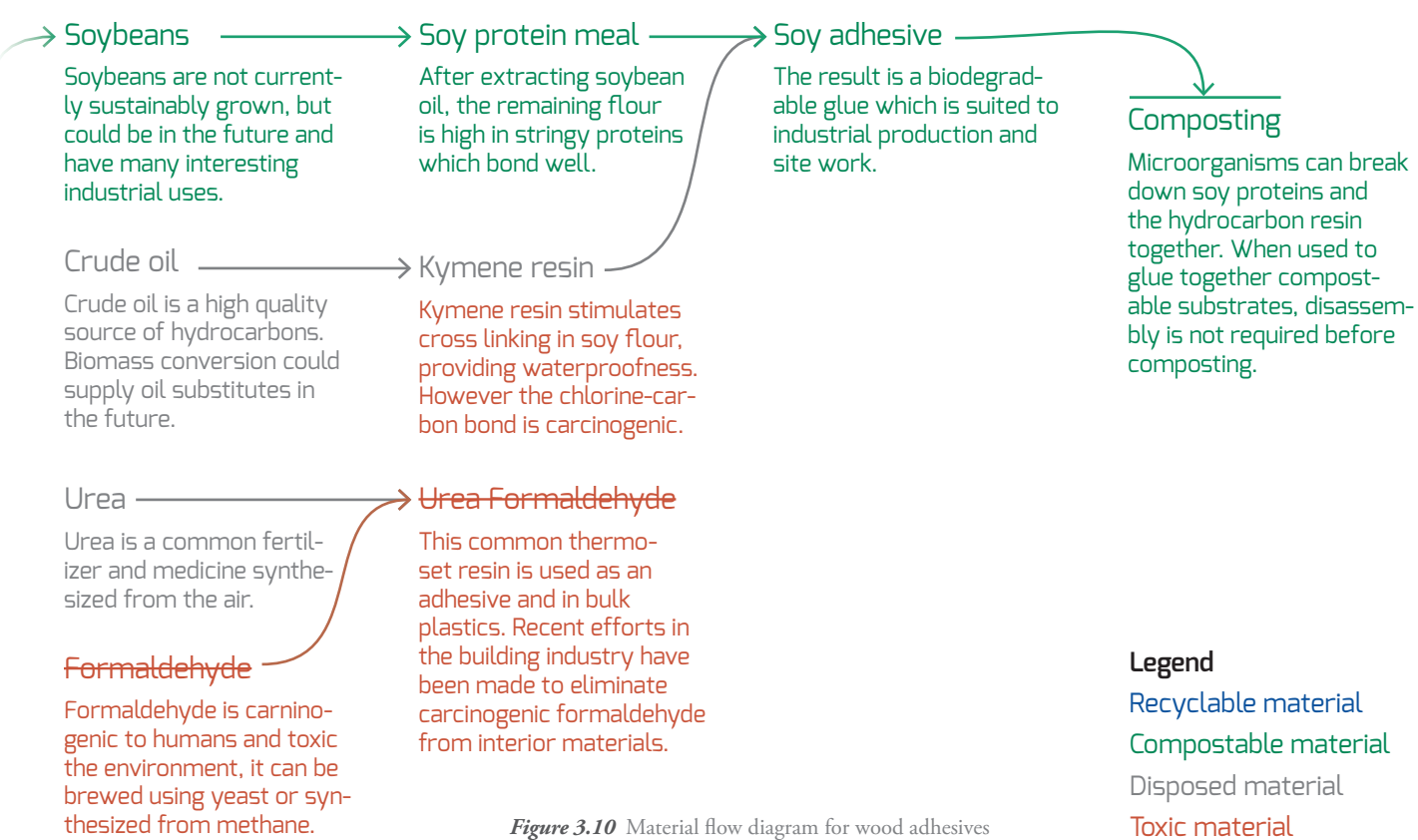


Figure 3.10 Material flow diagram for wood adhesives

Polyethylene

Modern, high performance buildings could not be constructed without plastics. They provide invaluable assistance in sealing envelopes, isolating thermal and electric forces, and creating functional coatings. The challenge in designing the life cycle of plastic building components is selecting nontoxic chemistries that can be recycled. Polyethylene is the best construction plastic for closed life cycles. It is the world's most common polymer, synthesized from simple hydrocarbon precursors without toxic chlorine bonds.<sup>22</sup> Polyethylene, along with PET in beverage bottles, are the only two commonly recycled plastics.<sup>23</sup> When several cycles of use have weakened or contaminated polyethylene it can be chemically broken down the original monomers for feedstock recycling.

22. Li Shen and Ernst Worrel, "Plastic Recycling," in *Handbook of Recycling*, ed. Ernst Worrel and Markus A. Reuter (Amsterdam: Elsevier, 2014), 180.

23. Jefferson Hopewell, Robert Dvorak and Edward Kosior, "Plastics recycling: challenges and opportunities," *Philos Trans R Soc Lond B Biol Sci.* July 27, 2009; No. 364: 2115–2126. DOI: 10.1098/rstb.2008.0311

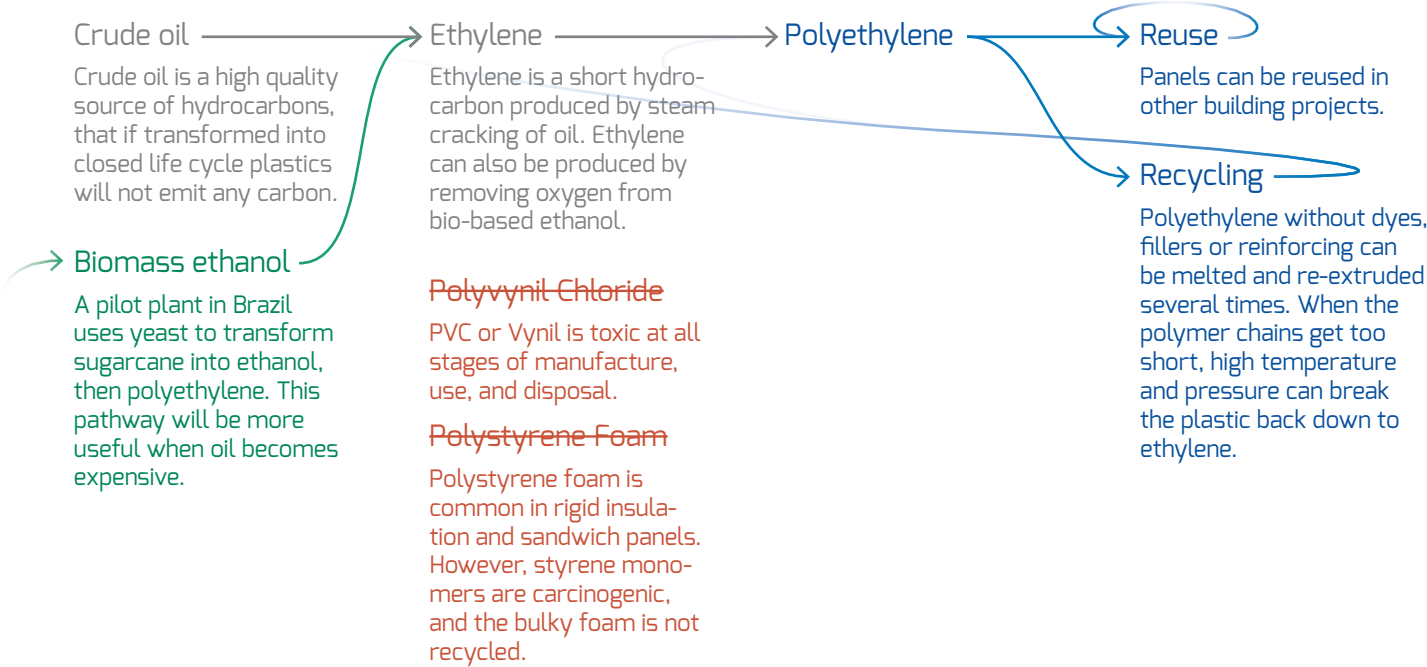


Figure 3.11 Material flow diagram for polyethylene

## Conclusion

Material flow diagrams are designed to communicate with clients and suppliers the recycling or composting goal of a building. The simplicity of a single causal flow makes the story of materials accessible to non-experts. Such simplicity can also conceal or misdirect however. Real world complexity cannot be represented in such a simple manner, so the author of diagrams is responsible for accurately representing material streams. In the hands of manufacturers and salespeople the diagrams could be another tool for green-washing by omitting ingredients and harmful adjacent processes. In the hands of an architect the diagrams are a powerful tool to communicate to the client a building's material ecologies. Material flow diagrams could have a longer-term effect if they were visible to occupants. Communicating circular material design to maintainers and users of a building has a big impact on the latter stages of material life cycles. Occupants determine the building's program and have an effect on material wear and replacement.

Ultimately, material flow diagrams are only theoretical tools. Until architects begin to diagram flows in the construction of real buildings their effectiveness is speculative. Many processes in manufacturing and construction vary by geography and hence require local modifications to ensure recycling of a building. Practical research into the recovery of building materials requires a quicker feedback cycle than the eighty year life of most structures.

The ephemeral architecture of a world Expo is the perfect venue for experimentation. Creative architecture is celebrated, while being assaulted by a constant stream of visitors which simulates accelerated aging. When the Expo closes six months later, disassembly, reuse and recycling of pavilions can be evaluated. Precedents of short lived architecture carry lessons on assembly and disassembly which are applicable to the wider building industry. Bringing the world together to solve the waste of architecture is necessary, and an Expo could serve as the catalyst to change society's view of reuse and recycling.





# 4.

## *Precedents*

**Figure 4.1** Used doors for sale at Kitchener's Habitat for Humanity ReStore. Recovery and storage of reusable materials is expensive.



## 4. Precedents

### Learning from impermanence

Most buildings are erected without a plan for end of life. The death of a structure is beyond the planning horizon, or even the lifetime of clients. Advancements in building science and durability now deliver buildings that last from sixty to over a hundred years. In practice, buildings are demolished much earlier than their best before dates for reasons other than technical failure.<sup>1</sup> Redevelopment pressures, lack of maintenance and changing needs are the most common causes of building obsolescence. Architects discount the impact of these forces which are beyond their control. We have to look to impermanent structures for good examples of circular material streams where the designer is responsible for take-down.

Temporary buildings pop up and disappear on the fringes of architecture. While most practitioners are designing for the appearance of permanence, ephemeral gestures in building have much to teach the broader discipline. The marvellous thing about temporary buildings is that designers can plan for end of life without admitting the building is a failure. It is expected that a pavilion or pop-up will return to the ground, part of a natural cycle. Writer Eric Felten, in the essay “In Praise of Impermanence”, appeals for the construction of temporary buildings.<sup>2</sup> If freed from the necessity of enduring, experimental and wild styles can be erected. Successful experiments, such as the Eiffel tower, can grow into permanence while the rest are disassembled, fleeting as memories.

In selecting precedents for recyclable buildings, explicitly temporary structures stood out as the only ones designed for end of life. Temporary use need not be a death sentence, in several of these cases communities could not bear to demolish their transient buildings. When architect Shigeru Ban was asked about his temporary structures upon receiving the Pritzker prize, he opined “there is no difference between temporary and permanent. Even if a building is made out of paper, if people love them, then they will become permanent.”<sup>3</sup>

1. Jennifer O'Connor, “Survey on actual service lives for North American buildings,” (paper presented at the Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, October 2004), [http://cwc.ca/wp-content/uploads/2013/12/DurabilityService\\_Life\\_E.pdf](http://cwc.ca/wp-content/uploads/2013/12/DurabilityService_Life_E.pdf) 3.
2. Eric Felten, “In Praise of Impermanence,” *Wall Street Journal*, April 19, 2012. <http://www.wsj.com/articles/SB10001424052702303425504577353790993830980>
3. Matthew Ponsford, “Shigeru Ban: Pritzker winner’s paper palaces could last forever,” *CNN*, November 2, 2015, <http://www.cnn.com/2015/09/29/architecture/shigeru-ban-pritzker-permanent/>

Some more recent selected precedents develop innovative methods of design for disassembly or creative reuse. The success of temporary architecture has a lot to teach architects, because on a larger time scale all buildings are temporary.

### The Crystal Palace

In 1851 the world’s first exhibition building materialized, glittering, in a park. For Expo architects, Joseph Paxton’s Crystal Palace remains the building to beat. Its soaring lace-work of iron supported acres of glass, at a time when neither were common. Constructed in a mere six months, the hall introduced Londoners to cast iron structures, prefabrication, and an early form of mass production.<sup>4</sup> Inside, exhibits from around the world drew huge crowds but the building itself was the most impressive industrial feat. At the Expo’s conclusion the Crystal Palace was disassembled and the park returned to grass. While its pieces sat in storage, several years of design competitions for re-erection followed. One of the most ambitious schemes proposed that a 305 metre tower be constructed from the same parts.<sup>5</sup> Eventually a slightly modified hall was assembled on Sydenham Hill. Events and exhibits were held there for the next seventy years until in 1936 a fire brought an end to the Palace.<sup>6</sup>

From Joseph Paxton’s background in greenhouse design, the Crystal Palace was a huge increase in scale. He was aided by the new structural use of cast iron. Just a few modular elements could be assembled into a colossal hall. In an age of riveting, Paxton’s use of reversible bolted connections between casts parts made disassembly easy.<sup>7</sup> The small palette of materials was rounded out by thin glass panes and wood muntins. Even today we can marvel at the lacy, lightweight structure. Everything was not perfect however: skylight glass panes less than 2mm thick would shatter and rain down with some regularity.<sup>8</sup> But the Crystal Palace proved itself at the Expo’s close, when it had to move. Cast iron and glass are valuable,

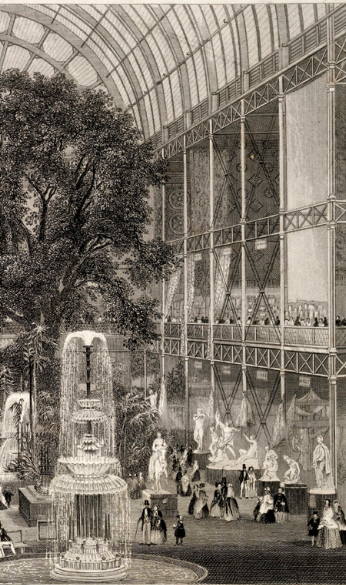


Figure 4.2 The Crystal Palace, Joseph Paxton (1851)

4. Wolfgang Friebe, *Buildings of the World Exhibitions* (Leipzig: Edition Leipzig, 1985), 19.
5. Ibid. 23.
6. Patrick Beaver, *The Crystal Palace, 1851-1936 : A Portrait of Victorian Enterprise* (London: Hugh Evelyn, 1970), 141.
7. Friebe, *Buildings of the World Exhibitions*, 19.
8. Ibid. 19.

they could have been sold for remelting, but the building had been so successful that it warranted reconstruction.<sup>9</sup> Paxton’s ingenious system of prefabricating identical modules created great flexibility in reuse.

Eiffel Tower

Gustave Eiffel brought the use of iron to a climax in the thousand foot tall Eiffel tower. Originally intended as a temporary centerpiece for the 1889 Expo, the tower has endured and grown to symbolize Paris.<sup>10</sup> The tower was riveted together out of wrought iron plates, prefabricated in sections at nearby factories. In contrast with Paxton’s few modular parts, the Eiffel tower was detailed with twelve thousand drawings. Such specialization forecloses opportunities for reusing the building material, though success relieved the tower of that difficulty. Alterations or deconstruction are enabled by the robust structure. A plan to disassemble the tower, ship it to Montreal, and create a French presence at Expo 67 was at one point agreed upon by Jean Drapeau and Charles de Gaulle.<sup>11</sup> Luckily, concerns that the Eiffel tower would not return safely scuttled the plan. Such an ambitious relocation is a testament to the disassembly benefits of steel. A hundred years of alterations and painting have done little to reduce the recycling potential of its structure. The tower that stands today is a testament to Eiffel’s engineering, its cultural impact, and tireless maintenance of the structure’s one million rivets.<sup>12</sup>

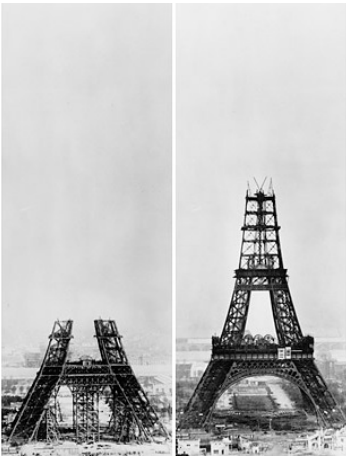


Figure 4.3 Eiffel Tower (1889)

9. Beaver, *The Crystal Palace*, 72.  
10. Friebe, *Buildings of the World Exhibitions*, 100.  
11. “How this city nearly got the Eiffel tower,” *Montreal Gazette*, Sept. 15, 1980, <https://news.google.com/newspapers?id=eJckAAAAIIBAJ&sjid=raQFAAAAIIBAJ&pg=1682%2C2718377>  
12. Friebe, *Buildings of the World Exhibitions*, 96.

Swiss Sound Box

For Switzerland’s pavilion at Expo 2000 in Hannover, Peter Zumthor designed a maze of sensuous heavy timber stacks. The smell of pine and food permeates through the partially open stacks while views and sounds are attenuated. Zumthor states that he was inspired by a lumberyard, which he follows through in the method of construction.<sup>13</sup> Sawn lumber is borrowed for six months and dry stacked to form the Expo pavilion, before returning to use in building construction. The temporary appropriation of green lumber is a great precedent for no impact life cycles: during the Expo timber slowly dried out, returning to the building industry more valuable than before. By stacking wood, boards are at once a commodity and a module. Designing an assembly method that did not damage the boards was essential to preserving future potential uses. This was not easy, as each stack of boards would dry, shrinking more than 17 centimetres during six months.<sup>14</sup> The solution was to tension stacks together with a metal spring accommodating creep. Heavy walls of wood form a solid enclosure, with the tactile and sonic romance of using a real material in contrast with modern lightweight pavilions.



Figure 4.4 Swiss Sound Box, by Peter Zumthor (2000)

Cellophane House

With a commission from the Museum of Modern Art, KieranTimberlake designed and assembled Cellophane House in eleven months.<sup>15</sup> The building was delivered in July 2008 as a feature exhibit on prefabricated housing in downtown New York. Three months later, the house was disassembled and packed away on trucks. The ephemeral nature of this building made it a unique test for technologies and materials. KieranTimberlake had just completed Loblolly House, a cottage bolted together out of aluminum extrusions. Cellophane House takes design for disassembly further, rising five stories tall with a unique plastic film window system.



Figure 4.5 Cellophane house, Kieran-Timberlake (2008)

13. Peter Zumthor et al., *Swiss Sound Box : A Handbook for the Pavilion of the Swiss Confederation at Expo 2000 in Hanover* (Basel ; Boston: Birkhäuser, 2000), 240.  
14. Ibid. 212  
15. Stephen Kieran and James Timberlake, *Cellophane House* (Philadelphia: Kieran-Timberlake, 2011), 5.



Architecturally, Cellophane House embraces transparency. In addition to full glazing, the house has translucent plastic floors and walls. On the interior, the requirement of disassembly causes fasteners to be visible and bracing structures protrude. Plastic glazed walls along two sides are reinforced with an aluminum extrusion at handrail height, presumably to stop falls thought the thin membrane. To counter the weakness of structural aluminum, Kieran Timberlake assembled Cellophane House out of a surfeit of Bosch Rexroth extrusions.<sup>16</sup> The bolt channels on these are augmented by custom steel brackets. Profiled aluminum was chosen for its versatility, though so many holes have been drilled through the aluminum for reinforcement that adaptation will not be possible. The aluminum structure is completed with polymer floors, walls, and fixtures. Kieran Timberlake designed the building as a technical nutrient, entirely recyclable at end of life. For the most part this was well carried out: acrylic panels used on the interior are un-pigmented and mechanically fastened. However, fibreglass bathrooms and adhesives used in plastic windows do not permit wholesale recycling. The house's admirable material life cycles are somewhat diminished by energy failings. The heavy aluminum structure has gargantuan embodied energy and conducts amply in thermal bridges.<sup>17</sup> Full glazing of every surface creates a greenhouse environment. Stephen Kieran commented that the building was designed to 1/32" tolerances, made possible by computerized milling and factory pre-assembly. This led to difficulties during assembly, with very fine control needed to fit pieces together. It is doubtful that this level of precision is either desired or warranted in the wider construction world. At the close of the exhibition, the house was disassembled over the course of a month into sticks and panes and loaded in five semi trucks. Plans for sale to a private buyer fell through, so the house has been sitting in storage for the past eight years.<sup>18</sup> For all the effort and precision put into making the house re-assemblable, its fate rests on the whims of investors.

16. Ibid. 24.

17. Ibid. 121. The embodied energy calculated for Cellophane House is ten times greater than a typical house of the same area.

18. Ibid. 130.

## Holding Pattern

For a summer pavilion at New York's MoMA, Interboro subverted the waste of a temporary structure by ensuring reuse.<sup>19</sup> The architects matched community needs with items that would furnish the site, ensuring a home would be waiting after the objects were 'held' in a pavilion over the summer. As the pavilion was disassembled, trees, street furniture and play structures were donated to neighbourhood organizations. By asking others what is needed, the architects pioneered an unusually successful form of reuse. The narrative of future users enriched the pavilion, with yellow stickers on each item stating who things were held for. This strategy holds great promise for Expo construction, as six months is short enough for a recipient to wait. The sourcing and manufacture of materials is completed for the first use, removing much of the waiting from a second construction. Designed reuse does require flexibility on the designers side: Interboro was challenged to bring consistent design language to a disparate collection of artifacts. This method is limited by the patience and foresight of recipients, it would not be suitable for more traditional building time frames.

## The Living Hy-Fi

Mushrooms made their building debut a few years ago in a MoMA pavilion by The Living. The architects seeded wheat straw with fungus spores and a carbohydrate food source to grow organic bricks.<sup>20</sup> During an incubation period fungus fibres bind the straw together into a white mass. When stacked in a running bond, the bricks formed a completely biodegradable shade structure. The ability to grow biodegradable material quickly into any molded shape creates opportunities for sensuous curved architecture without the waste of offcuts. All other mold-able materials require high energies to melt or chemically cure in an unrecyclable manner. Fungus is so far unproven as a longer term construction material, but is suitable for temporary structures. Some concealed steel reinforcing in the Hy-Fi project indicates that mushrooms may also lack strength.



Figure 4.6 Holding Pattern at MoMA  
Interboro (2011)



Figure 4.7 Hy-Fi by The Living  
(2014)

19. Daniel D'Oca et al., "Checking in on Holding Pattern" *Inside/Out* (blog) Museum of Modern Art, January 12 2012, [https://www.moma.org/explore/inside\\_out/2012/01/12/checking-in-on-holding-pattern](https://www.moma.org/explore/inside_out/2012/01/12/checking-in-on-holding-pattern)

20. David Benjamin, "Hy-Fi by The Living," *Young Architects Program and MoMA*, 2014, [https://www.moma.org/interactives/exhibitions/yap/2014ny\\_living.html](https://www.moma.org/interactives/exhibitions/yap/2014ny_living.html)

Serpentine pavilions

Each year the design world watches starchitects making their mark with the erection of a new pavilion at the Serpentine Gallery. But few know that the pavilions do not disappear at the end of summer; every one has been sold privately.<sup>21</sup> Pavilions reappear a few years later on the estates of wealthy families or as event spaces. It has not always been easy to find a buyer: the very first pavilion by Zaha Hadid was used by a Shakespeare troupe, a farmer, and now shelters theme park attendees. Selling the pavilion enables the gallery to recoup a portion of construction costs. Success and international attention received by pavilions has made them into status symbols, with recent pavilions sold before construction. The second lives of Serpentine pavilions attest to the value of reusing architecture, and the resulting stories about intriguing past uses of adapted buildings.



Figure 4.8 Toyo Ito Serpentine gallery pavilion (2002)

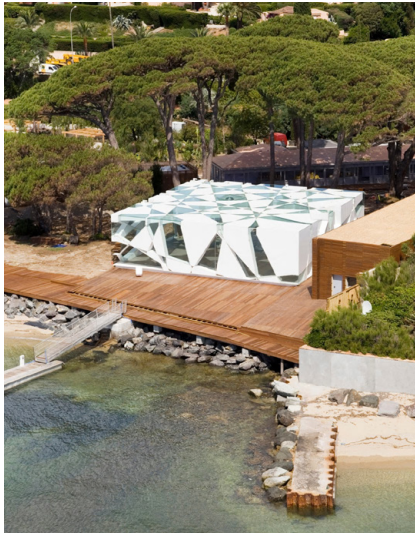


Figure 4.9 The Toyo Ito pavilion is now a beach-side cafe (2015)

21. Oliver Wainwright, “Beach cafe, billionaire’s retreat, wedding marquee: second lives of the Serpentine pavilions,” *The Guardian*, June 16, 2015, <https://www.theguardian.com/artanddesign/2015/jun/16/serpentine-pavilion-second-lives-zaha-hadid-toyo-ito-frank-gehry>

ICEhouse

William McDonough unveiled a technical nutrient pavilion at the 2016 Davos World Economic Forum. With a palette of just four recyclable materials, the small meeting space aims to showcase circular material streams to the rich.<sup>22</sup> The aluminum space frame structure feels like a retrogression, but its single uniform module is easy to reassemble in other shapes. The walls and roof are made of aerogel filled polycarbonate extrusions which diffuse light into the space. At this point the ecological story woven by McDonough falters. Passing over low impact building materials like wood, he chooses high energy aluminum and aerogel. While aerogel may be nominally recyclable, a UV protection layer will consign the polycarbonate to downcycling. ICEhouse succeeds in sparking interest in life cycle design while demonstrating the difficulty of doing it right.



Figure 4.10 ICEHouse by William McDonough (2016)

Conclusion

The diverse approaches to reuse and circular material streams presented here are hopeful indications of a wealth of design opportunities. Paxton’s Crystal Palace and the Eiffel tower stand out as impressive technology demonstrations, whose success is reinforced over time. Simple materials and elegant detailing have outlasted many fashionable pavilions which have come and gone. Cellophane House and ICEhouse attempt to update the technical pavilion with plastics and better comfort, with mixed results. Both are bold, but have a small impact in a more diverse building industry than Joseph Paxton’s time. TheLiving’s mushroom pavilion is the most daring, and points to a hopeful future for buildings that can be grown. Zumthor and Interboro take a radical stance by choosing to be interim users of material. It takes humility to design a building as a temporary resting place for materials in a larger story. Temporary buildings are a model for how all buildings should work: they are designed through disassembly and reuse, leaving their sites clean for future occupation. Bringing together the international ingenuity presented here would do a great service to the world by demonstrating a sustainable material future.

22. “ICEhouse,” Davos, Switzerland: *William McDonough + Partners*, 2016, <http://www.mcdonoughpartners.com/projects/icehouse/>





# 5.

## *Design for Expo Toronto*

**Figure 5.1** Shattered acrylic rods during demolition of the British Seed Cathedral at Expo 2010 represent the waste that follows temporary buildings.



5. Design for Expo Toronto 2030

World Expositions are ripe for re-imagination. A hundred years ago, world fairs offered a vision of the future, while today they are fading from relevance. Constructing a small town for only six months is short-sighted and wasteful. Expositions are in need of a cause to make them relevant again, a reason to bring people from all over the world together.

Designing an Expo around circular material streams provides a compelling reason to visit in person: to participate in the physical process of material use and regeneration. By viewing expositions as a temporary use of materials, their buildings become the ideal platform for experimentation in recycling and reuse. Short time frames and intense occupancy give immediate feedback on the durability and recyclability of speculative architecture. By inviting the public for a ‘sneak peak’ of the Expo site during construction and later again during demolition, people will become more aware of the processes outside the ordinary static occupation of buildings.

The diversity of exhibiting countries and visitors will contribute a multiplicity of creative solutions to eliminate waste. An Expo commands the media attention necessary to shift public perception on recycling and reuse, redefining them from downcycling to genuinely productive processes. World Expositions can once again be indicators of a better future.



Figure 5.2 After Expo ‘67, demolition of Man the Explorer pavilion with Buckminster Fuller’s dome in the background.



Figure 5.3 Demolition of the Yukon Pavilion at Expo ‘86 in Vancouver.

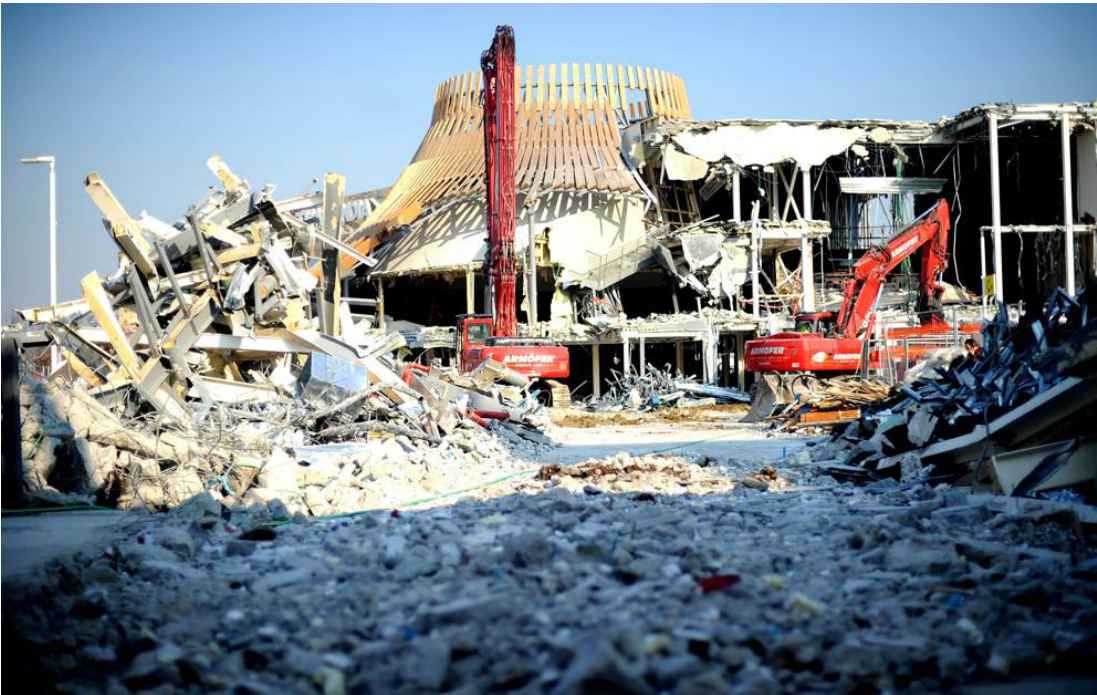


Figure 5.4 Destructive demolition of the Thai Pavilion after Expo 2015. How can we end this pattern of waste?



Learning from Milan

World expositions are now held every five years. The largest was hosted in Shanghai 2010, as a patriotic celebration of Chinese strength. Only three countries abstained from the most expensive Expo ever.<sup>1</sup> Most recently, Expo 2015 was a sustainability-focused event held in Milan. Organisers hired a design team including Jaques Herzog and William McDonough to plan the event.<sup>2</sup> Together they decided to reject the nationalistic showcase of a world’s fair and focus on a humanitarian Expo theme: Feeding the World. This radical take on Expo design proposed identically sized plots for each country where crops could be raised. Pavilions were restricted to farm buildings or tasting rooms. William McDonough rekindled the idea of a waste free Expo first attempted at Hannover in 2000. By dispensing with spectacle, the designers hoped to concentrate the attention of attendees on education and the issue of food quality and supply. While the concept was intellectually engaging, politicians responsible for the project refused to carry out the plan. A humble Expo dismisses the economic and touristic reasons for hosting the event. The design team quit in 2011, leaving the masterplan unexecuted.<sup>3</sup> Lines drawn by the team were filled in with a typical assortment of country pavilions and the Expo proceeded without them.

The ideas of Herzog and McDonough can still be found as suggestions in Expo guidelines, though the pattern of waste creation has continued.<sup>4</sup> Out of 65 pavilions, 12 will be reused, with discussions ongoing about the reuse of 8-10 others.<sup>5</sup> Plans by the Milan design team were creative

1. Rodolphe El-Khoury, Andrew Payne and Nic Lehoux, *States of Architecture in the Twenty-first Century : New Directions from the Shanghai World Expo* (Singapore ; Philadelphia: Oscar Riera Ojeda Publishers, 2011), 13.  
Andorra, Congo, the Holy See, Macedonia, Sao Tome and Principe, South Sudan, and Swaziland did not participate, but the Cook islands, Macau, Taiwan and Hong Kong are counted as countries though they are territories. China must have provided heavy incentives to get countries such as the Maldives to attend.

2. Florian Heilmeyer, “Putting an End to the Vanity Fair,” *Uncube Magazine* no. 32 (2015), 57, <http://www.uncubemagazine.com/magazine-32-15358283.html#!/page53>

3. Ibid. 58.

4. *Guidelines - Sustainable Solutions - Design, Construction, Dismantling and Reuse* (Milan: Expo 2015 S.p.A., 2013)

5. “Expo, congelamento invernale Albero della vita costa 360.000 euro,” *Askaneews.it*, November 12, 2015, [http://www.askaneews.it/regioni/lombardia/Expo-congelamento-invernale-albero-della-vita-costa-360000-euro\\_711674161.htm](http://www.askaneews.it/regioni/lombardia/Expo-congelamento-invernale-albero-della-vita-costa-360000-euro_711674161.htm)



Figure 5.5 Herzog and De Meuron’s masterplan for Expo 2015, featuring mostly farmland, with shelter canopies by the organisers.



in engaging current issues, but they picked the wrong venue for activism. Attempting to strip commercialism from the Expo broke a successful formula begun with the Crystal Palace; competition for attention at exhibits attracts investment and creativity.

Designing a regenerative Expo

The radical redesign of Milan 2015, while not acted upon, is proof that the time is right for an overhaul of Expo excess. With the pressure of scarcity greater than ever before, a showcase for the future that did not generate so much waste would be a valuable focal point for society. A world exposition is the perfect venue to demonstrate material sustainability through design for disassembly and material reuse. Expos have a long history of showcasing technological advances, coupled with the media attention necessary for the concept of circular ecologies to get wider attention. A world Expo built on circular material streams would enrich and inform.



Figure 5.6 Site remediation after Expo Milan 2015

The aspirations of a regenerative Expo are well summed up by Rob Wilson in an essay on Expo 2000.

(The conundrum of a sustainable Expo is) “how to celebrate human ingenuity, yet replace the passion and spectacle generated by national or commercial rivalry in order to attract visitors, and how to deliver a sustainable legacy message from what is, by its nature, a one-off wasteful event. For aside from the über-duck or über-shed exceptions, the appropriate legacy, as with any travelling fair, should be an empty camp site, containing nothing more than the carefully kicked-over embers of a fire.”<sup>6</sup>

6. Rob Wilson, “Live Fast, Die Young - After the party at Hannover Expo 2000,” *Uncube Magazine* no. 32 (2015), <http://www.uncubemagazine.com/magazine-32-15358283.html#!/page51>



Figure 5.7 Expo architecture can learn from the low impact inhabitation of fields during a music festival. After the event the land will be returned to productive use.



The opportunity

Twenty years ago Toronto bid on Expo 2000, losing to Hannover by a small margin. Representatives of the Expo governing body visited Toronto in January 2016 to court a bid for Expo 2025.<sup>7</sup> This was a second chance for Toronto and Canadian culture to make an impression on the world. Over the summer of 2016 city hall debated the event and commissioned an auditor’s report on the costs of hosting.

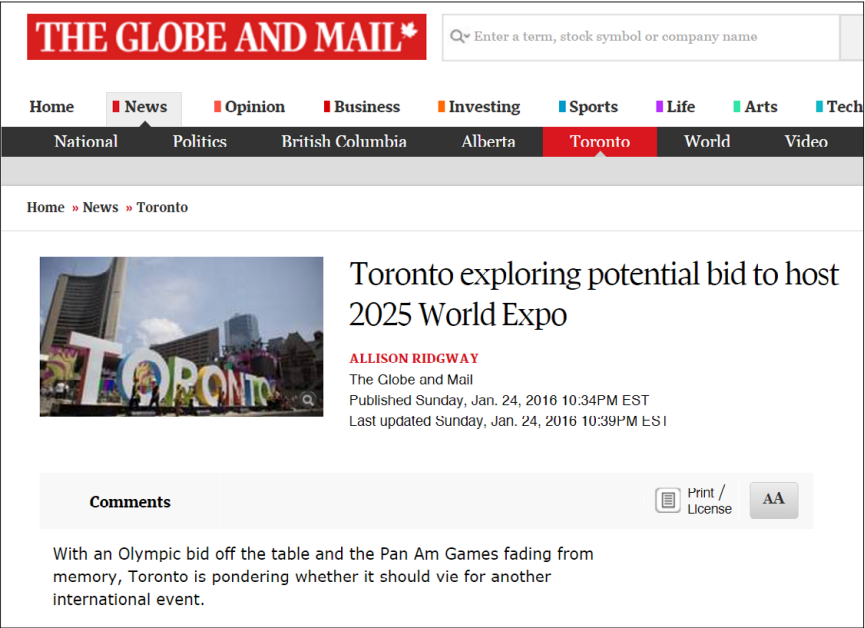


Figure 5.8 Newspaper article on the Toronto Expo debate.

As politicians and business leaders chose to support or oppose an Expo bid, contention was focused on the cost of hosting. World expositions are typically money losing events for host countries.<sup>8</sup> Frequent news stories on the costs of holding other big events like the Olympic games and the FIFA World Cup corroborate fears that improbably optimistic budgets will balloon.

7. Allison Ridgway, “Toronto exploring potential bid to host 2025 World Expo,” *Globe and Mail*, January 24, 2016, <http://www.theglobeandmail.com/news/toronto/toronto-exploring-potential-bid-to-host-2025-world-expo/article28367594/>

8. Oliver Wainwright, “Expo 2015: what does Milan gain by hosting this bloated global extravaganza?” *The Guardian*, May 12, 2015, <https://www.theguardian.com/cities/2015/may/12/expo-2015-what-does-milan-gain-by-hosting-this-bloated-global-extravaganza>

Recently the hosting of these large events has been awarded to countries with weak democratic institutions, where money can be spent without accountability. The Olympics have become an expensive public relations project for China in 2008, Russia in 2014, and Brazil in 2016. Beijing’s recent win of the winter Olympics for 2022 in a city with no snow indicates a continuing trend of events as expensive marketing tools. Hosting the FIFA World Cup has also fallen to countries who can pay the most, with Russia and Qatar next on the schedule.<sup>9</sup>

It is hard to blame responsible communities for refusing to bid after seeing recent events as case studies in cost overruns and unnecessary infrastructure. In 2014, Boston retracted their bid for summer Olympics over worries about unpredictable costs.<sup>10</sup> World expositions risk becoming inaccessible to most countries as expectations and budgets balloon. Dubai will host the next Expo in 2020, which promises to be an extravagant show. Accountable governments need to take back the Expo as a model for participation, not public relations. Toronto could be a role model for the world by hosting a sustainable, cost conscious Expo.

9. Mark Hosenball and Katharina Bart, “FBI extends FIFA scrutiny to World Cup host bids of Russia, Qatar,” *Reuters*, June 5, 2015, <http://www.reuters.com/article/us-soccer-fifa-idUSKBN0OI22P20150605>

10. Katharine Q. Seelye, “Boston’s Bid for Summer Olympics Is Terminated,” *New York Times*, July 27, 2015, <http://www.nytimes.com/2015/07/28/sports/olympics/boston-2024-summer-olympics-bid-terminated.html>

Toronto rejects Expo waste

One year after speculation began, the city of Toronto voted not to bid on Expo 2025. A city staff report concluded that the event had a “very real risk of significant cost overruns.”<sup>11</sup> Opponents of the Expo criticized the estimated two billion dollars of temporary buildings which were planned.<sup>12</sup> Toronto’s rejection of a bid for Expo 2025 is an explicit rejection of waste. The future of world expositions in responsible cities depends on redesigning the wasteful archetype.

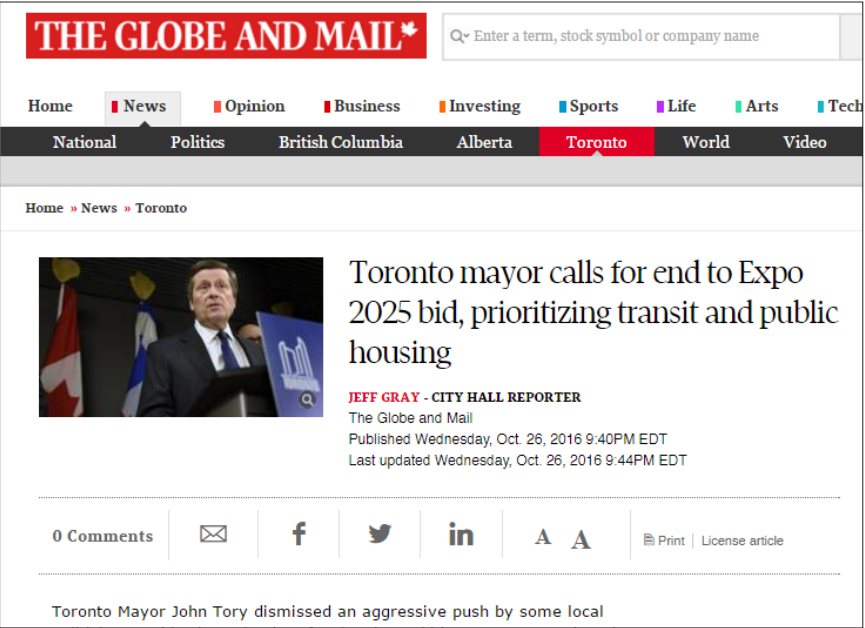


Figure 5.9 One year later the debate is over “for now” (John Tory)

Mayor John Tory’s decision not to bid on an Expo did not foreclose re-examining the opportunity in the future, just “not right now.”<sup>13</sup> Toronto’s decision to postpone hosting reinforces the need to change how Expositions are built. A fiscally responsible and sustainable expo would find an ideal home in the progressive and multicultural city of Toronto.

11. Jeff Gray, “Toronto mayor calls for end to Expo 2025 bid, prioritizing transit and public housing,” *Globe and Mail*, October 26, 2016, <http://www.theglobeandmail.com/news/toronto/toronto-mayor-calls-for-end-to-expo-2025-bid-prioritizing-transit-and-public-housing/article32541876/>

12. “The Wrong Stuff Gets Built... Poorly,” *No Expo 2025*, <http://www.noexpo2025.ca/2-the-wrong-stuff-gets-built.html>

13. Gray, “Toronto mayor...”

Now is the time to reflect on how an Exposition can better serve Toronto. In order to deliver an exemplary Expo, Toronto must respond to concerns that too much money will be spent, in a small area benefiting few, for only short term advantage. Designing the event for reuse and circular material streams is the key to reducing funding worries. Instead of money spent on disposable infrastructure and set dressings, planning in life cycles means the investment is not voided on closing day. Money will be invested in material with future uses. The low density Expo village is not an appropriate long term use of urban land in Toronto, so pavilions and site furniture will be designed for disassembly and immediate reuse around the country, bringing benefits to all the taxpayers who are asked to bankroll the event. Distributing the expo legacy across Canada will attract federal funds by expanding the event from local to national scale. Toronto will benefit from the Expo kick-starting infrastructure construction in currently vacant land. When the even is over, flood mitigation work and services installed along future streets will be ready to accommodate new development. By designing a future beyond the Expo, hosting becomes a responsible choice. Toronto has the opportunity to be a good role model for global cities hosting such large events.

Over the following pages this thesis proposes the design of a sustainable Expo 2030 in Toronto. By painting a picture of what might have been, the design aims to illustrate that expositions can be reinvigorated as a hopeful gathering of the world. Bidding on 2025 was Toronto’s second chance, but not its last. The city has five years to reflect on hosting an exposition, with another opportunity coming in 2030.



## A proposal for Expo 2030 in Toronto

This thesis proposes the Portlands in Toronto as the schematic site for a World Exposition. The event will occupy several square kilometres of mostly vacant post-industrial land adjacent to downtown Toronto. A world Expo provides a unique opportunity to build out new transit, roads and buried utilities for the event that will service future neighbourhoods. Feasibility studies in 2006 and 2016 have both concluded that Toronto's Port Lands are the best venue for an Expo.<sup>14</sup> Planned environmental restoration of the Don River mouth will be undertaken in the next few years, transforming the area into a case study for sustainable urban renewal, worthy of showing off to the world.

Before construction begins for the Expo, a spine of elevated walkways will be erected to bring visitors safely through the site. Early public access makes the construction process part of the exhibits, furthering the expo's goal of communicating buildings as part of a larger life cycle than simple use.

In the centre of each island, an east-west material axis (in white) distributes goods and collects waste. All the garbage and recyclables for each day will be accumulated and exhibited in material recovery yards on the east end. Material reclamation work that is undertaken along these axes leverages the Expo's spotlight to make recycling more visible.

Each country or city will be given a plot for their pavilion and an equal amount of space for material laydown. During the Expo each country's yard can be animated with events or installations. At the Expo's conclusion, the ample space eases disassembly and sorting of materials. Elevated walkways will bring the public safely above deconstruction sites to watch pavilions decamp for new sites around Canada.

While most pavilions can be erected directly on existing asphalt, a selection of campsites will be available for low impact pavilions in the newly restored green landscape. These wild plots challenge participants to build and live in a way that leaves no trace.

The Expo will demonstrate the power of architecture to regenerate land, inhabiting it temporarily and returning it in better condition than it was received.

14. "Staff report on Toronto 2015 World Expo Bid," TEDCO and Toronto 2015 World Expo Corporation, May 11, 2006, 34, [urbantoronto.ca/forum/attachments/expo-it001-pdf.51944](http://urbantoronto.ca/forum/attachments/expo-it001-pdf.51944) and "World Expo Canada 2025 Feasibility Study," World Expo Canada Bid Corporation, Toronto, 2016, 4, <http://www.expo2025canada.ca/world-expo-canada-2025-feasibility-study/>

**Figure 5.10** Schematic masterplan for Expo 2030. The Expo grounds are populated with recyclable and compostable pavilions developed in the following chapter.





A vision for the Expo

Toronto’s World Expo will be a vibrant celebration where every element offers a glimpse into the future through planned reuse. By conceiving it not as an Expo, but a group of stories that begin at the Expo and continue beyond the event to benefit the community, value for the city is ensured. The effervescence of nationalist expression will be recaptured into a circular life cycle to deliver renewed materials to the city. Taking cues from Interboro, the Expo will ask the city what it needs and build out needed infrastructure which can serve the community after the event. Planning within circular economies creates opportunities for abundance without burdening the future.



Figure 5.11 Proposed Expo 2030 poster representing the beautiful diversity of inviting the world in.

Regenerative Stories

The twentieth century was a period of exploration and extraction. Humans settled the furthest places on earth and expanded cities to capture more than half the world’s population. We have exhausted new territories, the focus in our new century will be on regenerating what we have. Our rapid expansion has left inequalities and opportunities in its wake. Regenerative Stories will be a forum for countries to share their experiences of renewal. It is an invitation to gather in sober thought at our failures, to celebrate successes, and share knowledge on how we can improve. The frontier life is over, we have settled the earth and are must

now learn to live within limits.

For the first time, Expo 2030 will invite cities along with all the countries of the world. Mayors and cities are on the forefront of regeneration on a local scale, renewing neighbourhoods and infrastructure with a detailed understanding of stakeholders and local history. While cities may not have the presence of national pavilions, their added diversity will contribute with engaging stories.

Each participating city or country will be paired up with a Canadian sister city. After the Expo, pavilions will be disassembled and immediately put back to use in sister communities across Canada. Linking Expo participants to a future user eliminates the uncertainty of reuse by selecting a specific next client. Organizers of large events typically have to choose between a dense site which contributes only to local communities, or one that distributes benefits geographically with shuttle buses and other transportation woes. Reusing architecture enables the event to be spatially concentrated, with distributed long term benefits from relocated buildings.

Making the challenge of sustainability central to an Expo is a big change from the previously open requirements for participants. Countries may balk at restrictions imposed onto their carefully curated exhibits, but sustainability is key to the theme of regeneration. It should not be possible to respond to a brief on reuse with disposable architecture. Sustainability is not a set of requirements to be adhered to in a public relations event, but a challenge to respond in a creative and sustainable way. Diverse interpretations of the brief are a compelling reason to attend the Expo.

Some people might question the necessity for a large gathering when Internet connectivity is ubiquitous. Aside from the tangible benefits of face to face relationships, the Expo’s theme of material regeneration is a powerful incentive to visit in person. Material qualities cannot adequately be abstracted in photographs. The most successful pavilions will weave sublime experiences from the stories of reused and reusable materials.

What happens the day the Expo closes?

The success of circular life cycles at the Expo will be determined by its legacy. Only valuable materials designed for reuse and forward looking infrastructure should remain at the Expo’s conclusion. The challenge is to create a positive cultural and financial legacy for Toronto. The stories, relationships, and materials from the Expo will live on in the city.



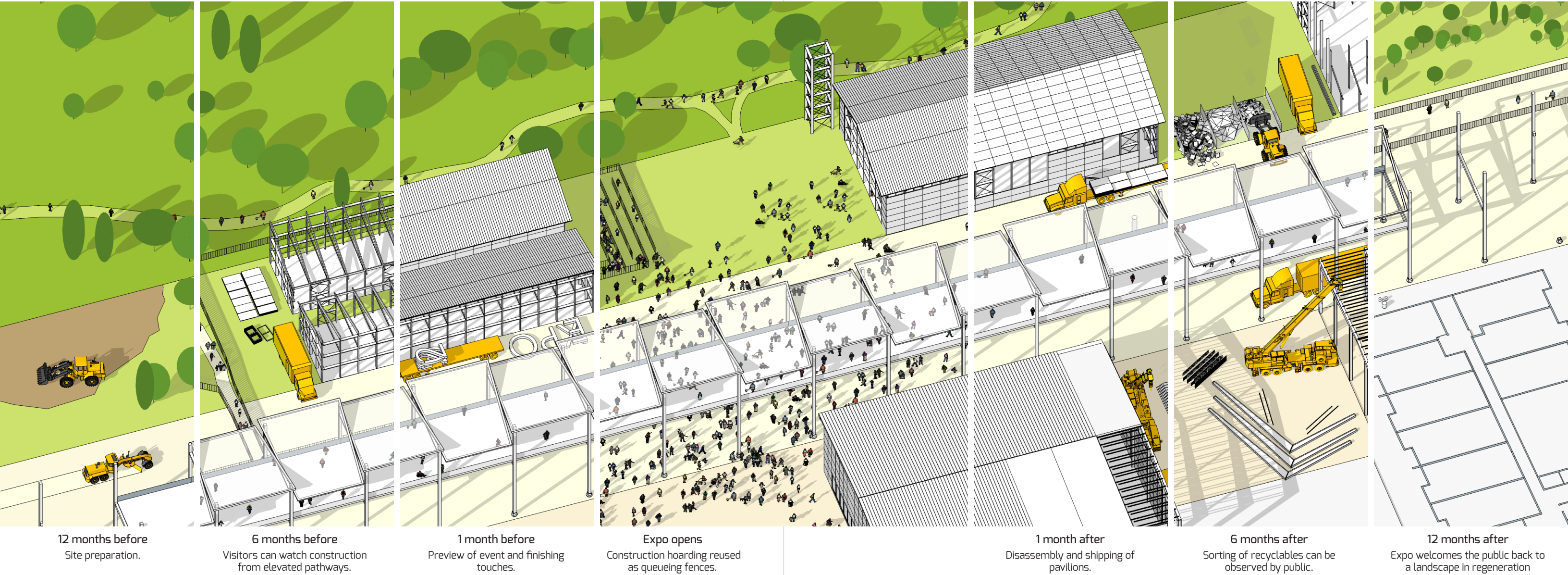
Before the Expo

Buildings designed for a circular life cycle are constructed and disassembled differently than throwaways. To demonstrate the care taken in planning, the Expo will be open in a limited fashion during construction. Visitors can get a peek at innovative assembly methods, and monitor the creation of construction waste through conspicuous collection and storage. Safe elevated walkways bring visitors through the active construction site, encouraging them to consider the sources of building materials and the process of construction.

Figure 5.12 Time lapse of expo site from construction through use and regeneration.

After the Expo

Demolition has traditionally been a messy process, hidden away and done quickly. Toronto’s Expo aims to shine light on this practice by inviting visitors into the site as everything is taken apart. The public will be able to see which pavilions are cleanly disassembled and which require messy wrecking. Materials generated from the site can be followed from building, through sorting, to reuse or recycling. Watching a favourite pavilion being dismantled will hopefully prompt visitors to consider what end of life awaits their home or workplace.





Pavilion design

National Expo pavilions first appeared at the Paris 1867 exposition as singular houses from around the world.<sup>15</sup> Countries constructed the stereotypical building which best represented them. Over time nationalist novelty wore off, and the representation of countries became more abstract. Contemporary Expo pavilions are celebrated architectural experiments, each one unique, representing a concept or experience. The challenge for Expo organizers will be to balance architectural freedom with sustainability. For Milan 2015, the organizers produced 66 pages of guidelines for sustainable design.<sup>16</sup> While some countries embraced responsible design, photographs of the event’s demolition show ugly compromises made to save money and time. Expo 2030 makes sustainability mandatory, and to succeed the rules must be more accessible. Prescriptive requirements will be left behind in favour of a pithy, performance oriented approach to sustainability. For Expo 2030 there are five principles to build on, with the hope that creative implementation of pavilions in a loose framework will generate new solutions. Each country is encouraged to bring their local interpretation of design for disassembly, life cycles and reuse.

Countries are asked to plan a second life for their pavilions before construction. Should countries fail to find a buyer for their pavilions, the organizers will match them up with a needy Canadian community. In cases where countries shirk their duties, a deposit made before construction will be used to pay for disassembly and re-erection. Six months after the Expo closes the result will be a clean site, while small communities around Canada inaugurate new civic facilities.

15. Wolfgang Friebe, *Buildings of the World Exhibitions* (Leipzig: Edition Leipzig, 1985), 45.

16. *Guidelines - Sustainable Solutions - Design, Construction, Dismantling and Reuse* (Milan: Expo 2015 S.p.A., 2013)

Five principles for Expo pavilion design

Recycling

There will be no demolition at the exhibition’s close, only disassembly. Every part of the pavilion must have a designed end of life, through recycling or composting of organics. Care should be given that materials are not downcycled. The goal is to generate no waste at the Expo’s conclusion. After six months of disassembly time, the Expo grounds will reopen in 2026 for a show on stories post-Expo, and exhibit what waste remains to foster responsibility by participants.

Reuse

Six months is too short a life for a building. Pavilions must be reusable in their entirety or in parts. Reuse removes the incentive to create lightweight pavilions which wear quickly, becoming garbage by the Expo’s close. The goal is to amortize the Expo’s cost and resources over a longer period of time.

No toxins

Materials we build with should not be toxic to the environment, or to the building’s occupants. Chemicals on the Living Building Institute’s Red List of harmful substances shall not be used. The goal is to challenge designers and manufacturers to become aware of these toxic substances and curtail their use.

Universally accessible

The Expo will welcome everyone: people of all ages, abilities, and cultures. The goal is to create a vision of the future in which everyone can see themselves.

Reduce negative impacts

Pavilions should strive to reduce the unavoidable impacts of their presence in energy use, site disturbance, and social impacts. The goal is to live lightly on the land.

Generic pavilions

Every Expo has a number of pavilions built by the organizers for small countries. These are typically a local variation on big rectangular sheds. Some expos include architectural flourishes on generic pavilions, other times they are anonymous boxes. Each country leases a generic enclosure with basic services, erects exhibits inside, and decorates the exterior within a fixed budget. The adaptability of shell space to different countries also confers adaptability to future uses. Unlike the national pavilions competing on uniqueness, specifically generic pavilions are flexible and best suited to diverse next-use programs after the Expo.<sup>17</sup> Leased pavilions present the largest opportunity of all buildings for circular material streams. While technologies and materials used in custom pavilions may be expensive and unusual in order to attract attention, common materials and techniques developed for shell space are widely applicable to the world of construction. Decorated sheds, whether occupied as office, retail, storage, or industrial space, represent the highest turnover pieces of architecture. Redesigning them in a renewable manner would effect a large reduction in demolition waste. In the following chapter two generic leased pavilions will be developed for adaptation, reuse and recycling.



Figure 5.13 High tech leased pavilions at Expo '86, Vancouver

17. Kiel Moe, *Convergence : An Architectural Agenda for Energy*, London: Routledge, Taylor & Francis Group, 2013, 259.

Generic pavilions at Shanghai Expo 2010



Figure 5.14 Lebanon Pavilion, 2010



Figure 5.15 Brunei Pavilion, 2010



Figure 5.16 Sri Lanka Pavilion, 2010



Figure 5.17 Colombia Pavilion, 2010



Figure 5.18 Vietnam Pavilion, 2010



Figure 5.19 Iceland Pavilion, 2010





# 6.

## *Design Proposal for a Leased Expo Pavilion*

**Figure 6.1** Leaves returning their nutrients to the soil through decomposition. Buildings should strive to fade away as gracefully as leaves.



6. Design Proposal for a Leased Expo Pavilion

The story of a building’s whole life cycle

The core of this thesis is the design of two leased pavilions representing organic and technological life cycles for the upcoming Expo 2030. Growth is natural, humans have more trouble returning material to new life cycles, so the pavilions are named after their methods of disposal. The first, a compostable pavilion, strives to be entirely biodegradable, free of toxins that could not be returned to the soil. Composting need not occur directly after the expo, but would replace landfill after a lengthy second use as a community building. The second pavilion is recyclable, adapting a common steel commercial building type so its components are entirely reusable and recyclable.

Designing buildings with a life cycle approach requires thinking beyond construction and demolition. The provenance and destination of every component must be considered. Common life cycle assessment techniques do a good job of evaluating the creation of products, but remain vague about what happens at end of life. Architects prefer to not to think about the death of their buildings. If we begin to tell stories about how buildings will be adapted or decommissioned, architects open themselves to designing for uses beyond the current client. The Expo provides a unique circumstance for architects to design two lives for a building in one project. Architects will learn from decisions that affect disassembly and adaptation by designing construction and reconstruction simultaneously. The buildings that follow are pavilions designed for disassembly at the conclusion of a world Expo. After that the outlook is less certain, so several potential futures describe how these pavilions might be reused. Finally, the building elements are flexible enough to adapt into unforeseen reuses.

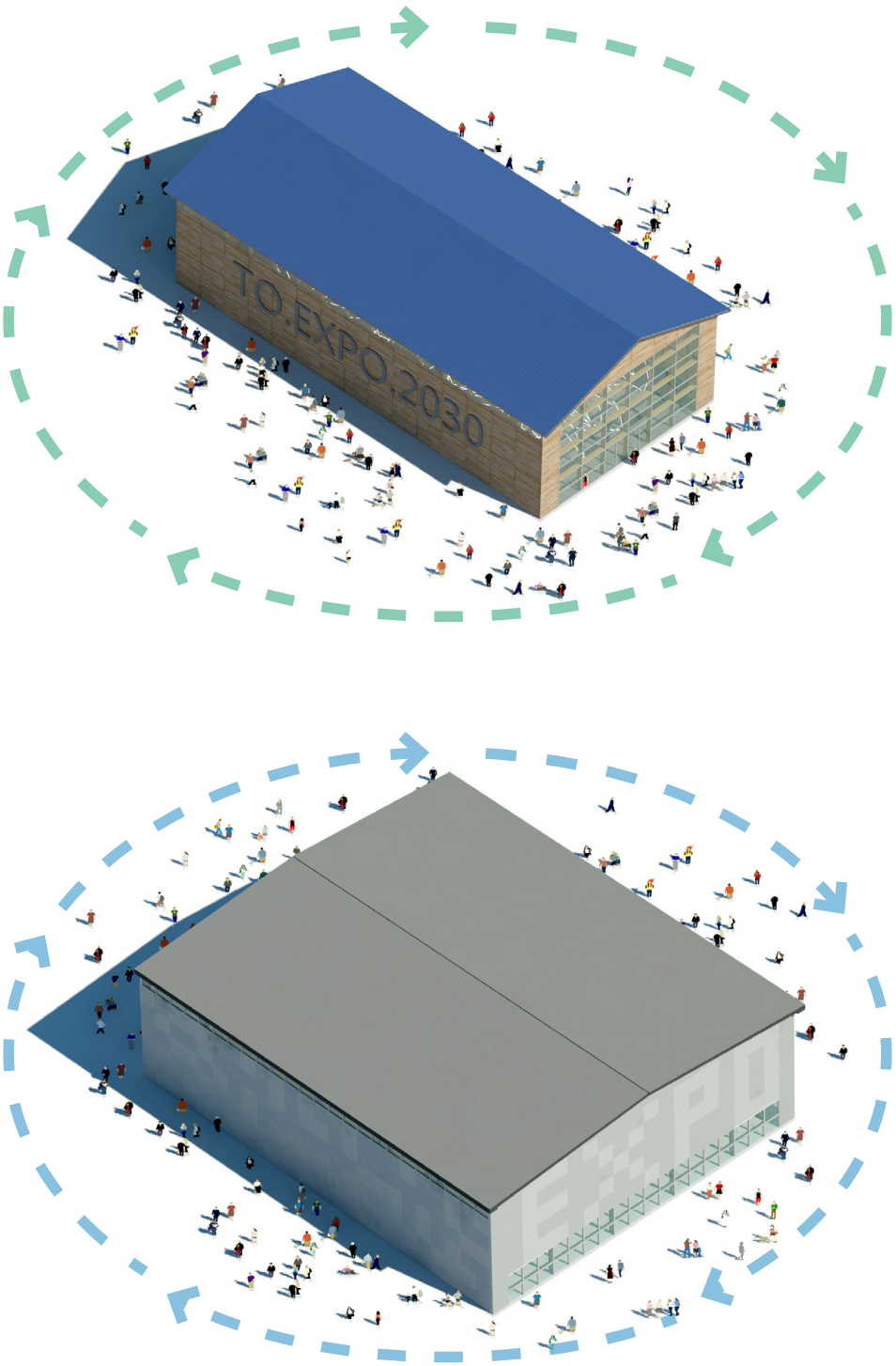


Figure 6.2 Compostable pavilion (top) and recyclable pavilion





Figure 6.3 Exterior view of Expo pavilions in their first life



Designed life cycle

The design story begins with material extraction, through manufacturing and then synthesis into building products. These materials are gathered into a kit of parts for quick assembly into an Expo pavilion in Toronto. At the conclusion of the Expo, each pavilion is re-purposed for a second life in communities across Canada. There the pavilions are reconstructed with local involvement as community infrastructure. The pavilions are designed to last a hundred years, but their modular and simple assembly opens opportunities for adaptation or reuse of the pieces in varied structures. At the end of each material's service life, every element is compostable or recyclable back into its original form. The result is a building designed for two uses, with the options for many more, and ultimately a closed life cycle for all its materials.

Program flexibility

Adapting well to unexpected uses is critical in extending a building's life. The pavilion is designed as a large, open-span shell space to accommodate varied programs. This preserves options for future decisions by local communities in filling the space. A minimum of demolition will then be required to re-purpose it.

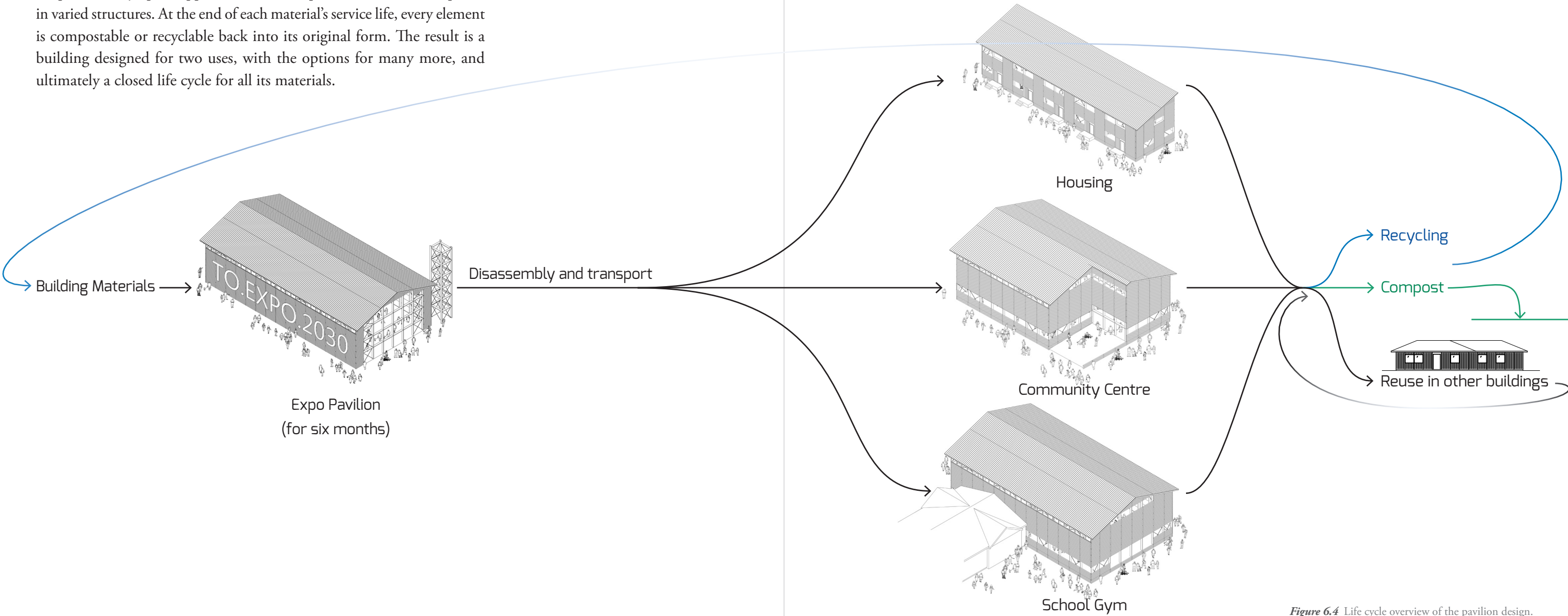


Figure 6.4 Life cycle overview of the pavilion design.

A second user community

Six months is too short for a building’s lifetime. With a modular, designed for disassembly system, the leased pavilions can be re-purposed into a range of public programs. The challenge given to all Expo participants will be to construct a building which is completely reusable on another site. As federal and provincial money is being spent, benefits from the Expo should be spread throughout Canada. Communities across Canada will be able to apply, and be evaluated by their need for a new public building.

Indigenous peoples will likely present the most compelling need for good new buildings. Their communities are challenged by remoteness, health problems and a lack of services. A new public building could house a variety of public programs and services. In the case of Attawapiskat, recreation programs coupled with community centre events and a library could coexist in the flexible space of a pavilion. This new community building is just one response to the public needs that will emerge as pavilions are relocated across the country.

Northern buildings suffer from harsh climatic conditions, difficult access, and tough economies. Designing for the north demands much more durability of the pavilions than would be necessary for a disposable building. The challenge of creating architecture that performs well in salty northern winds will produce design solutions suitable for any Canadian climate.

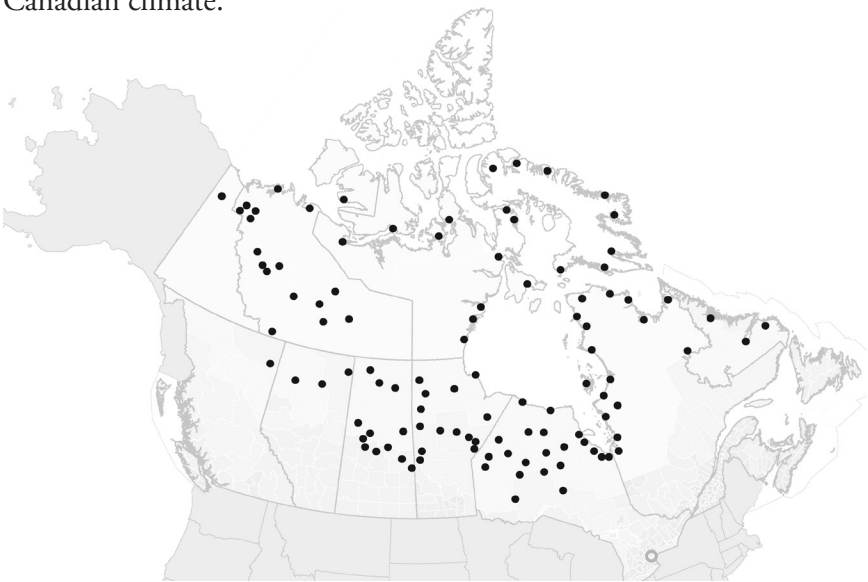


Figure 6.5 Northern destination communities for the regeneration of Expo pavilions.



Figure 6.6 Attawapiskat First Nation youth poster from Idle No More protests in Ottawa. 2016



The Client

In each life of the pavilion the client will have different goals. Client countries of the Expo will be looking for flexible shell space in which to exhibit. The pavilion architecture should recede behind a country’s brand.

In a second life the pavilions become community buildings. Their new clients are northern towns looking for a building to rally around. In addition to accommodating a different program, the walls of pavilions relocated to the north will expand to contain thick insulation and support regional cladding materials. Local communities will want to integrate the pavilion into their neighbourhoods.

The Program

From Expo exhibits to remote communities, the pavilions will have to be very flexible in housing diverse programs. Previous Expos have developed a standard size for leased pavilions of 60 by 120 feet. That generic rectangular massing fits national exhibits and corresponds well to the dimensions of a gymnasium, an exemplary multi-purpose space.

Architects designing for the expo will be challenged to create loose fit space for the expo any of several next uses. Individual countries will supply a program for the Expo, leased pavilions simply have to provide good shell space, with a high ceiling and no columns. During the Expo, the architects will travel to destination towns and work with communities to design a second life for the pavilion. The building program will be determined cooperatively through workshops with local groups. Programming would involve determining what the community needs and what it can provide to stake ownership in the building.

Challenging the architecture to adapt to immediate reuse privileges flexible design elements which reduce the demand for new resources in the future. Designing a loose fit generic pavilion maximizes the diversity of program which can be accommodated. As Rem Koolhaas puts it in *S, M, L, XL* “ Flexibility is the creation of margin—excess capacity that enables different and even opposite uses...”<sup>1</sup>

1. Rem Koolhaas and Bruce Mau, *S, M, L, XL* (New York: Monacelli Press, 1995), 239.

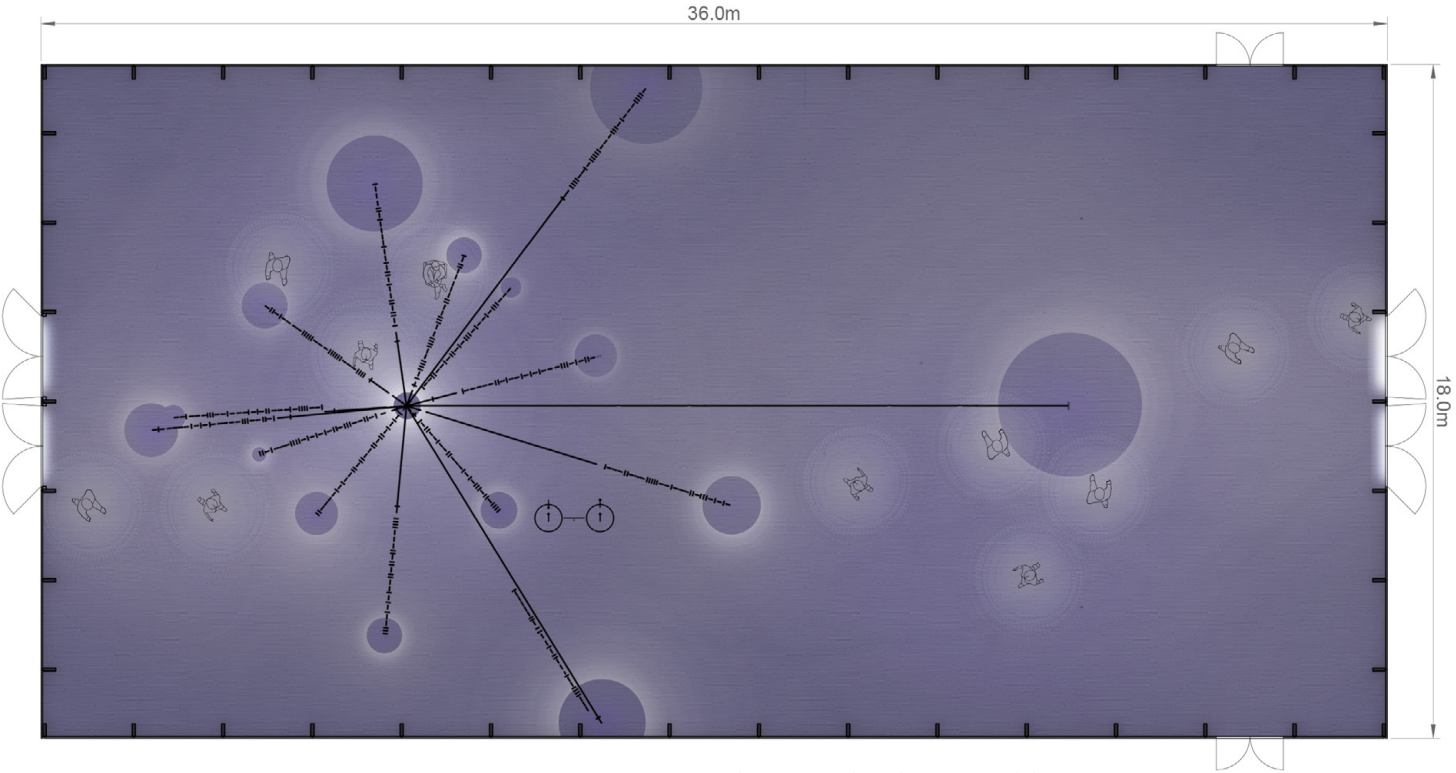


Figure 6.7 Open span space in the Expo pavilions hosting an exhibit

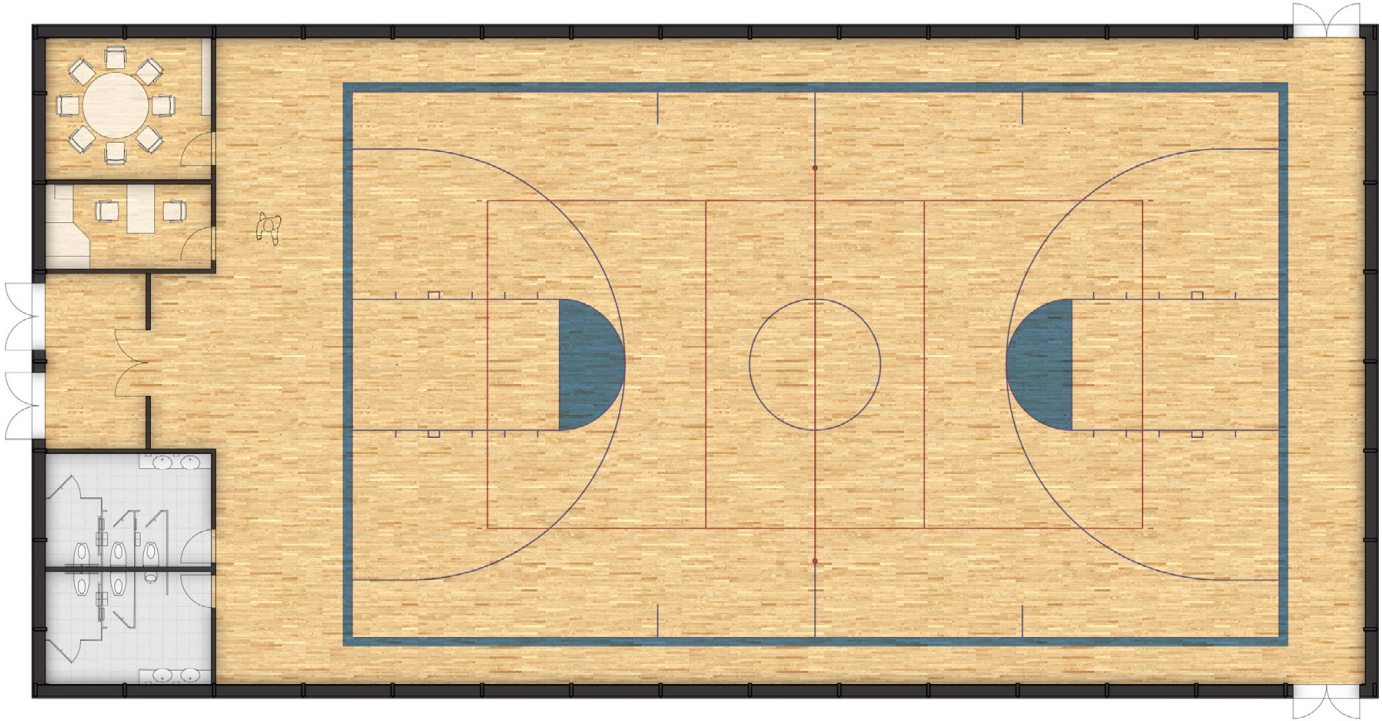


Figure 6.8 The Expo pavilion reused as a small town community centre.



Adapting to local communities

In re-purposing Expo pavilions, designers will aim to upcycle the building by weaving in local customs, materials, and economies.

How better to get people invested in a building than by inviting everyone to build it together? Community construction counters the perception of Canadian government programs in the north as packaged handouts without local involvement. Engaging the community in construction invites everyone to have a stake in the building’s success. On a more instinctive level, humans value things they work for more than they value things provided for free.

If local people assemble the building, then they will have knowledge of how it fits together. Renovation work is much easier if you know what lies inside the walls. Participation in construction will create a barn raising atmosphere, the stories of which will form part of community histories. The pavilion does not have to stand alone: it can be joined to and augment a school or community building. Tying the pavilion to an existing social institution makes it more robust through human relationships.

Choosing to spend money in the local community during construction and fit-out will further integrate the former pavilions. Local material resources will be used to adapt the pavilion. Harsh conditions in northern Canada constrain the palette of local building materials, but even in small communities rough sawn lumber can be made for exterior and interior cladding. Local ingenuity can put wood to use in canopies, extensions, and other augmentations. Local stones can be harvested for foundation walls and landscaping. And finally, a portion of the budget should be set aside for art.

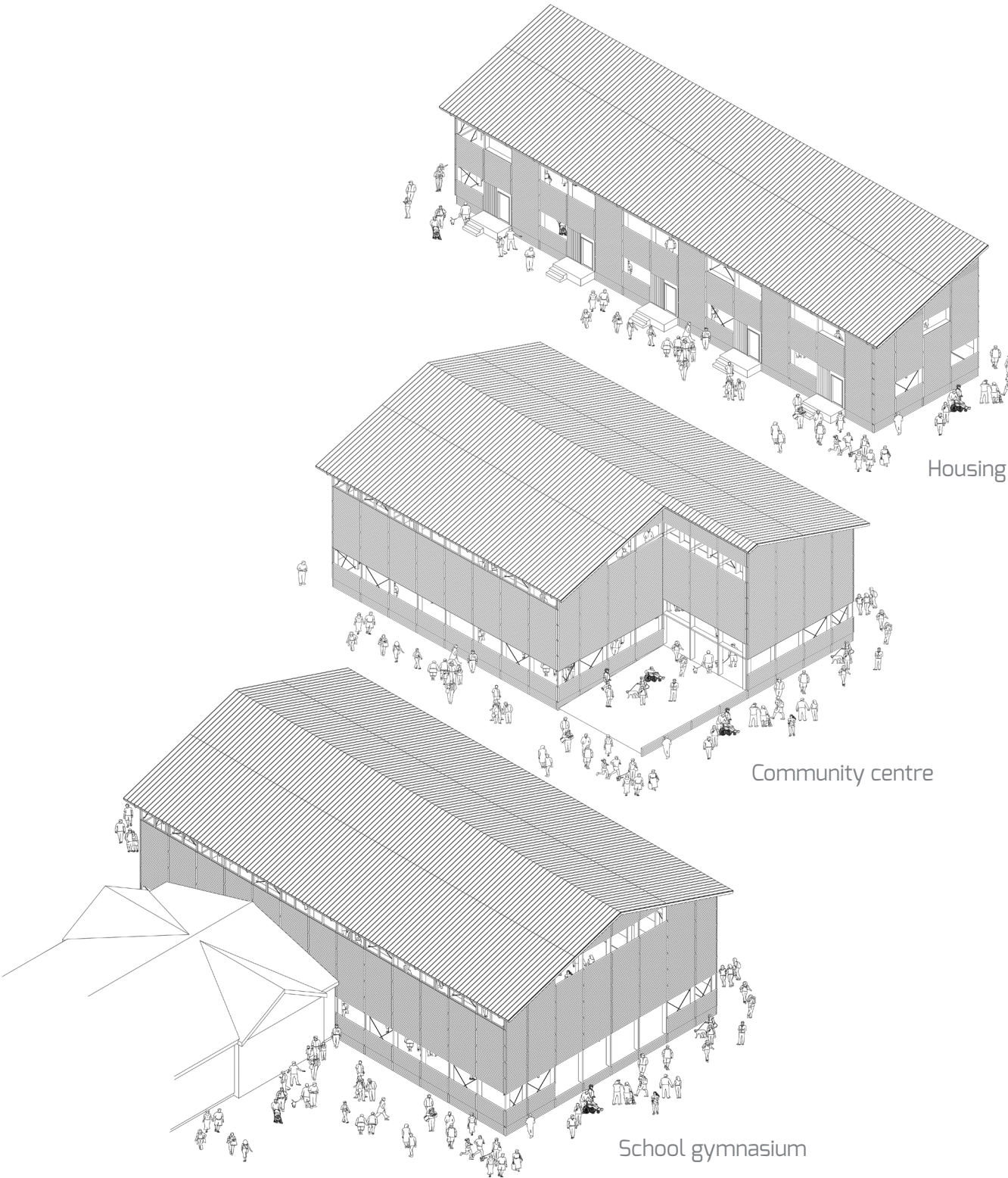


Figure 6.9 Three possible buildings from the Expo pavilion kit of parts.





Figure 6.10 Exterior view of an Expo pavilion transformed into a northern community centre.



Adaptability and module sizing

In modular building design, there is a temptation to design the perfect module, one which would fit any site and connect promiscuously to take any form. However, such a complex polyvalent module reduces opportunities for occupants to shape their surroundings in simple ways. Sophisticated modules are fragile to changes over time. They are more expensive to replace and difficult to customize or to renovate easily.

With the goal of extending building lifetime, construction elements should be simple to understand and easy to reconfigure. Current construction modules were arrived at through a long process of refinement. Two by four lumber is the right size for an eastern forest to be transported to the prairies and hand-assembled into housing. Bricks and cinder-blocks have a comfortable heft during assembly while maintaining enough bulk to be self supporting. Given more than a hundred years of use, it is likely these materials will still be available in another hundred. A building designed for long life would do well to build with such rudimentary dimensions so new materials are available for renovation or extension.

During the Expo ordinary materials and modules might seem decidedly pedestrian. Over time that will become their strength. Basic modules will do not go out of fashion like design fads. Replacement parts will be common and plentiful. Finally, at end of life, disassemblers will find standard modules useful in blending with other buildings built on the same dimensions.

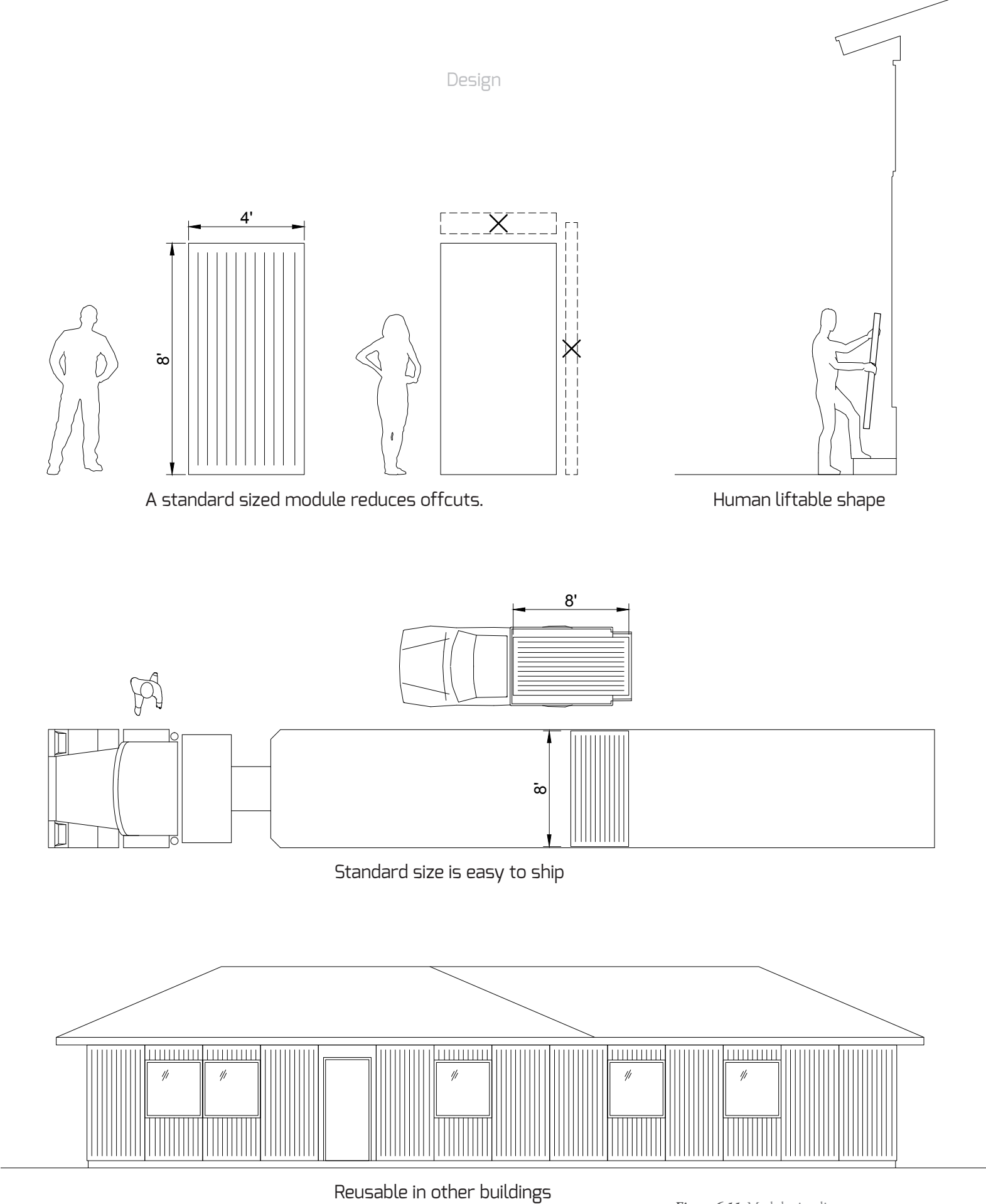


Figure 6.11 Module size diagrams



6.2 Compostable Pavilion

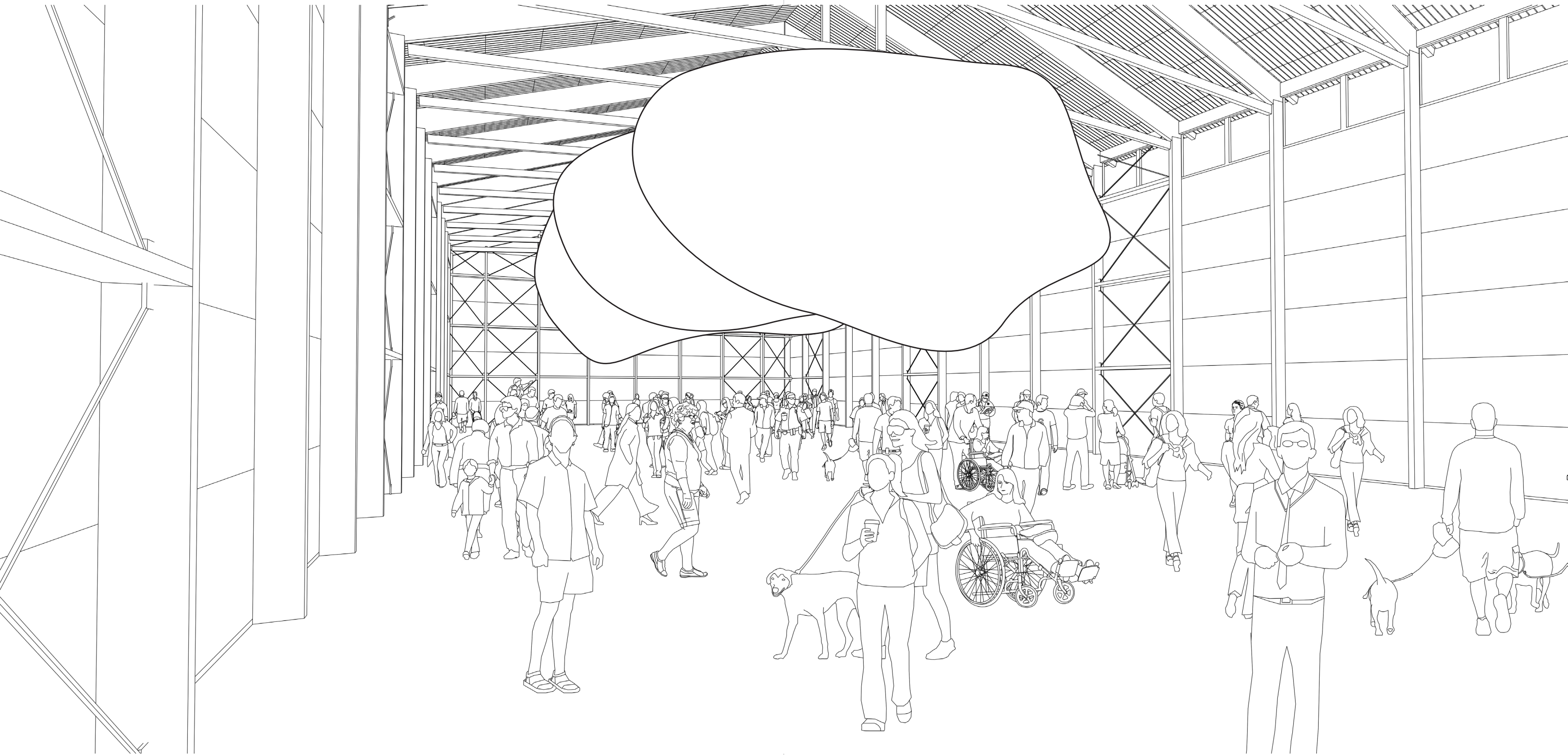


Figure 6.12 Interior perspective of the compostable pavilion

### The compostable pavilion

The design of an expo culminates with the implementation of circular life cycles in two pavilions. Research into life cycle diagrams provides a palette of compostable and recyclable materials. The first pavilion embraces biological life cycles through composting.

The ideal compostable building would be erected in a natural landscape where it could slowly decompose without human intervention, returning to the soil in a manner that left no trace of its existence. However, humans would like to live there for many years before decomposition begins. The compostable pavilion is not designed to biodegrade directly after the expo, but to avoid landfill waste after a fruitful second life spanning many decades. To provide good space, a hybrid building is necessary. The bulk of construction is compostable, augmented by inert elements such as a metal roof. Plastic and metal waterproofing elements stop decomposition during the building's useful life.

The challenge then, in designing for decomposition, lies in encouraging the recovery of inert recyclable elements at end of life. Compostable elements can be left where they fall to decompose. Fewer, larger recyclable parts speed separation from the compostable mass. Staples and finishing nails were eliminated from the pavilion design. Instead galvanized bolts fasten larger elements together. Galvanized screws might have sufficed for the fastening of exterior cladding, however by using stainless steel the higher cost of that material incentivises the recovery of many smaller fasteners.

Compostable construction holds a distinct advantage over recyclable buildings in that composites can be employed. Provided that the substrate and finish are both biodegradable, there is no penalty for bonding them together. Several benefits emerge from composite construction. The larger size of glued together wood products is critical to reducing fastener count. Biodegradable paints provide opportunities for occupants to personalize their space without foreclosing the potential of wood to decompose.

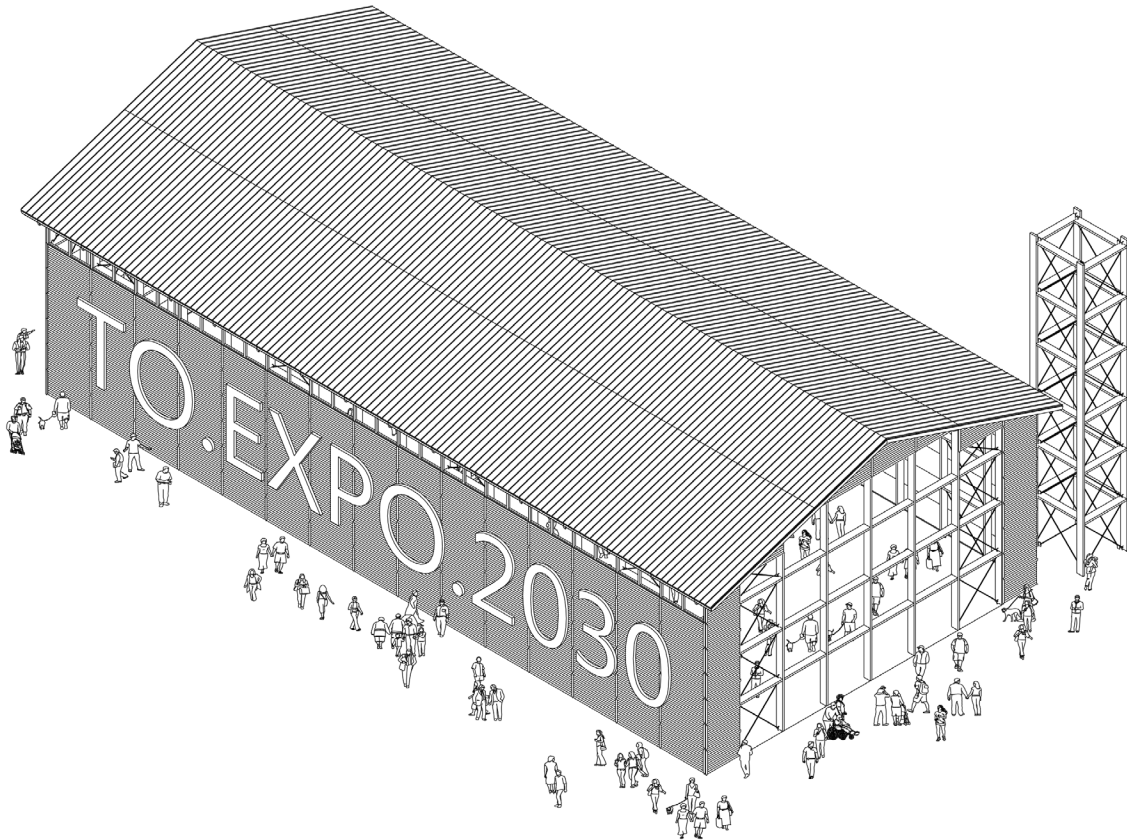


Figure 6.13 Exterior axonometric of compostable pavilion

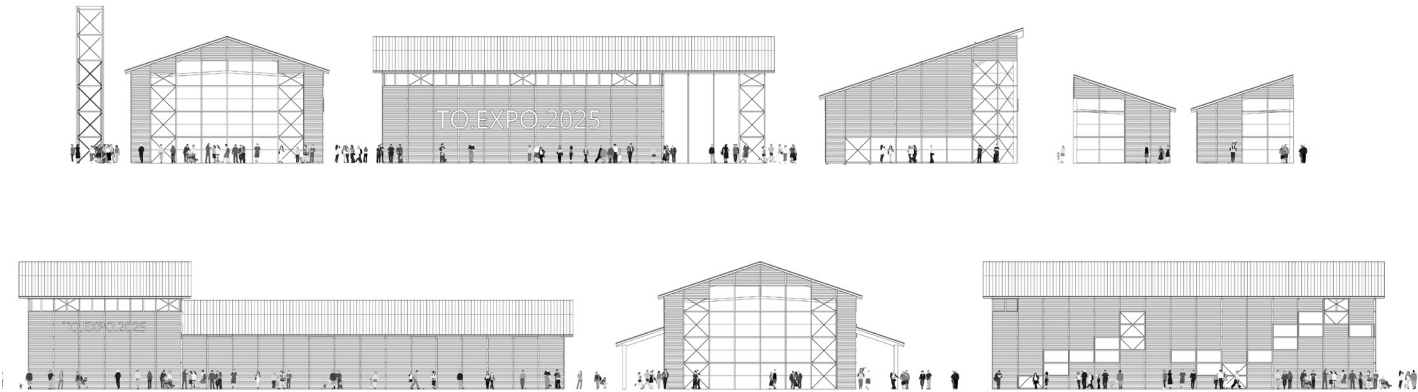


Figure 6.14 Alternate configurations of the compostable pavilion.





Figure 6.15 View of a basketball game in the new northern recreation centres.



Building material flow diagram

Legend

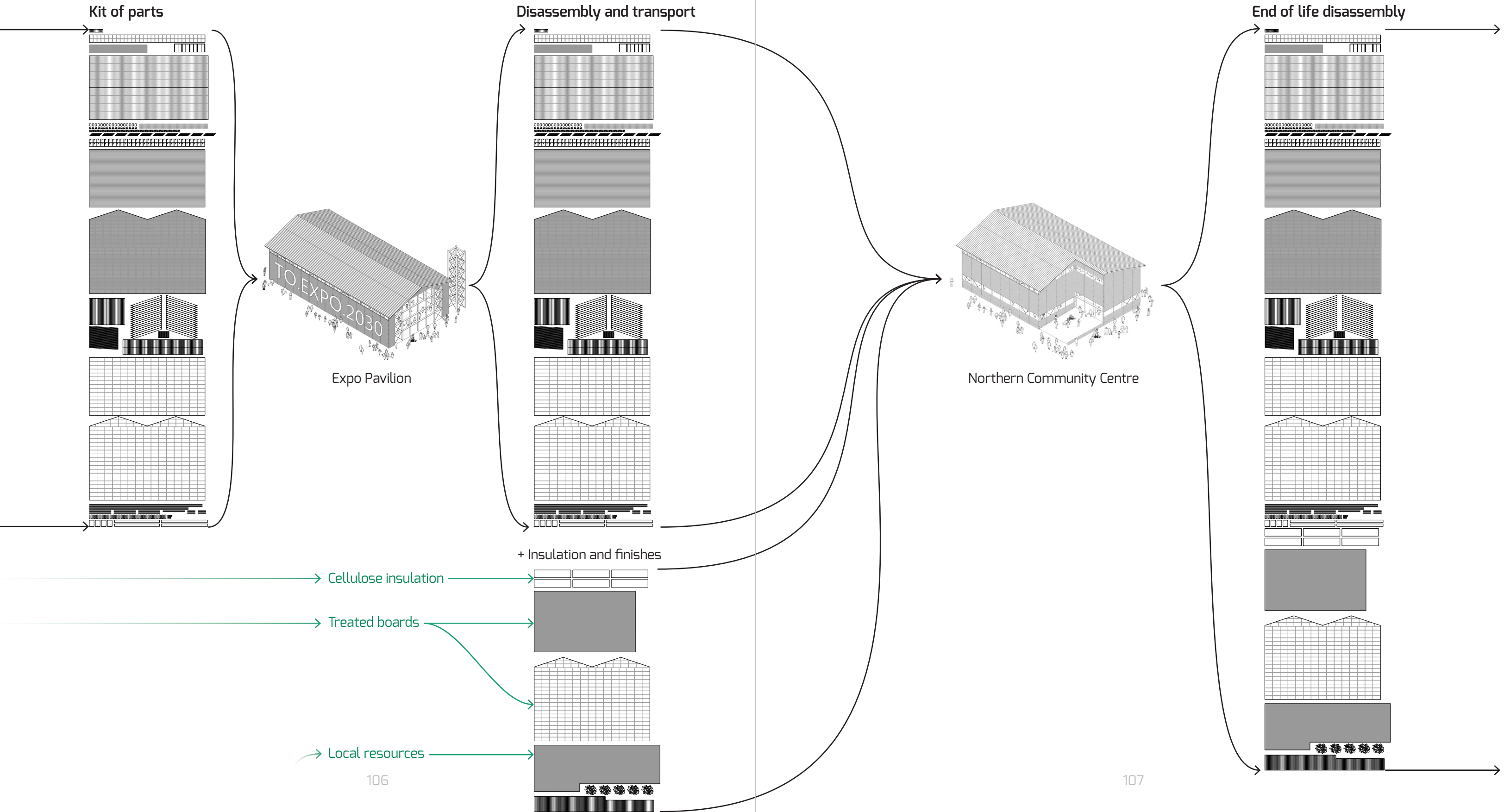
Recyclable material

Compostable material

Material used once







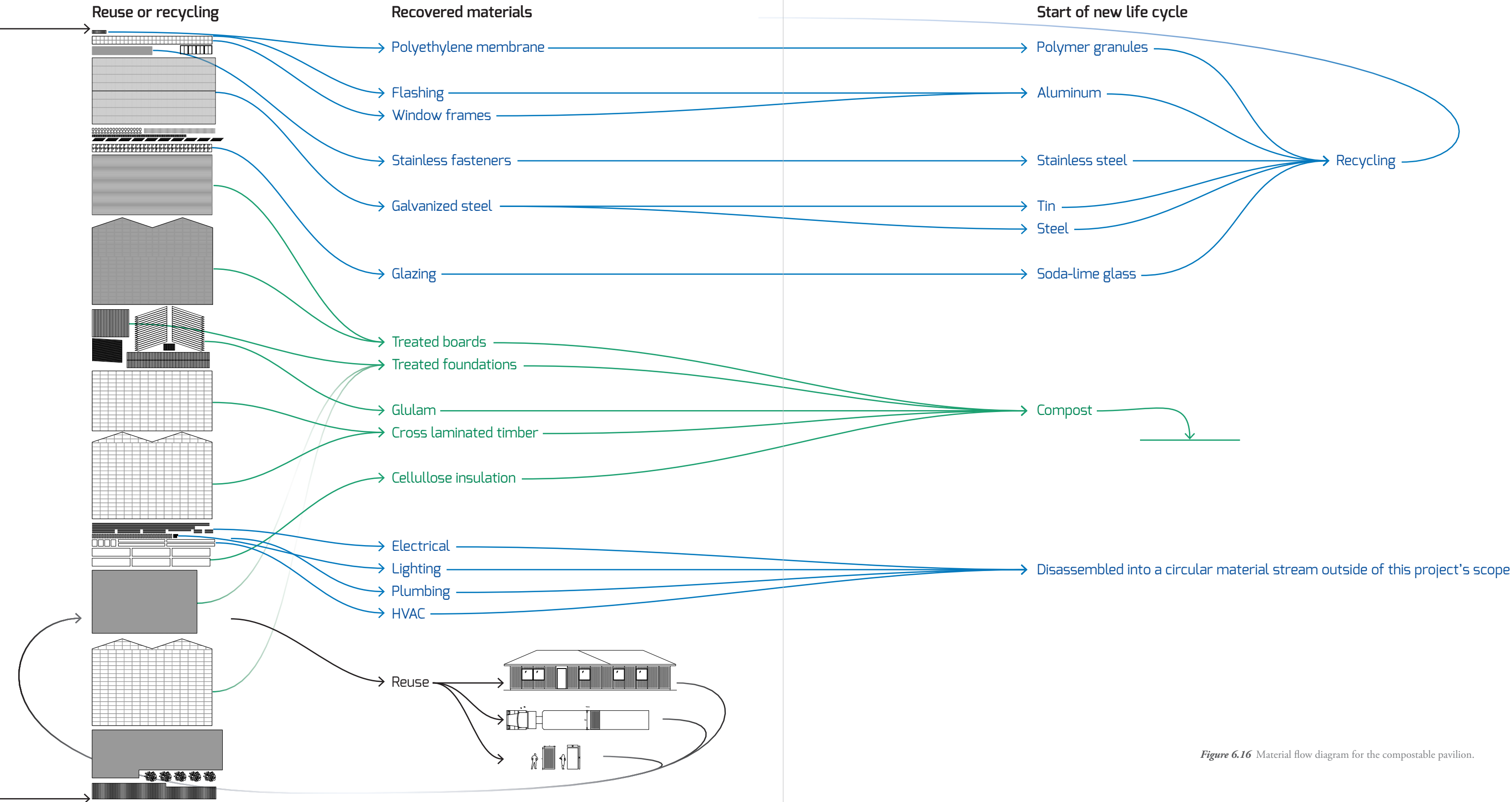


Figure 6.16 Material flow diagram for the compostable pavilion.



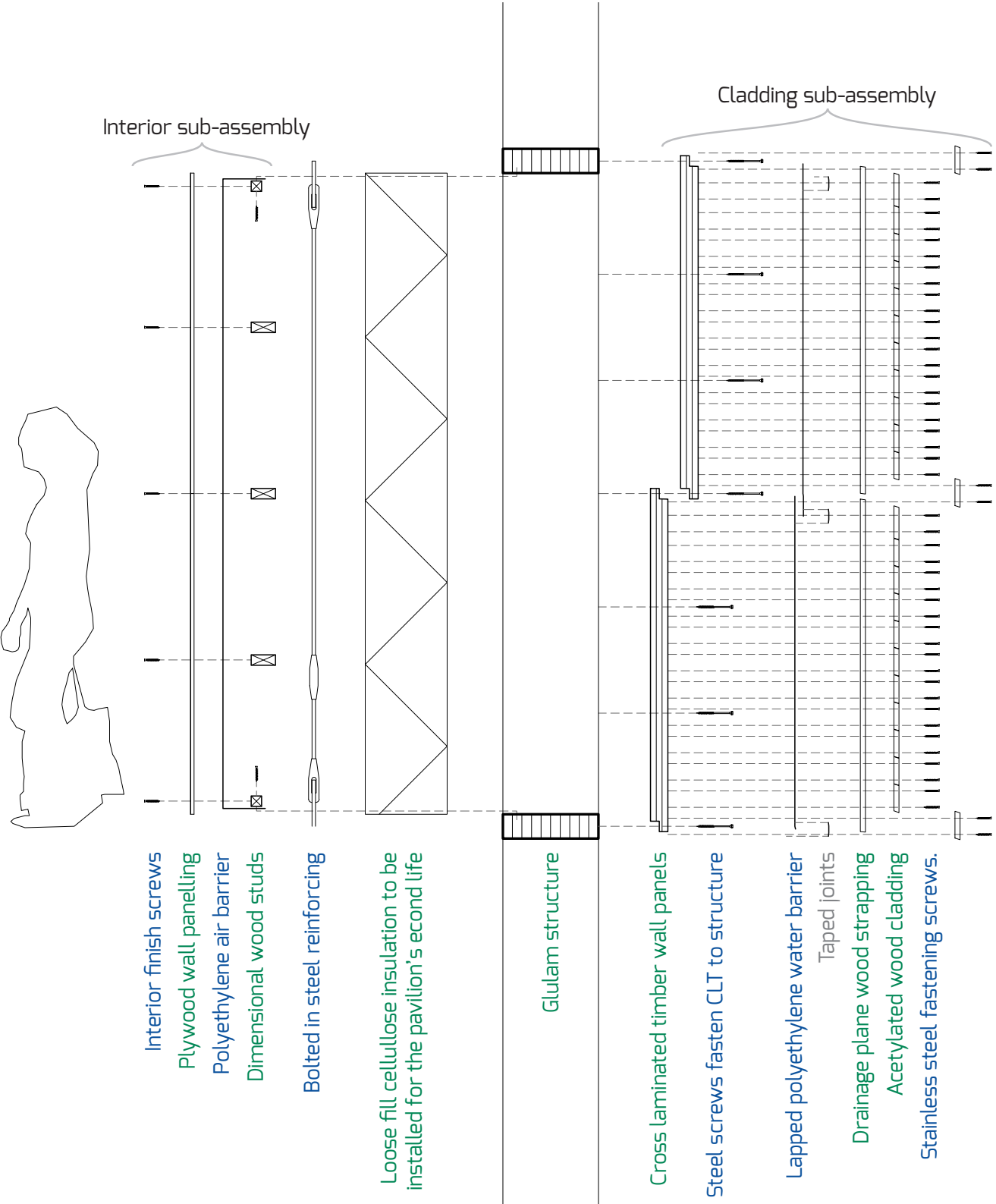
Assembly and disassembly

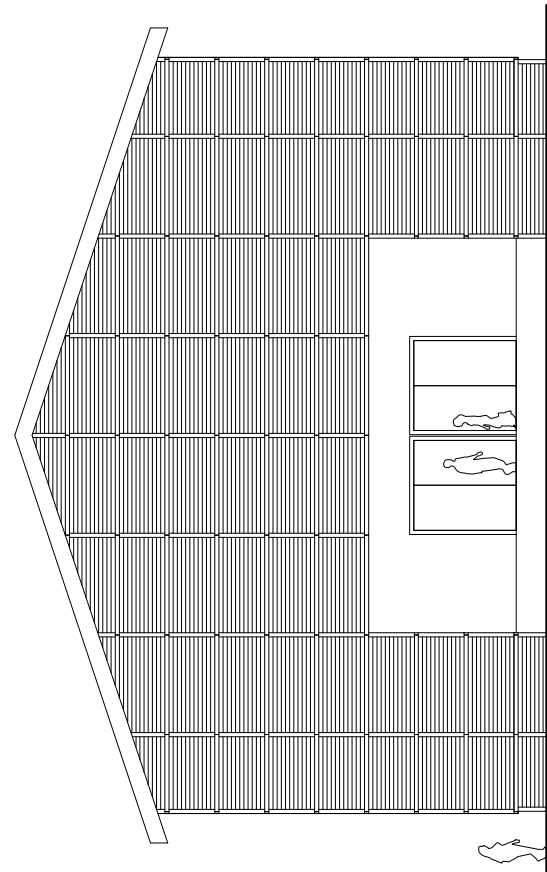
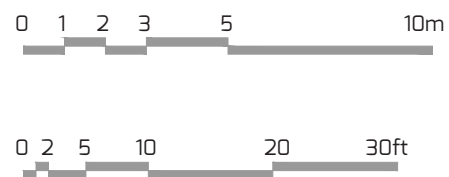
Moving pavilions from the Expo to a community hundreds of kilometres away presents a tough challenge for disassembly. While typical buildings should be deconstructable enough for reclamation, rebuilding the same structure in a different location requires assemblies that separate down into their initial components. In addition to having reversible connections, building materials need to be sturdy enough to avoid damage during disassembly and shipping.

To ease the complexity of deconstruction, the compostable pavilion is composed of a small number of large interchangeable modules. Reducing the part count is critical to saving time in disassembly and reassembly. Instead of choosing custom modules with all their drawbacks, sub-assemblies made from common building materials are designed to aggregate small fasteners into units that can be reused whole. These assemblies can be prefabricated indoors. Later, communities can adapt pavilions with hand tools, possibly breaking assemblies down into building materials for another use.

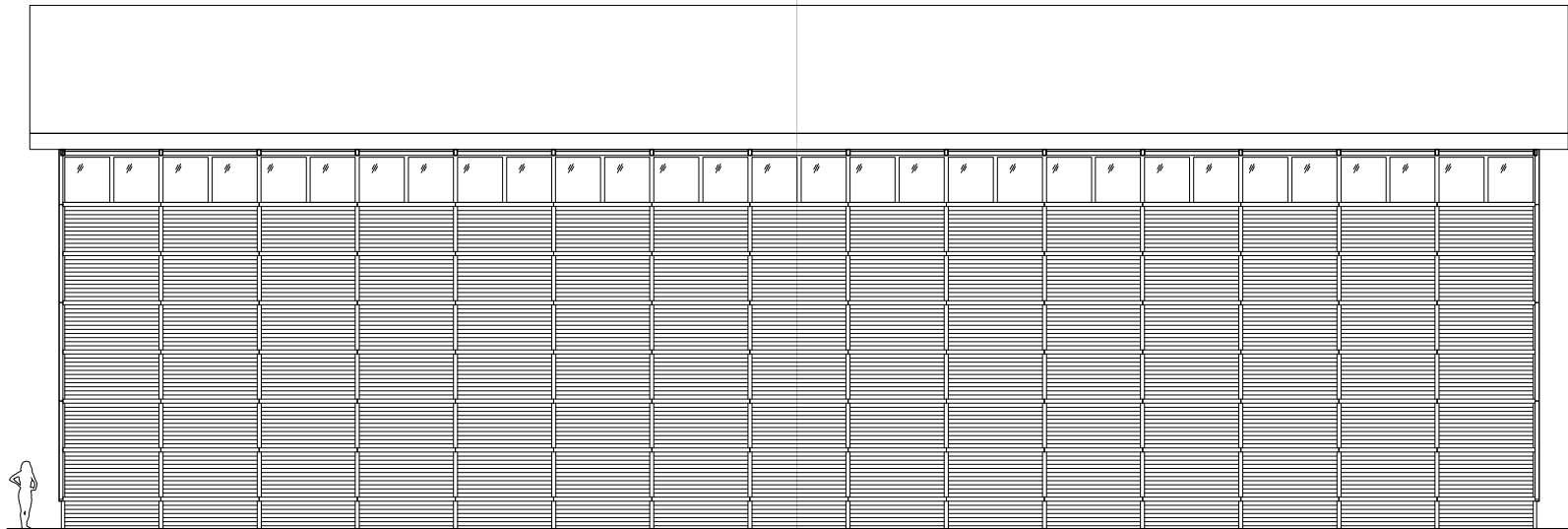
Sealing the building remains a problem in reusable architecture. For the interior air barrier a foam gasket seal is compressed between wood strapping and the structure. On the exterior, temperature and moisture shifts will cause wood to change shape over time, potentially opening cracks in a gasket. The compromise here is in using disposable tape to seal joints in a polyethylene water barrier. Fortunately the plastic film is only fractions of a millimetre thick, so not much waste is generated.

Figure 6.17 Exploded section assembly diagram

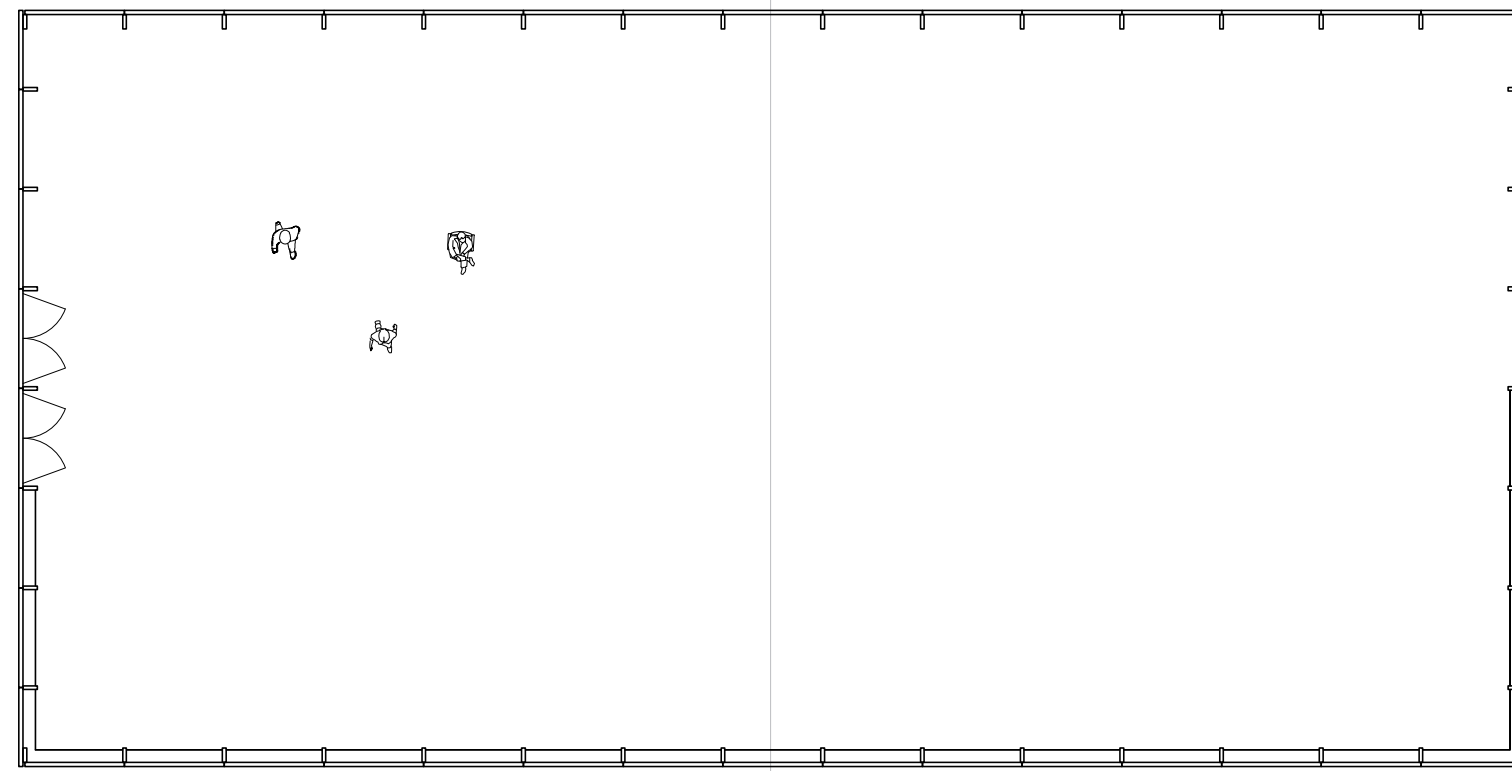




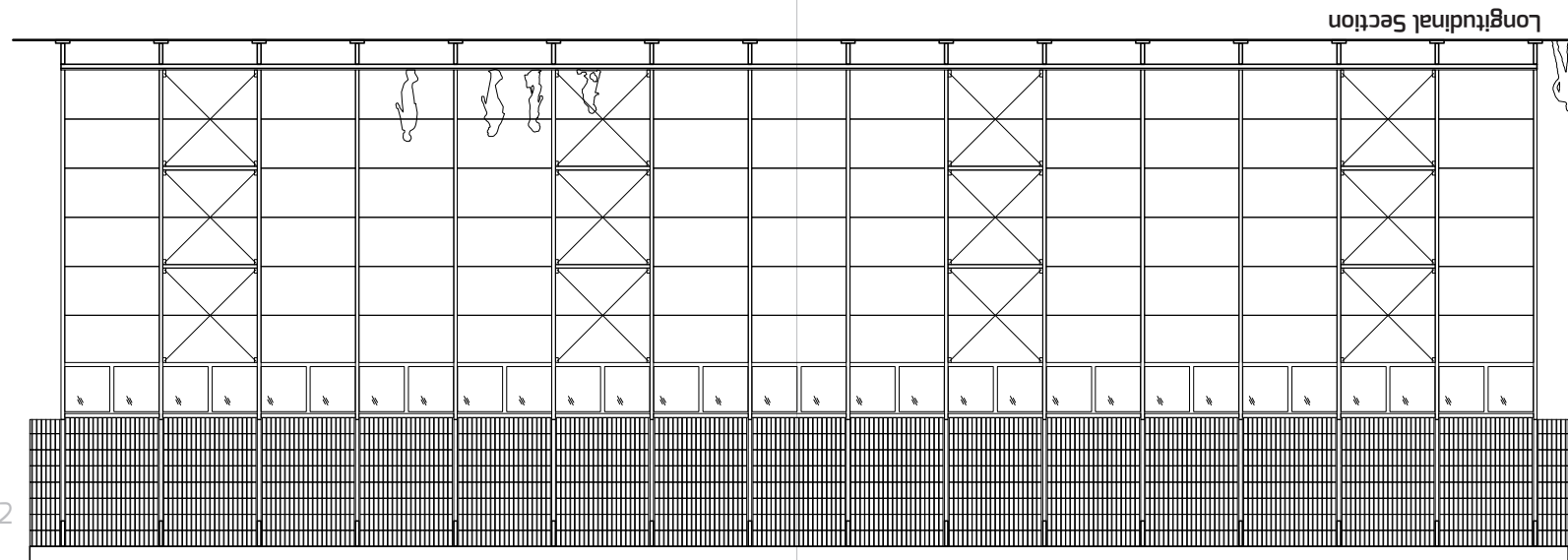
Front Elevation



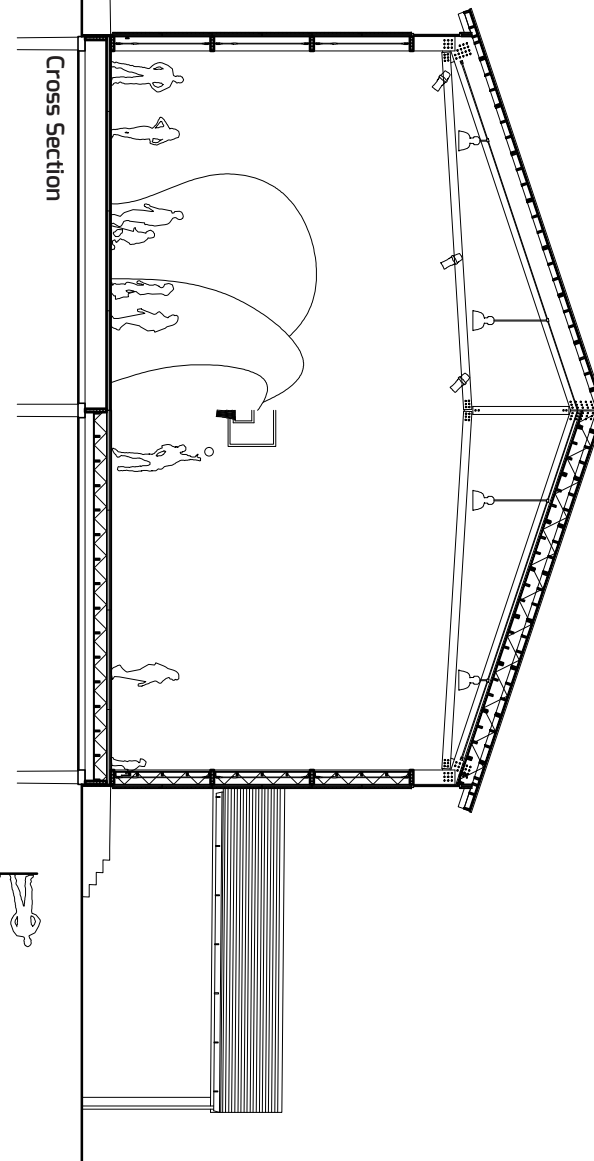
Side Elevation



Floor Plan



Longitudinal Section



Cross Section

Figure 6.18 Orthographic drawings of compostable pavilion



At the conclusion of the Expo

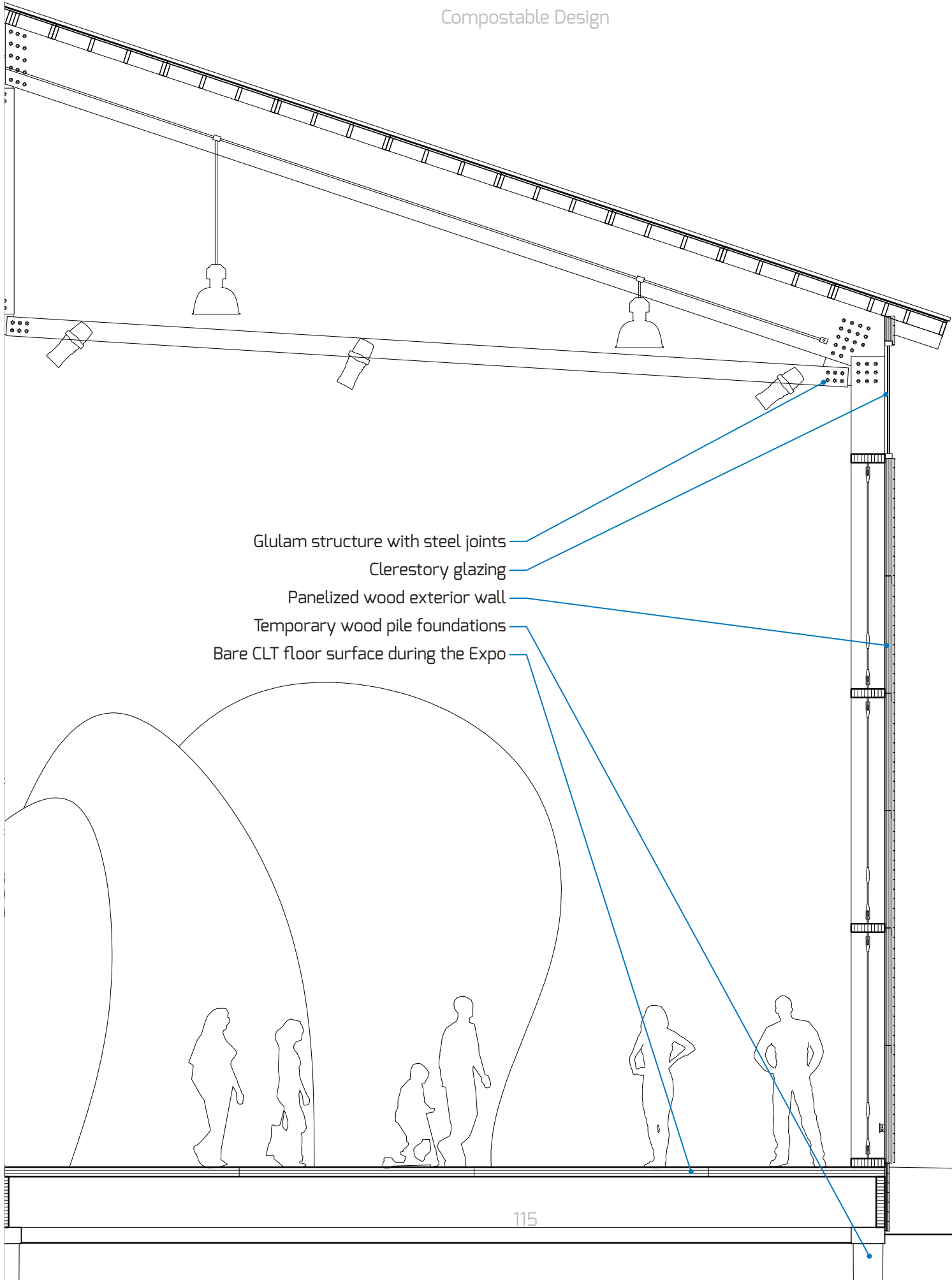
During the Expo the appearance of a compostable pavilion draws attention to the biological processes that support life. Wood construction also reflects local Canadian history and character.

Designing a biodegradable building required a surprising amount of recyclable material to preserve it from early decomposition. Fortunately, these inert materials are needed in areas where appearance is secondary to performance, so they can be selected for maximum recycling potential. The inertness necessary for waterproofing is also a benefit for recycling, as materials will not degrade over time. Compostable materials used in this pavilion all come from wood, though straw or bamboo are good alternatives. Quality wood products can be sourced locally in Canada; a compostable pavilion constructed elsewhere might adopt different materials. Finding wood assemblies without embedded poisons was difficult, nearly all coatings and treatments had to be excluded.

For the client country, material stories are secondary to flexibility. Wood buildings are easy to edit on site with simple tools. Should something not fit, saws and drills can quickly enlarge a hole without compromising the material. On a steel building, changing bolt locations would require disrupting corrosion resistance and fireproofing layers. The grain structure of wood makes it less universally adaptable than the isotropic structure of steel though. Wood can handle reassembly a few times, but fastening locations become looser with each use. The lower environmental footprint of wood construction is appropriate for temporary structures where a material will not have time to decompose before the building has served its purpose.

The six month temporary Expo is a short sprint for reuse. The real challenge will be reuse of buildings with a hundred year lifetime.

Figure 6.19 Detail of compostable pavilion during the Expo



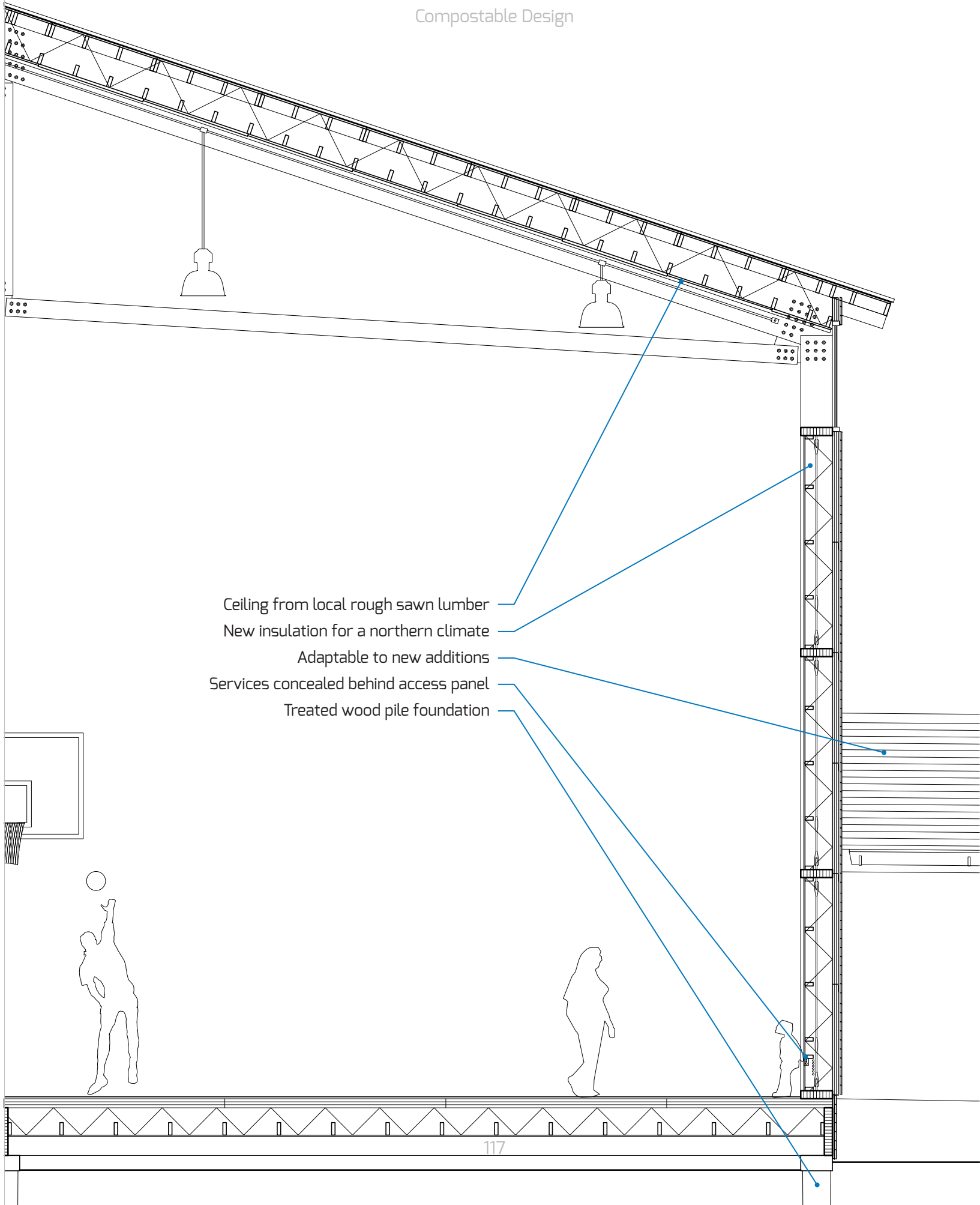
Beginning a second life

After the Expo the pavilion passes to a new site, new owner, and new program. It will be well accommodated in northern Canadian towns where wood construction is the vernacular. Recent years have brought a trend of replacing wood exteriors with modern materials such as unattractive vinyl siding and metal sandwich panels. This trend can be reversed by high performance timber buildings such as this pavilion. To function in northern winters, a thick sweater of cellulose insulation is wrapped around the building. If the pavilion can flourish in Canada’s harsh climate then any site is possible.

Engaging the pavilion’s new neighbours in a feeling of ownership is essential for success as a community centre. The task of enlisting everyone in assembling the building is made easy with familiar wood construction. Adaptability permits customization during construction and easy renovation later. A complex modular structure or heavy steel construction would be less accessible to occupants wishing to make small changes. Wood construction also mitigates troublesome thermal bridges common in steel buildings. However, there is a troubling contradiction in durable compostable construction. Removing toxic treatment from wood leaves it open to decomposition. The ready decay of compostable buildings will have to be arrested with regular maintenance to ensure longevity.

When the community centre reaches end of life, valuable materials used in construction will encourage reclamation. By using just a few different components, a sizable supply of identical parts will be available for reuse. Compostable materials that are beyond recovery can be mulched on the plot where wood for a replacement building is harvested. If knowledge of the building’s intended biodegradable future is lost then the wrong glue or paint could poison land on which the material is spread. While architects cannot control events after completion, maintenance documentation and encouraging the client to tell the pavilion’s story is a robust method of ensuring responsible care.

Figure 6.20 Detail of compostable pavilion as a community centre





6.3 Recycleable Pavilion

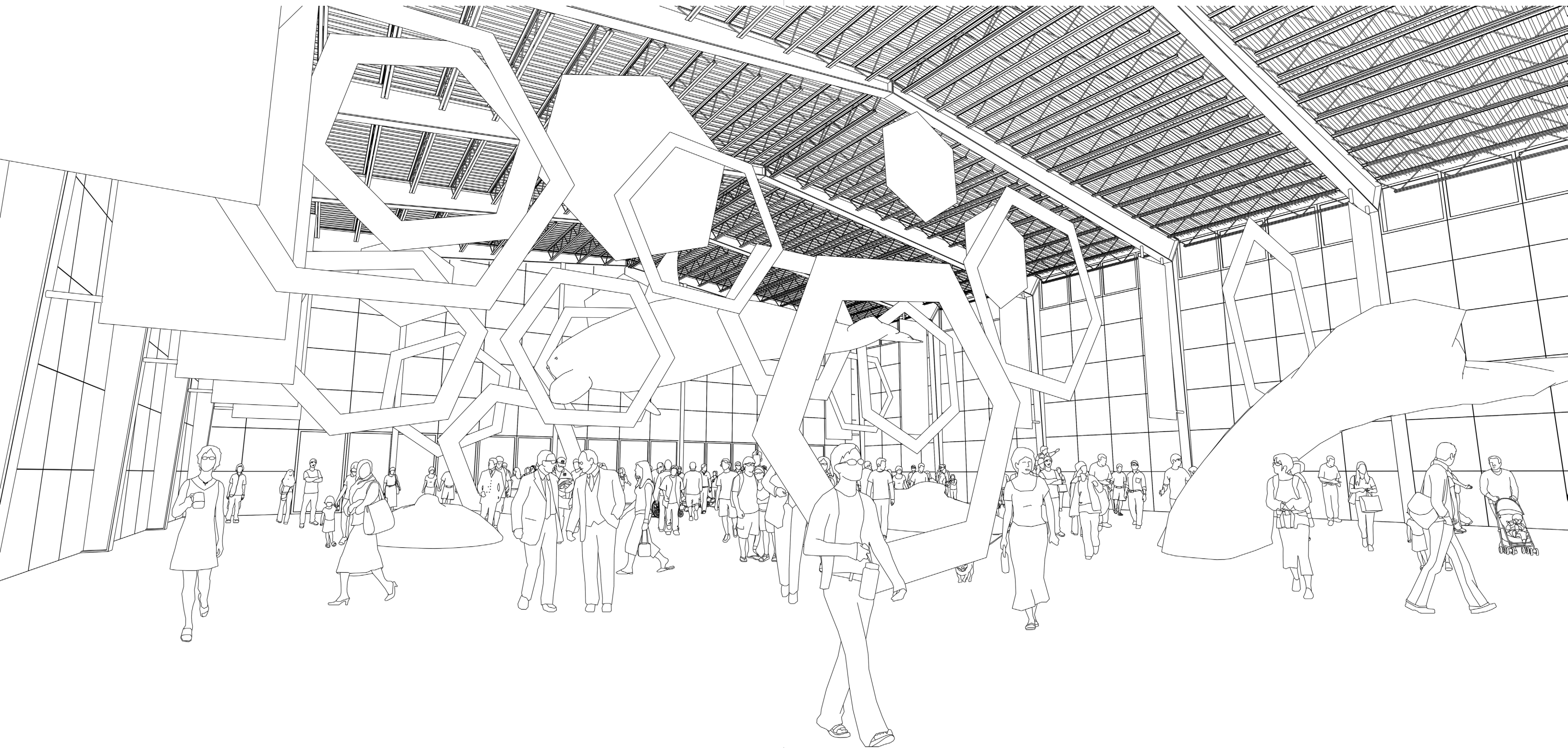


Figure 6.21 Interior perspective of recyclable pavilion



The recyclable pavilion

The design of a fully recyclable building opens up possibilities of short term use without the guilt of quick waste production. A steel structure is non-combustible and quick to assemble, expanding the potential of waste free buildings beyond what wood construction can offer. The goal is flexible space where the cost of adapting the building to occupants is reduced by circular material streams.

A significant challenge while designing the pavilion was in characterizing truly recyclable materials. To sort through the ocean of products, materials were evaluated and explicitly white-listed for recycling. The result was a limited palette of known good chemistries, which has advantages for end of life recovery when fewer different materials simplify sorting.

Designing a good building envelope for disassembly was challenging. Sealing the building against air infiltration proved intractable in a reusable manner. The solution is a taped together polyethylene air barrier which is recycled after each use.

An even more difficult problem emerged from the many thermal bridges in a steel structure. Northern Canada’s tough climate will quickly infuse these areas with condensation, corrosion and mould. Typical contemporary solutions are not appropriate to a recyclable building: Insulated sandwich panels use carcinogenic polystyrene which is not recycled. For curtain walls, insulating spacer clips made of fibre reinforced plastic are common, but that composite material is unrecoverable. To mitigate thermal bridges in this pavilion, either solid polyethylene or wood spacer blocks are employed in the facade and roof.

The result is an easy to disassemble kit of parts for high quality shell space. Materials used here preserve value in their potential for reuse or recycling into fresh constructions. The kit of parts is not intended as a universal modular system, rather a proof of concept and demonstration of mechanical fastening techniques for material reuse.

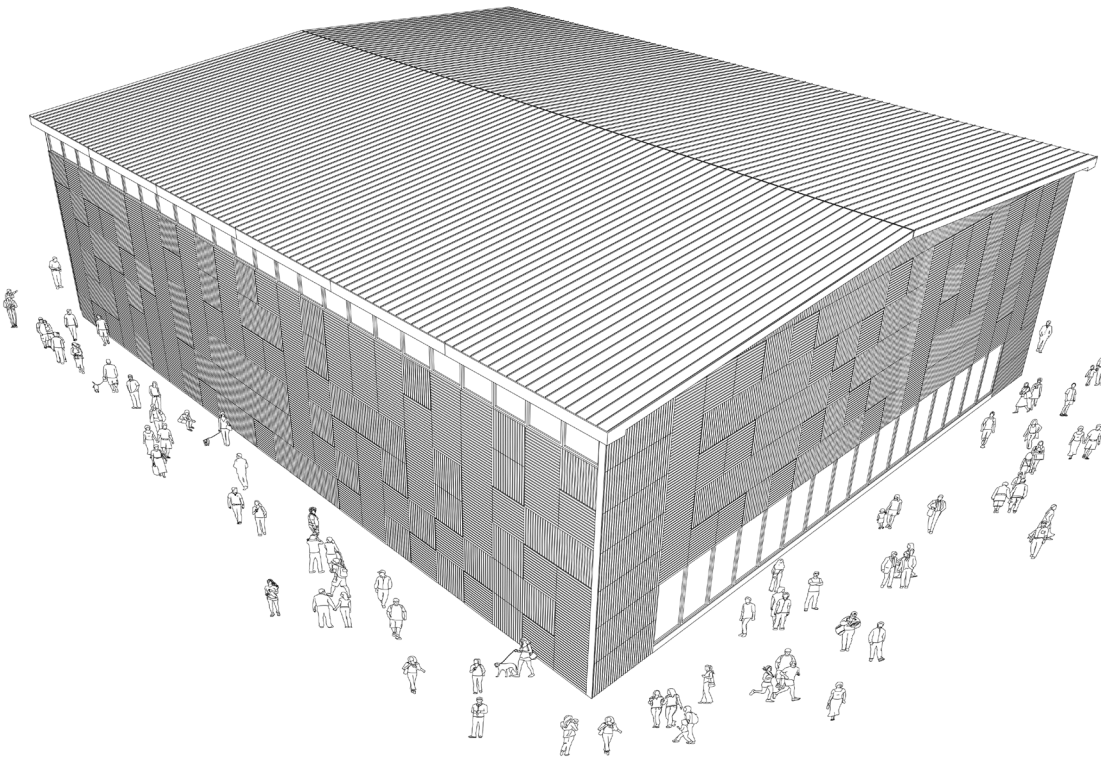


Figure 6.22 Exterior axonometric of recyclable pavilion

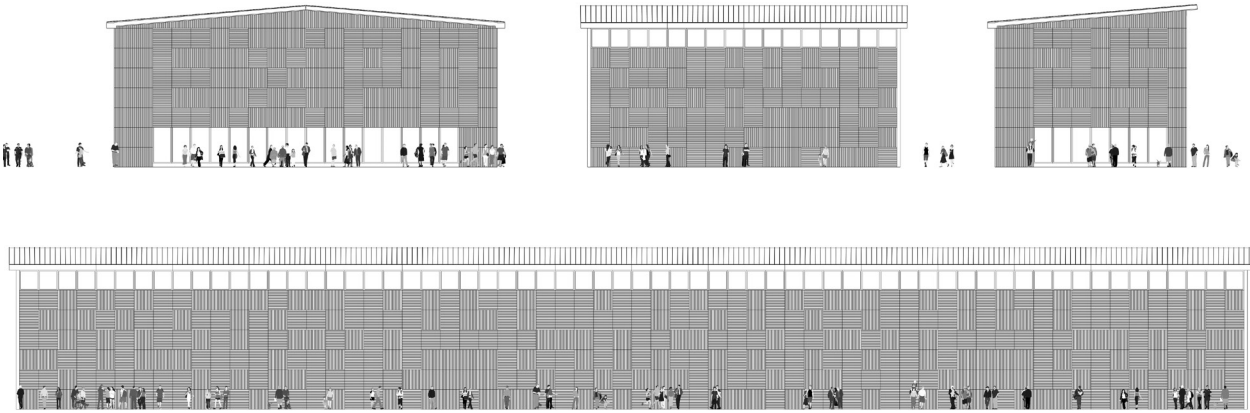
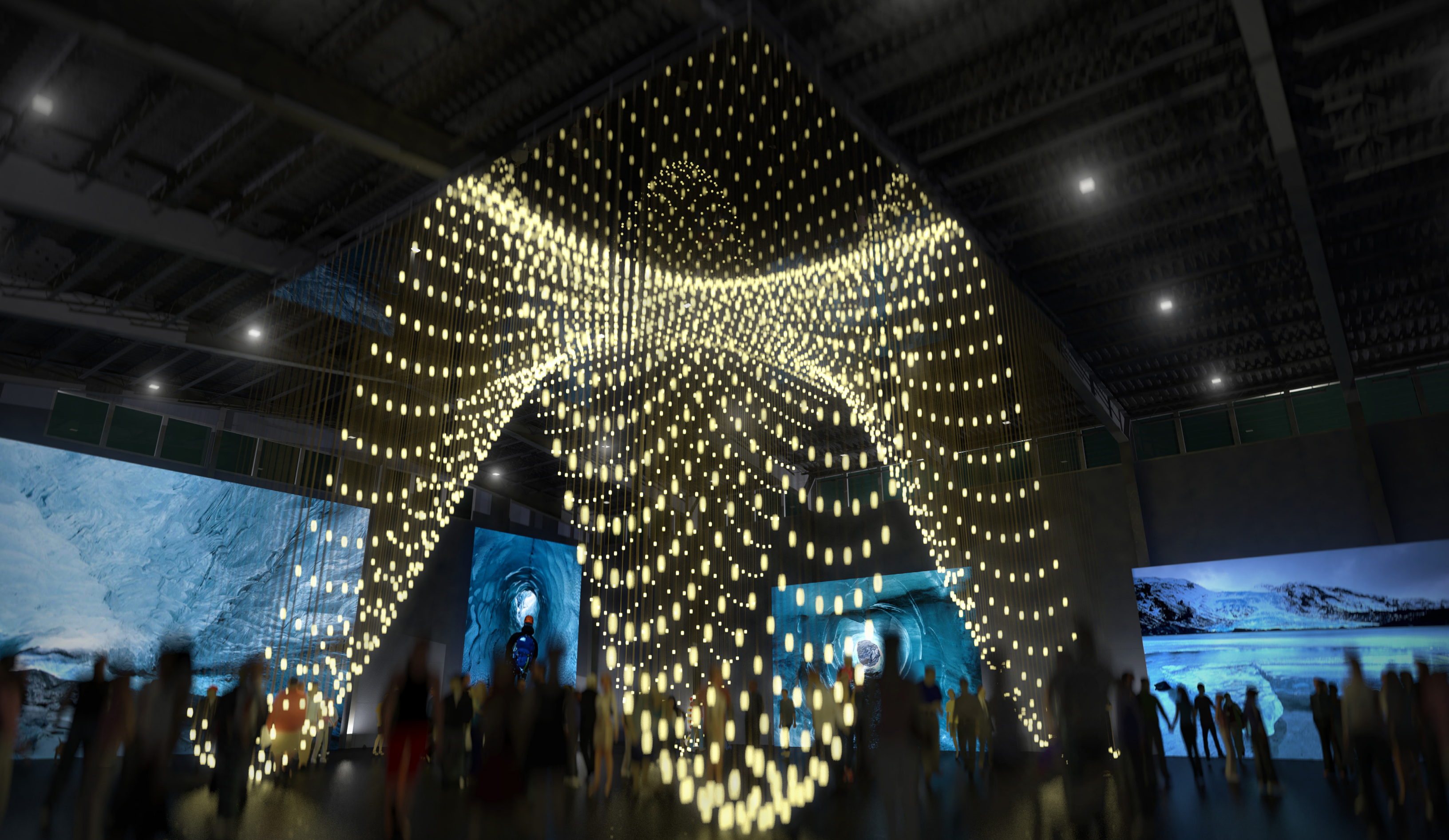


Figure 6.23 Alternate configurations of the recyclable pavilion



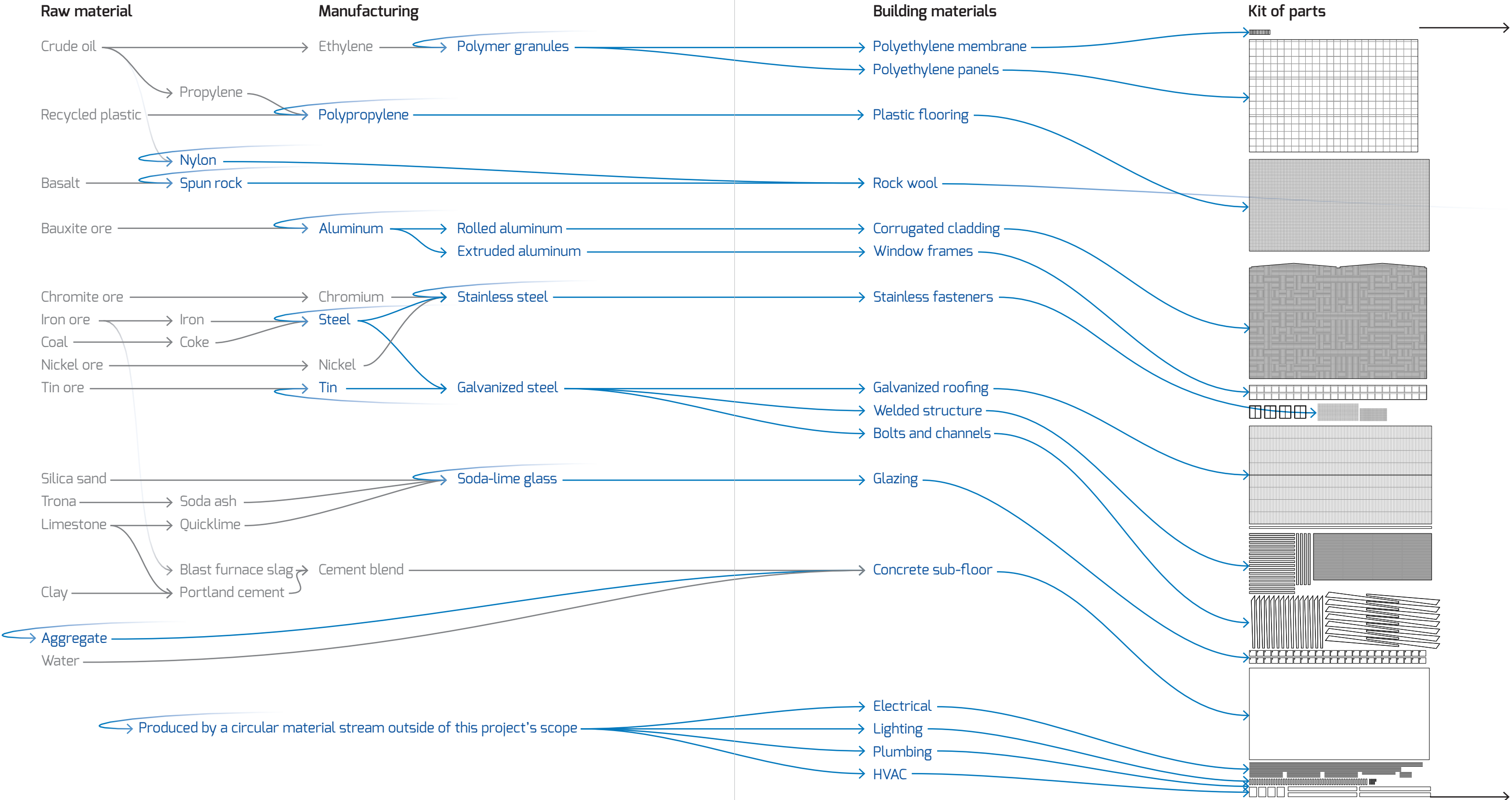




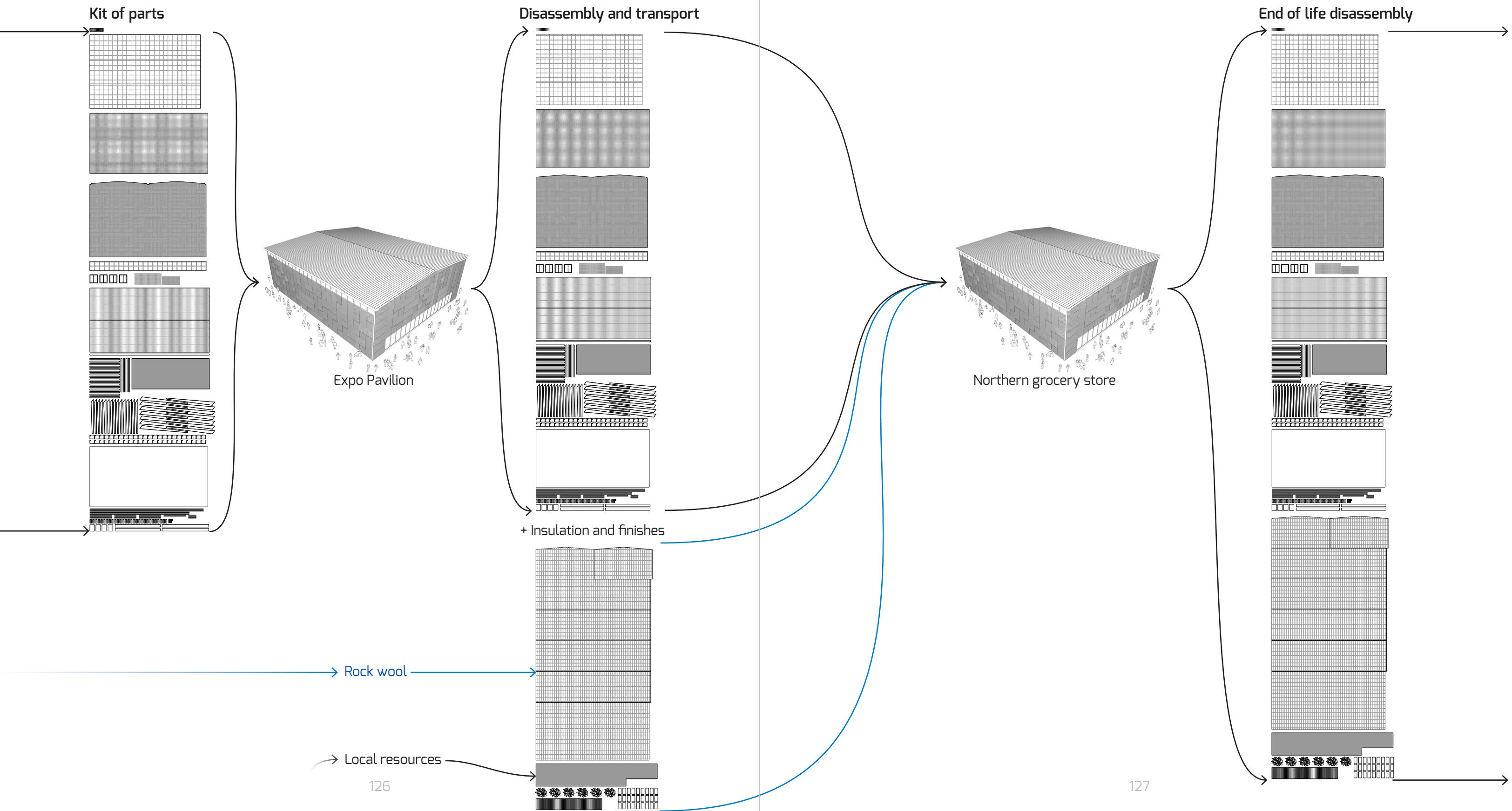
Building material flow diagram

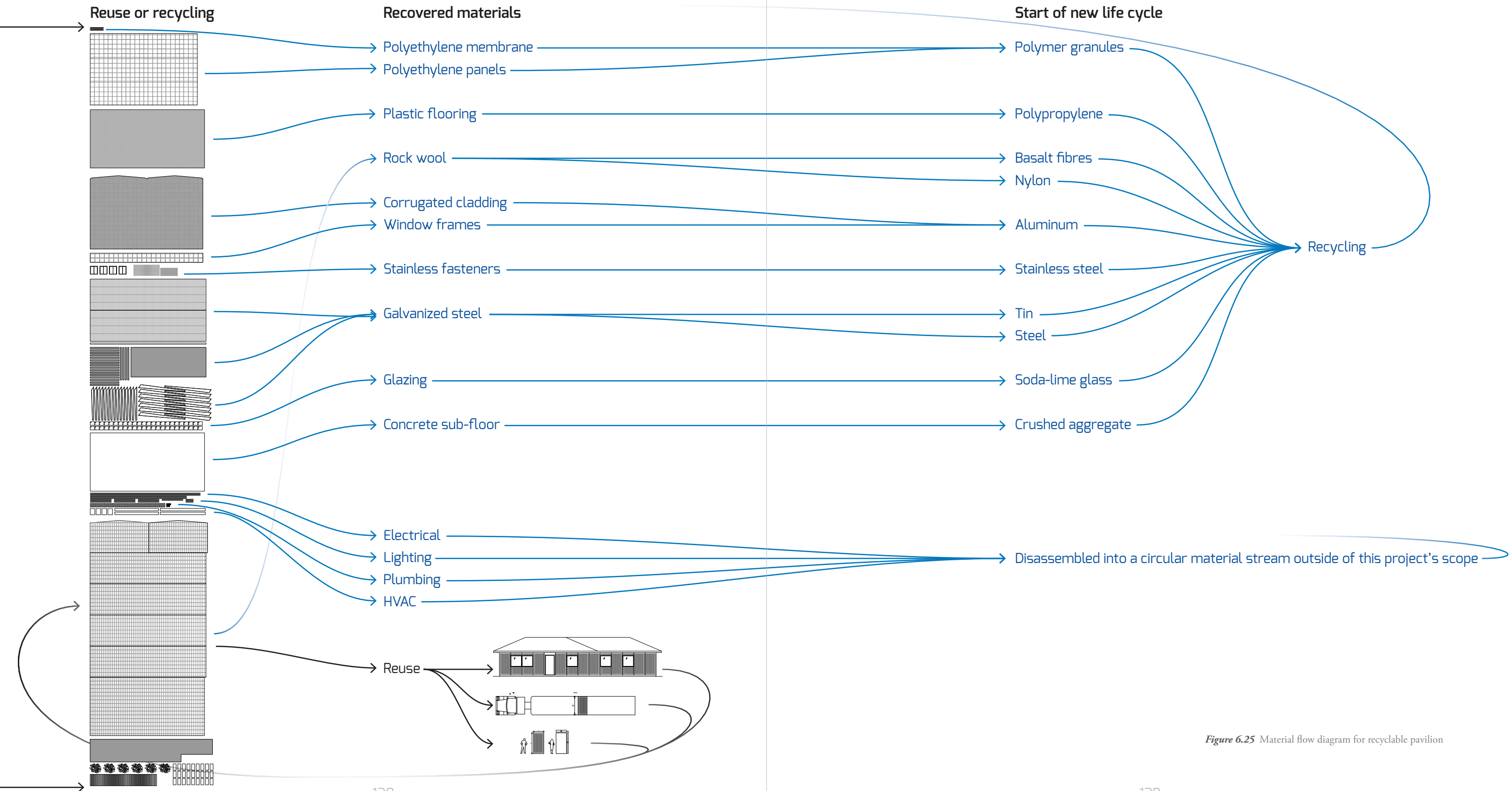
Legend

- Recyclable material
- Compostable material
- Material used once









**Figure 6.25** Material flow diagram for recyclable pavilion



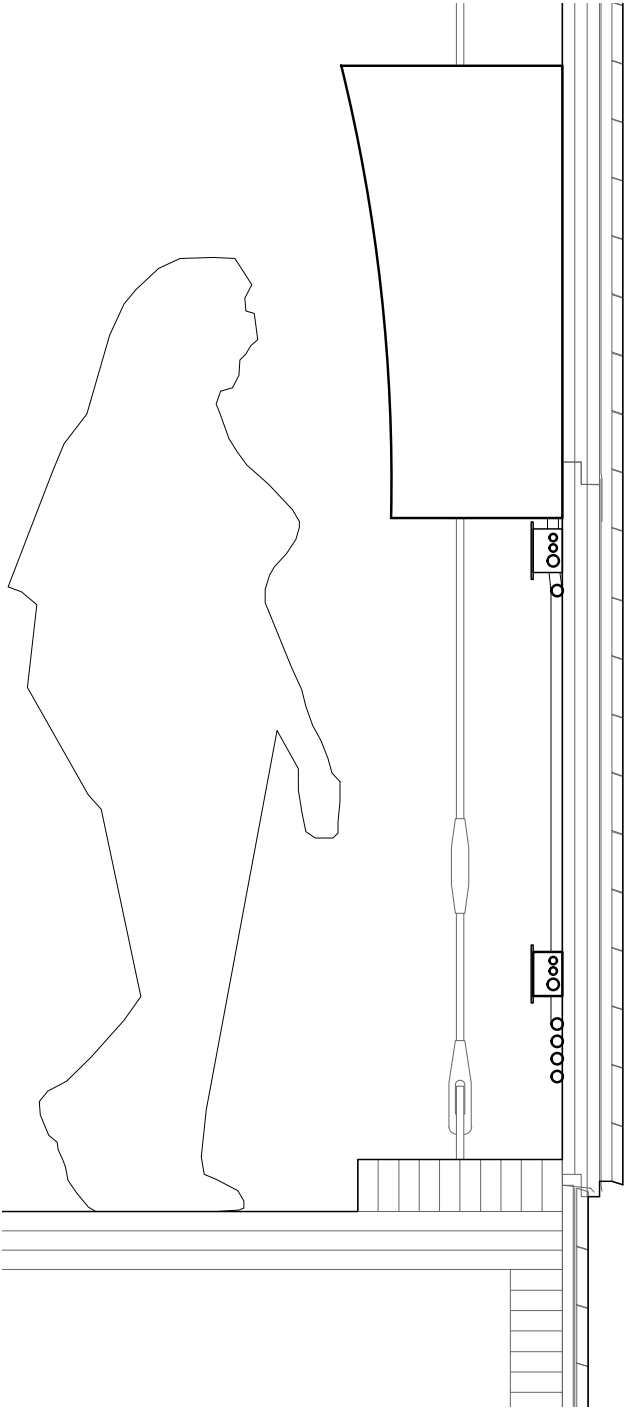
**Building services**

Complex engineered services that supply the building with heat, water and electricity are renewed on a shorter time scale than the structure to which they are fixed. To encourage improvement of the building as new technologies become accepted, access to services should be provided in a non-destructive manner. This is a natural extension of design for disassembly principles, with the caveat that services should be exposed early in the disassembly process.

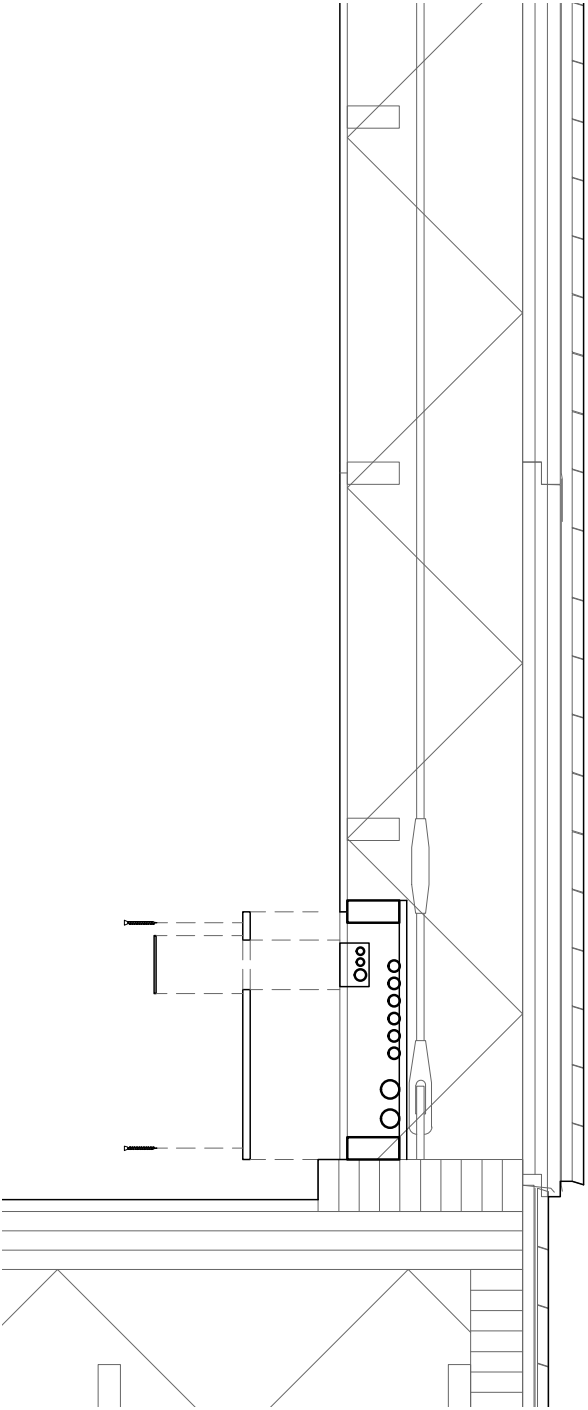
The most straightforward way to build accessible services is to expose conduits. These can be routed in a pleasing pattern if left visible. In the longer term, incremental changes will muddy the pattern, communicating disorder. More commonly, services are routed out of direct sight-lines on the ceiling, with a monochromatic paint to camouflage the clutter. Exposing services is a suitable strategy for Expo pavilions in short term use and with the benefit of easy comprehension by leasing countries.

For longer building lifetimes, service chases with access hatches are more appropriate. Wholesale replacement of systems can be conducted without disruption to the building. Because a fully disassemblable building has panelized walls, the pavilions are easy to retrofit. Services will be installed together in a chase which circles the perimeter at ankle level. Future installations could unscrew any of the interior wall panels to route power and data where they are needed.

The result of providing easy access into walls through disassembly is flexible design and renovation of services. If these services are provided through a closed life cycle, there will be no waste created when upgrading the building.



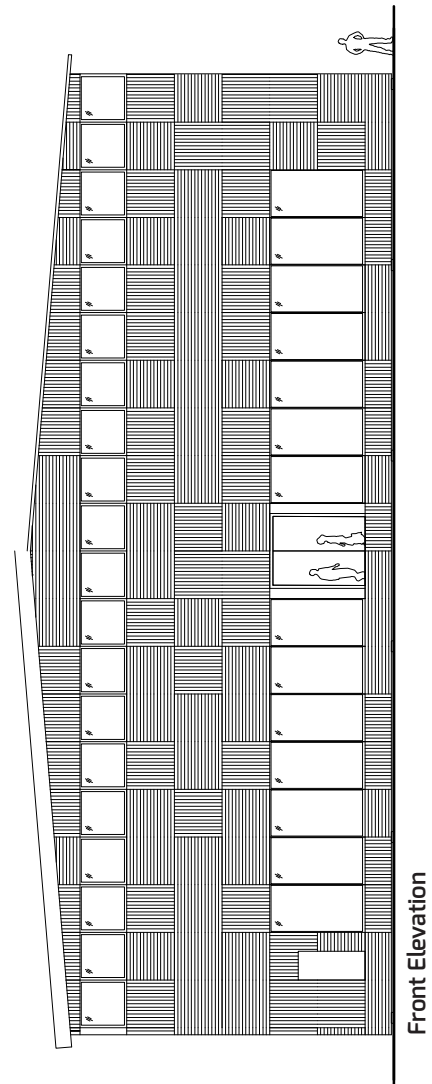
**Figure 6.27** Detail section of building services. During the Expo building services are exposed for easy installation of exhibits.



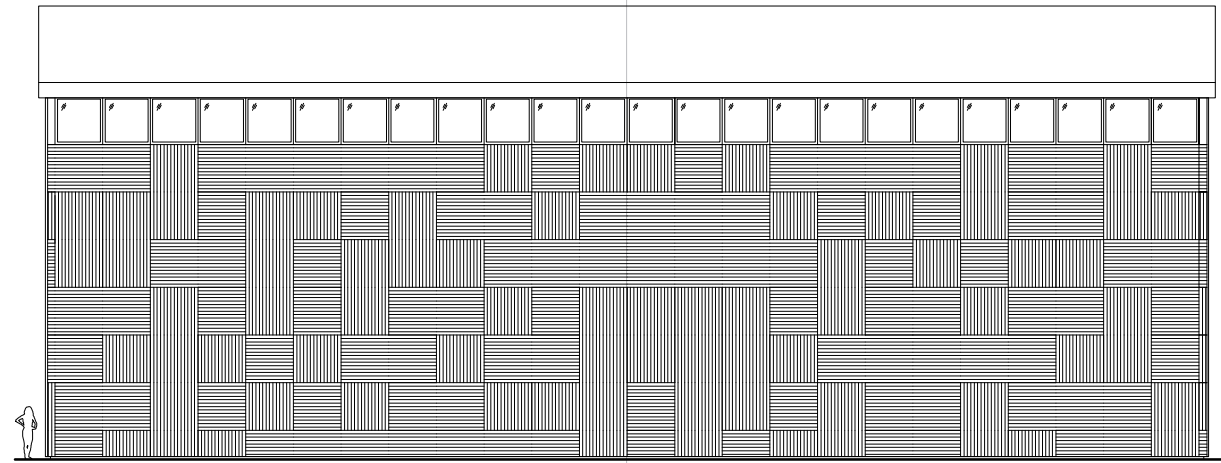
**Figure 6.26** Detail section of building services. For longer term use a continuous access panel conceals services in a chase.

0 1 2 3 5 10 15m

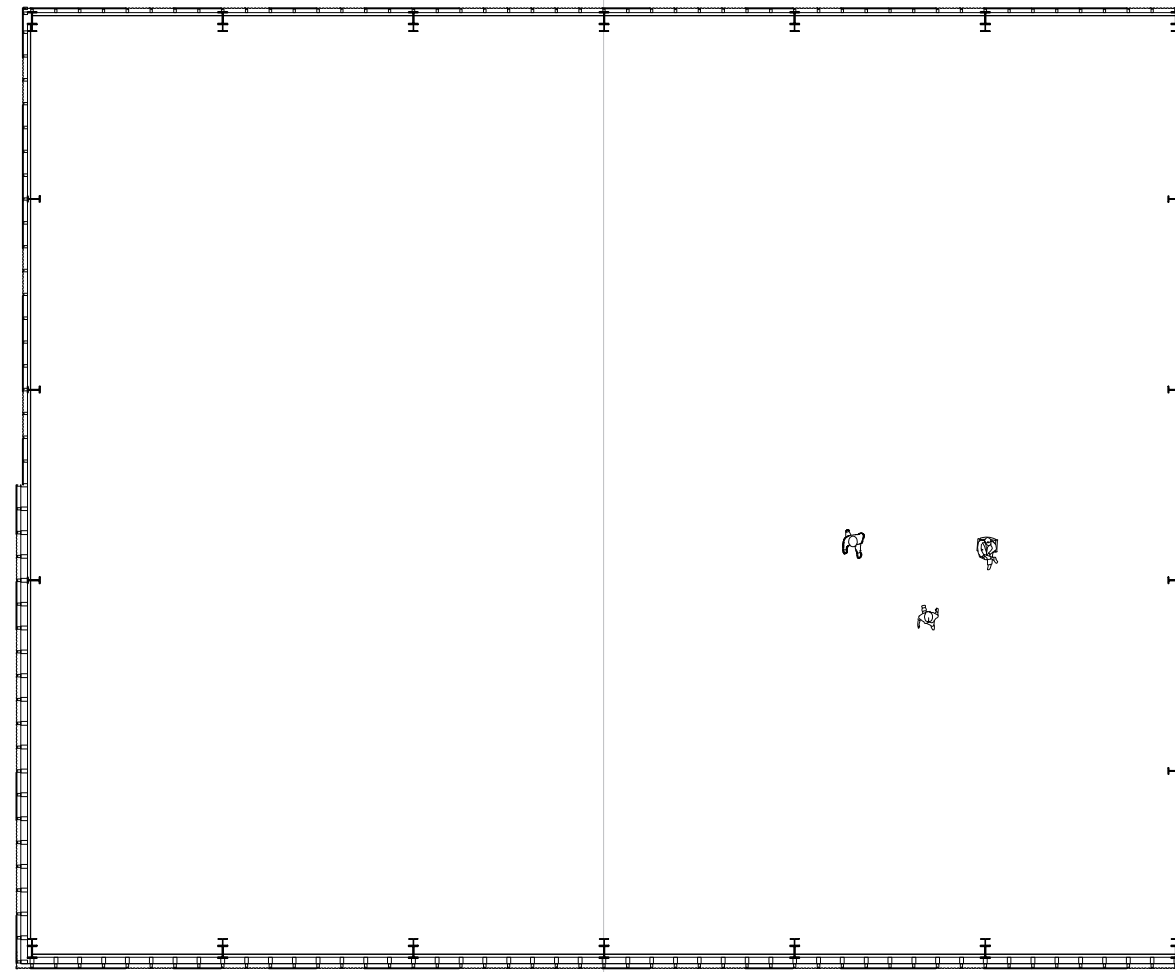
0 2 5 10 20 30 50ft



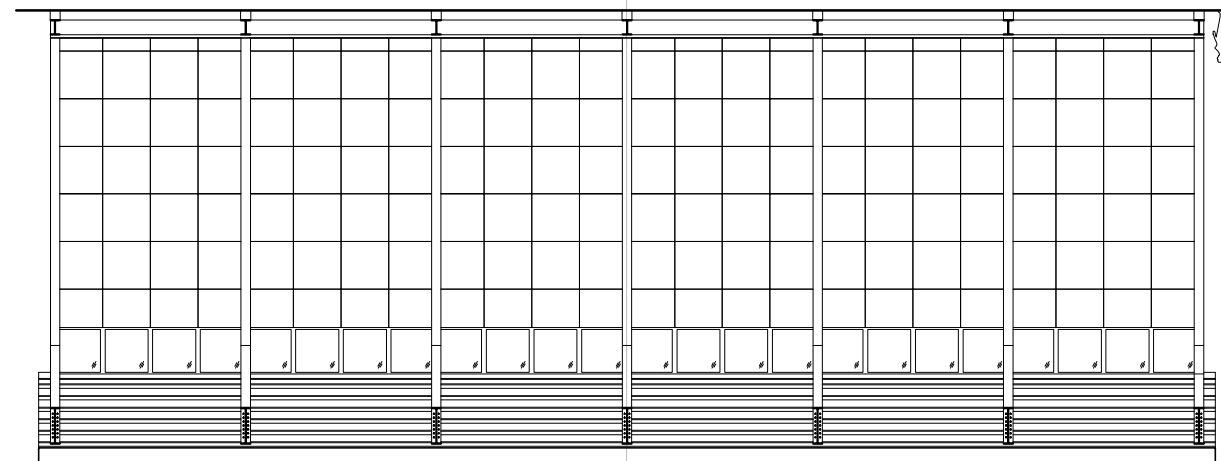
Front Elevation



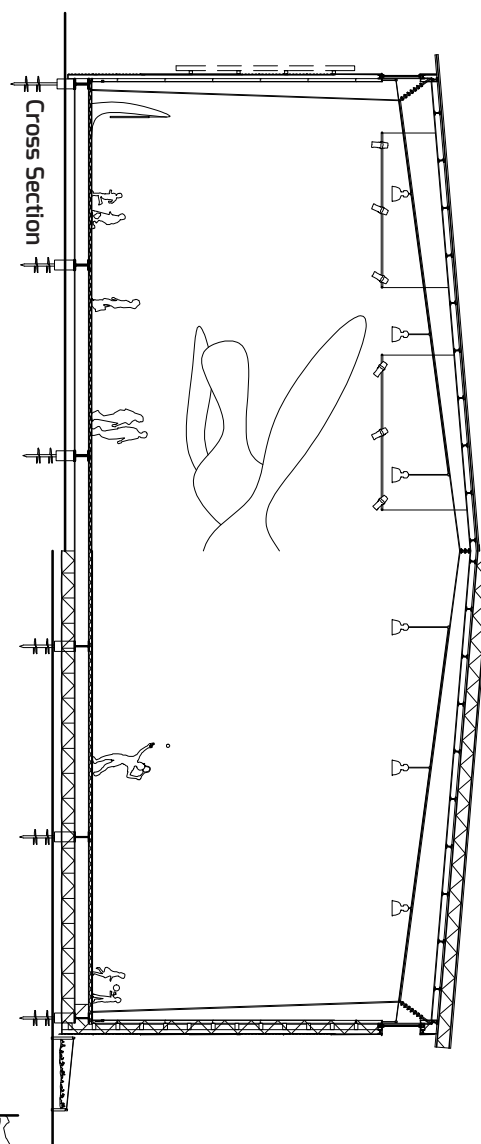
Side Elevation



Floor Plan



Longitudinal Section



Cross Section

Figure 6.28 Orthographic drawings of recyclable pavilion



At the conclusion of the Expo

During the Expo a steel pavilion follows the long history of light-weight metal exhibition halls. Steel’s strength in long spans is a natural fit for open shell space. For weathering, ageless aluminum cladding shelters the exterior. The metal frame is finished on the interior with softer polyethylene panels. The effect of a metal building is futuristic, though somewhat industrial as well. A clean modern look suits exhibits, but may not adapt well to reuse in a community.

To simplify recycling a handful of materials are employed throughout the building. Rather than using stainless steel fasteners, galvanized steel structure is joined with galvanized fasteners to form a mono-material assembly. Because the fasteners and substrate do not have to be separated for recovery, many smaller fasteners can be employed.

On the Expo’s short schedule rapid assembly of a steel building is advantageous. Computerized manufacturing can accommodate some design variation at no cost in complexity. However, when on site a bolted steel system is not as flexible as wood; changes may require re-manufacturing of problem parts. Steel is best employed when it can be reused several times; disassembly and reassembly is possible without loss of performance. Mobile structures such as concert stages benefit greatly from the ease of reassembly, and amortize environmental impact over longer time periods. The large carbon footprint of steel and plastic is wasted if they are used only for a short time. Recyclable pavilions are an admirable temporary use of material; the challenge is to design them for reuse.

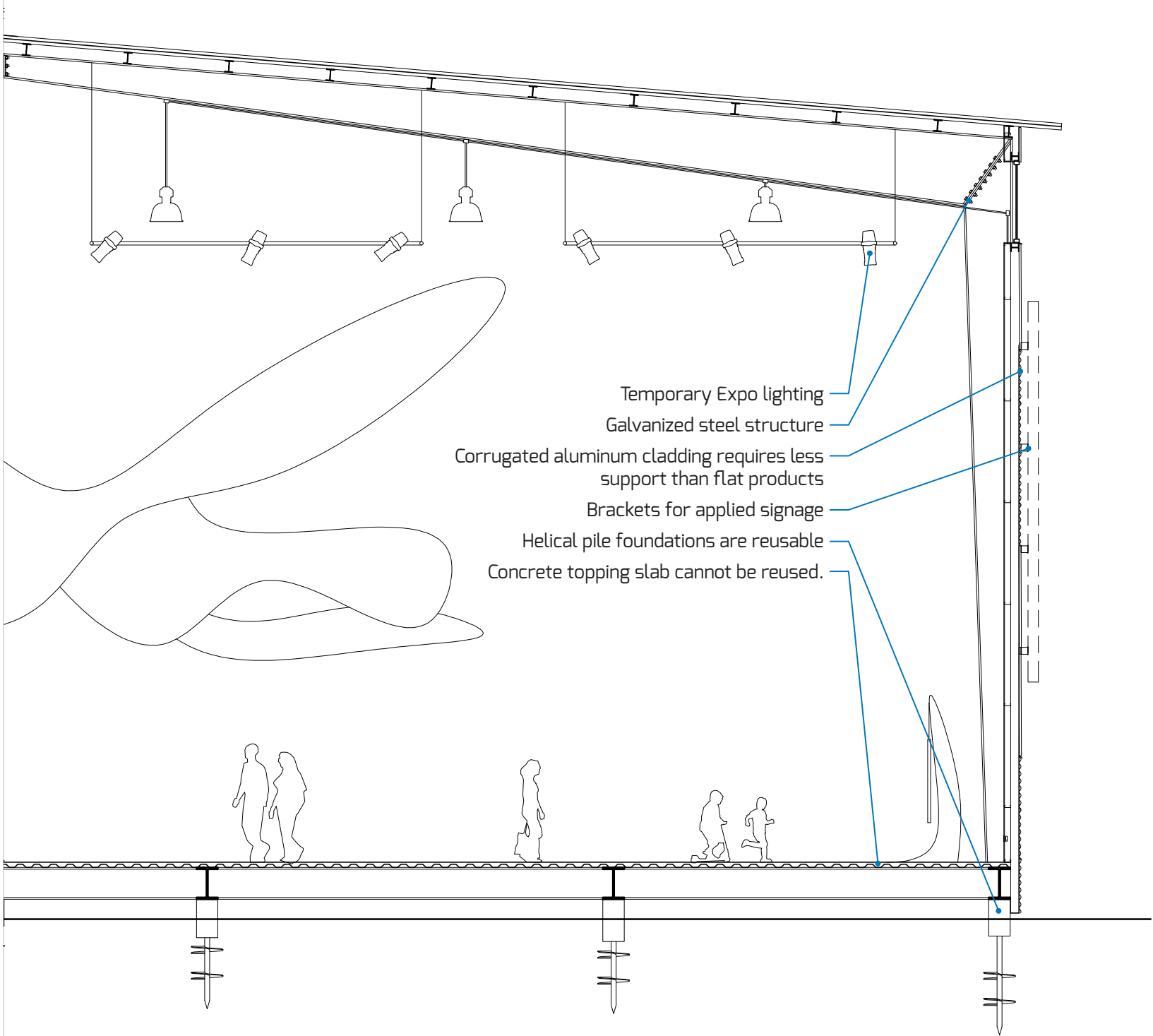


Figure 6.29 Detail of recyclable pavilion during the Expo

Beginning a second life

After the Expo the recyclable pavilion will be reassembled to serve a small Canadian town. The cold metal structure is less suitable for housing community program than warm wood from the compostable pavilion. Because recycling and reuse is mandatory, the building’s metal structure could not be softened by disposable gypsum board walls. Plastic panels used here are an inferior substitute for the sound absorption and thermal mass of mineral boards. For cradle to cradle architecture to succeed, some form of recyclable mineral sheathing will be necessary for acoustics and fire resistance. Fortunately both leased pavilions are small enough to avoid a fire rating, but fireproofing will be a challenge in more widespread adoption of recyclable buildings. Creating a continuous fire barrier involves the same difficulties in disassembly as sealing the building from weather; current fireproofing for steel relies on wet applied barriers or boxing out with disposable gypsum board. Neither of these is reusable, and a solution to recyclable fireproofing is not apparent so far.

While the compostable pavilion is suited for public uses, the recyclable pavilion is designed to replace the ubiquitous warehouses, retail, and commercial buildings which have short service lives. Metal structure has several advantages over wood in these buildings: it is cheaper, lighter weight, and non combustible. However future occupants will have a harder time adapting a metal building with common tools. Painting the structure is complicated by the choice of materials, inert aluminum and plastic require more reactive paint chemistries that will be impossible to separate at end of life. Given the building’s bland appearance, it might be suited to use as a hockey rink or grocery store.

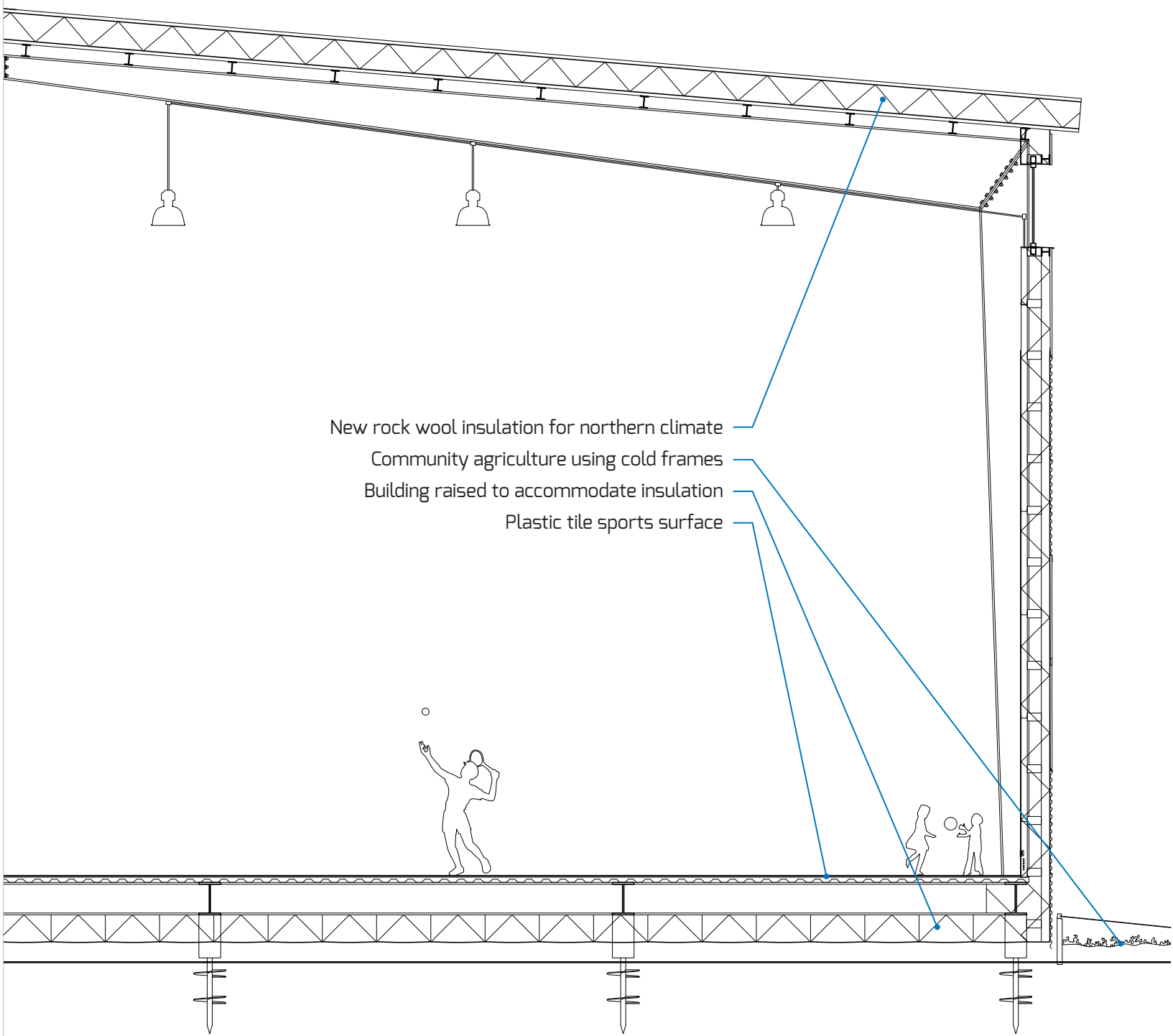


Figure 6.30 Detail of recyclable pavilion as a community centre





# 7.

## *Conclusion*

*Figure 7.1* Reclaimed sinks and toilets at the Cambridge waste transfer station

## 7. Conclusion

Regenerative Stories redesigns the Expo as a bold challenge for participants to take responsibility for the future of their temporary buildings. Exhibiting the use and regeneration of physical material is powerful reason to attend the Expo in person. In 2030 Toronto can raise the Expo from its status as public relations event to a forum for sharing experiences of renewal.

The proposed masterplan for an Expo in Toronto's Port Lands exemplifies regeneration by returning industrial land to community use. Every part of the event will be reusable and recyclable, with pavilions destined for communities across Canada. Designing expo architecture for circular material streams is a gesture of hope and responsibility for the future.

Cradle to cradle design enables architects to stop the conversion of resources to waste. It is unacceptable that buildings are disposed at end of life. Resources are finite and becoming scarcer; environmental harm from further extraction can be stopped by reusing what we already have.

Stories begun when buildings are designed with circular material streams will be carried into the future through materials. A renovated building becomes richer through traces of previous use. Construction materials reused in new buildings carry visual and tactile connections to the past. Recycled materials are able to tell an origin story of regeneration instead of extraction. These stories reach beyond the death of a building, giving the architect tools to improve the future through their work.

Intensive research into material ecologies culminates in two Expo pavilions. A compostable building is designed to biodegrade entirely after several cycles of adaptation, when its materials wear out. The alternate building is entirely recyclable at end of life. Each strategy for recirculating materials has drawbacks when used in architecture. Compostable buildings are ready to decompose at any gap in waterproofing or maintenance oversight. Recyclable buildings are assembled from cold metals and plastics whose surfaces are unpleasant to touch. The use of recyclable components in waterproofing compostable buildings suggests that in practice hybrid buildings could combine benefits from each life cycle. The primary advantage of life cycle design is plentiful options for the future created when adapting and re-cycling buildings.

Convincing clients to pay more for recyclable buildings will be challenging, as intrinsic qualities of design for disassembly will increase material costs. Without composites and glues, thicker and stronger ele-

ments are needed to span between fewer fasteners. Higher quality materials will be required to replace cheaper goods which depend on inseparable coatings. A well designed building might be able to balance high material cost with reduced labour from easy assembly. Even if construction is no more expensive than traditional building methods, extra design work and the experimental nature of early buildings will increase costs. Clients that are willing to build the first life cycle buildings will be making very long term investments. The benefits of adaptability do not bear fruit until the first renovation, and value in demolition could be a hundred years away. Media attention from the first few buildings might be valuable enough for manufacturers and clients to justify the cost. After that, organizations that plan on extremely long time scales will have to take a leap of faith. Churches, land trusts and museums are some potential clients who are patient enough to benefit from life cycle design. Those who invest in the future with cradle to cradle buildings will have a powerful story to tell while waiting.

Architects and designers are able to take away several principles from this thesis for application in everyday work. Life cycle design can begin with only one element of a product. Identifying the most recyclable or most valuable part and tweaking its design to ease recovery is a step towards eliminating waste. The process of thinking through disassembly and reclamation will prompt questions about what else can participate in closed life cycles. Asking about the end of life plans for everything expands design beyond the common short-sighted view. Some may be offended by talk about the mortality of something for which they care, but ignoring death does not make it any less inevitable. Along with acknowledging death, architects who perceive the danger of toxic materials in buildings will be recognized as forward thinking. Working to eliminate materials on the Living Building Challenge Red List from designs is a wise precaution. Building owners dealing with asbestos today would be happy to thank an architect who curtailed its use when the first warning signs emerged.

Architectural fashion is trending towards 'living' buildings that react through digital sensors. But what if the building fabric lived, reacting through small renovations to occupants on a year by year timescale, and participating in a continuous cycle of renewal? There should not be a single prescribed future for architecture. The best we can do is to make decisions that leave the maximum optionality for our descendants.



## Epilogue

During the thesis defence, a fruitful conversation grew from the future extension of ideas on building material reuse. This epilogue serves as a method of capturing that conversation to add perspective to the thesis. The discussion centered on a common question: if the ideas of this thesis were widely accepted, what might architecture look like in 100 years?

Given the adoption of Cradle to Cradle flows in building design, the form of architecture will change in the near future with a proliferation of visible joints. Buildings designed for disassembly are not compatible with the seamless surfaces of modern and postmodern architecture. Jointing presents an opportunity for architects to reintroduce functional ornament. Panelized interiors must make a comeback, displacing smooth disposable surfaces. Over time, architecture will become less uniform as reused pieces of old buildings appear in new construction. Architects will be challenged to unite the fragmented aesthetics of new and used materials with creative design. Architects can also play a role in communicating the provenance of materials, their recommended care, and next uses through design or by encoding that information directly into surfaces.

Communicating information is not sufficient, however, to ensure the care of durable buildings. To live long lives, buildings must be loved by their occupants. Natural materials foster love by improving with care; they are porous, and develop a patina of use. Soft materials must be supported by a durable foundation however, to resist deterioration in times of reduced care. Steward Brand's concept of building layers separates different paces of change in a building, but it could also apply to different intensities of maintenance. The interior and exterior layers of a building are personal, easy for occupants to love and care for. Between those layers, the structure and services should be durable, not anticipating any maintenance. Durable architecture need not mean concrete on all surfaces, but clarity in design between the parts of a building that are cared for and adaptable, as opposed to durable and static.

In the course of discussion during the defence, speakers contemplated how the reuse of materials would change world expositions. For this Expo, pavilions will be fabricated from virgin materials, but the next generation of Expo would be assembled from the materials of previous events. The challenge for architects will be to create all-new buildings from materials that have been previously used. Paul Dowsett proposed an analogy for building with used materials in the act of reaching into a

box of Lego. When you pull your hand out, the assorted pieces may not match in colour, but that does not constrain the creative possibilities in assembling them. The great benefit of hosting an Expo about reuse is in gathering the world's top architects and handing them a metaphorical box of Lego. As they work through the creative challenge of used materials and design for disassembly, it will hopefully change the way they think about material, and show the world that creative reuse is beautiful. To borrow a music metaphor, designing with pieces of past Expos is an opportunity to riff on and remix the past.

In fifty years, the role of an architect will evolve as more and more materials come from used buildings rather than virgin resources. Architects will work with demolition experts to source used materials, and direct the process of their refurbishment. As materials increasingly come from other buildings, architects will get feedback on the consequences of design decisions as they affect reuse. Architects will engage with demolition experts to better understand the processes of disassembly. Just as current buildings are designed with input from contractors for constructability, future buildings will be designed with demolishers in mind.

When the first generation of Cradle to Cradle buildings reach end of life, a flood of material will become available for reuse. The shift to material reuse at a large scale will change the economics of extraction and construction. While Canada's extraction industries will shrink from reduced demand, new employment opportunities will be created in material recovery, refurbishment and resale. Disassembly is more labour intensive than indiscriminate demolition, and new infrastructure for material warehousing will be needed at the community scale. Over time, global material suppliers will be displaced by the local recirculation of materials. Construction techniques that are no longer homogenized by commodity materials can slowly diverge into regional variations, leading to the reappearance of a local vernacular.

Social and cultural embracement of life cycle thinking will take a generation or two to become widespread. Education can accelerate this process by introducing the ideas in schools and universities. Perhaps the most effective way to spread life cycle thinking will be through the construction of schools according to Cradle to Cradle principles, where children can be immersed in an environment of re-cycling.

Over time, a material's accumulated re-uses weave powerful stories. There are cultural precedents for this in objects handed down through families, such as china or silverware. Eventually, building materials may accumulate stories as rich as family heirlooms, being passed down through generations or recovered from a building that no longer stands. The reuse of building materials means that architecture can no longer be erased from the city; the boards of a small postwar house will live on in the next building on that site. Society will no longer dispose of our built culture, but adapt it into the next generation of architecture, creating a palimpsest of material stories.

In locations with a scarcity of building materials, such as northern Canadian towns, Cradle to Cradle building design offers a method of breaking away from reliance on government aid. There is a long history of federal money being dumped into northern Canadian communities, with the presumption that the government knows what is best and the expectation that people will be grateful. Northern buildings constructed with grant money have failed quickly, either through maladaptation to the climate, to new uses, or shortsighted decisions made to save time on site at the expense of durability. Instead of delivering a single use building, the Cradle to Cradle pavilion design in this thesis assembles a collection of durable materials which can be adapted with hand tools. Should the pavilion no longer suit the community, people are empowered to adapt or disassemble it for another purpose. In this way, building materials become resources that do not depreciate, but can fuel future construction. The long term effect will be to free small communities from dependency on their larger neighbours by creating local circular material flows.

The stories embodied in reused materials are powerful, linking the present to the past and suggesting future uses. Architects as storytellers will have an important role in Cradle to Cradle design by using stories to increase the societal value of materials. After all, good stories are how we convince people to spend more money on something; we call that marketing. Telling stories is what makes us human, shapes our culture and our shared history. The as-yet unanswered question is how architects can design buildings so those material stories are resonant, in an architectural way which goes beyond the ubiquitous bronze plaque.



Bibliography

Arsenault, Peter J. “Full Transparency in Product Declarations: Specifying Products that are Consistent with Environmental Quality and Human Health.” *Architectural Record* 201, no. 7, (2013): 136-139.

Beaver, Patrick. *The Crystal Palace, 1851-1936 : A Portrait of Victorian Enterprise*. London: Hugh Evelyn, 1970.

Benjamin, David. “Hy-Fi by The Living.” *Young Architects Program and MoMA*, 2014. [https://www.moma.org/interactives/exhibitions/yap/2014ny\\_living.html](https://www.moma.org/interactives/exhibitions/yap/2014ny_living.html)

Berge, Bjørn. *The Ecology of Building Materials*. Oxford ; Boston: Architectural Press, 2000.

Beznogova, Anna. *Navigating the complexity of material sustainability for architectural practice*. Masters Thesis: University of Waterloo, 2016.

Borasi, Giovanna, and Mirko Zardini. *Sorry, out of gas : Architecture’s response to the 1973 oil crisis*. Montréal: Canadian Centre for Architecture, 2007.

Brand, Stewart. *How Buildings Learn : What Happens after They’re Built*. New York: Viking, 1994.

Brundtland, G.H., and World Commission on Environment and Development. *Our Common Future: Report of the World Commission On Environment and Development*. Oxford: Oxford University Press, 1987.

Catalli, Vince, and d’Esign consultants. *Designing for Disassembly*. Ontario: Canada Mortgage and Housing Corporation, 1998.

Choppin, Julien, and Nicola Delon. *Matière grise: matériaux réemploi architecture*. Paris: Pavillon de l’Arsenal, 2014.

“Clopyralid in Compost.” Washington State University Organic Farming Systems and Nutrient Management. accessed November 18, 2016. <https://puyallup.wsu.edu/soils/clopyralid/>

“Compost and mulch is now available at the Cambridge and Waterloo landfill.” *Region of Waterloo*. Accessed December 11, 2016. <http://www.regionofwaterloo.ca/en/aboutTheEnvironment/waste.asp>

Cowper, Charles, and Charles Downes. *The Building Erected in Hyde Park for the Great Exhibition of the Works of Industry of All Nations, 1851*. London: Victoria and Albert Museum, 1972.

“Cradle to Cradle Certified Products Registry” *Cradle to Cradle Products Innovation Institute*. accessed October 26, 2016. <http://www.c2ccertified.org/products/registry>

Dastidara, Trina Ghosh, and Anil N. Netravali. “A soy flour based thermoset resin without the use of any external crosslinker.” *Green Chem.* no. 15, 2013, 3243. DOI: 10.1039/c3gc40887f

Dirkx, Lizanne, and Pietro Galgani. “Soy Glue.” *WoodGuide.org*, accessed September 23, 2016. <http://www.woodguide.org/guide/soy-glue/>

D’Oca, Daniel, Tobias Armborst, Georgeen Theodore, Rebecca Beyer Winik, Interboro Partners. “Checking in on Holding Pattern” *Inside/Out* (blog) Museum of Modern Art, January 12 2012. [https://www.moma.org/explore/inside\\_out/2012/01/12/checking-in-on-holding-pattern](https://www.moma.org/explore/inside_out/2012/01/12/checking-in-on-holding-pattern)

El khouli, Sebastian, Viola John, and Martin Zeumer . *Sustainable Construction Techniques : From Structural Design to Interior Fit-out : Assessing and Improving the Environmental Impact of Buildings*. Munich: DETAIL, Institut Für Internationale Architektur-Dokumentation, 2015.

El-Khoury, Rodolphe, Andrew Payne, and Nic Lehoux . *States of Architecture in the Twenty-first Century : New Directions from the Shanghai World Expo*. Singapore ; Philadelphia: Oscar Riera Ojeda Publishers, 2011.

“End of Life.” *Accoya.com*. accessed December 13, 2016. <https://www.accoya.com/sustainability/end-of-life/>

“Environmental Product Declaration: Modular Carpet - Interface Americas Glasbac Re - Type 66 Nylon.” *Interface.com*, PDF, October 2016. [http://interfaceinc.scene7.com/is/content/InterfaceInc/Interface/Americas/WebsiteContentAssets/Documents/Technical/EPDBriefs/GlasBacRENylon66/wc\\_am-epdglasbacrenylon66oct2016.pdf](http://interfaceinc.scene7.com/is/content/InterfaceInc/Interface/Americas/WebsiteContentAssets/Documents/Technical/EPDBriefs/GlasBacRENylon66/wc_am-epdglasbacrenylon66oct2016.pdf)

Epstein, Eliot. *Industrial Composting : Environmental Engineering and Facilities Management*. Boca Raton, FL: CRC Press, 2011.

“Expo, congelamento invernale Albero della vita costa 360.000 euro.” *Askaneews.it*, November 12, 2015. [http://www.askaneews.it/regioni/lombardia/Expo-congelamento-invernale-albero-della-vita-costa-360000-euro\\_711674161.htm](http://www.askaneews.it/regioni/lombardia/Expo-congelamento-invernale-albero-della-vita-costa-360000-euro_711674161.htm)

Faircloth, Billie. *Plastics Now : On Architecture’s Relationship to a Continuously Emerging Material*. Abingdon; New York: Routledge, 2015.

Feldman, Edwin B. *Building Design for Maintainability*. New York: McGraw-Hill, 1975.

Felten, Eric. “In Praise of Impermanence.” *Wall Street Journal*, April 19, 2012. <http://www.wsj.com/articles/SB10001424052702303425504577353790993830980>

Friebe, Wolfgang. *Buildings of the World Exhibitions*. Leipzig: Edition Leipzig, 1985.

*Bibliography continued*

Fuller, Richard Buckminster. *Operating Manual for Spaceship Earth*. New York: Simon and Schuster, 1969.

Geiser, Ken. *Materials Matter : toward a Sustainable Materials Policy*. Cambridge, MA: MIT Press, 2001.

Goodbun, Jon, Michael Klein, Andreas Rumpfhuber, and Jeremy Till. *The Design of Scarcity*. Moscow: Strelka Institute for Media, Architecture and Design, 2013. (ebook)

Gordon, Rachelle. “The History of the Three R’s.” *Recycle Nation*, May 11, 2015. <http://recyclenation.com/2015/05/-history-of-three-r-s>

Gray, Jeff. “Toronto mayor calls for end to Expo 2025 bid, prioritizing transit and public housing.” *Globe and Mail*, October 26, 2016. <http://www.theglobeandmail.com/news/toronto/toronto-mayor-calls-for-end-to-expo-2025-bid-prioritizing-transit-and-public-housing/article32541876/>

“Guidelines - Sustainable Solutions - Design, Construction, Dismantling and Reuse. Milan: Expo 2015 S.p.A., 2013. <http://www.expo2015.org/archive/en/learn-more/sustainability/guidelines-for-participants.html>

Guy, Brad, and Nicholas Ciarimboli. *Design for Disassembly in the built environment: a guide to closed-loop design and building*. Seattle, WA: City of Seattle. 2006.

Heilmeyer, Florian. “Putting an End to the Vanity Fair.” *Uncube Magazine* no. 32 (2015). <http://www.uncubemagazine.com/magazine-32-15358283.html#!page57>

Heiskanen, Kari. “Theory and tools of physical separation.” In *Handbook of Recycling*, edited by Ernst Worrel and Markus A. Reuter, 39-61. Amsterdam: Elsevier, 2014.

Hopewell, Jefferson, Robert Dvorak and Edward Kosior. “Plastics recycling: challenges and opportunities,” *Philos Trans R Soc Lond B Biol Sci*. July 27, 2009; No.364 : 2115–2126. DOI: 10.1098/rstb.2008.0311

Hosenball, Mark, and Katharina Bart. “FBI extends FIFA scrutiny to World Cup host bids of Russia, Qatar.” *Reuters*, June 5, 2015. <http://www.reuters.com/article/us-soccer-fifa-idUSKBN0OI22P20150605>

“How Concrete is Recycled.” *CDRecyclingAssociation*. accessed September 15, 2016. <http://www.cdrecycling.org/how-to-recycle>

“How this city nearly got the Eiffel tower.” *Montreal Gazette*, Sept. 15, 1980. <https://news.google.com/newspapers?id=eJckAAAAIBAJ&sjid=raQFAAAAIBAJ&p-g=1682%2C2718377>

“ICEhouse.” Davos, Switzerland: William McDonough + Partners, 2016. <http://www.mcdonoughpartners.com/projects/icehouse/>

ILFI staff. “ILFI Announcing certification of 18 new living buildings.” *Trimtab* (blog), International Living Futures Institute, May 23, 2016. <http://trimtab.living-future.org/blog/ilfi-announcing-certification-of-18-new-living-buildings/>

IPCC “Summary for policymakers.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge ; New York: Cambridge University Press, 2014.

Jodidio, Philip. *Serpentine Gallery Pavilions*. Köln: Taschen, 2011.

Khatib, Jamal M. *Sustainability of Construction Materials*. Duxford ; Cambridge, MA; Kidlington: Woodhead, 2016 .

Kieran, Stephen, and James Timberlake. *Cellophane House : KieranTimberlake*. Philadelphia: KieranTimberlake, 2011.

Kieran, Stephen, and James Timberlake. *Refabricating Architecture : How Manufacturing Methodologies Are Poised to Transform Building Construction*. New York ; London: McGraw-Hill, 2004.

Klare, Michael T. *The Race for What’s Left : The Global Scramble for the World’s Last Resources*. New York: Metropolitan Books, 2012.

Knecht, Barbara. “Designing for Disassembly and Deconstruction.” *Architectural Record* 192.10 (October 2004) 181-188.

König, Holger. *A Life Cycle Approach to Buildings : Principles, Calculations, Design Tools*. Munich: Institut Für Internationale Architektur-Dokumentation, 2010.

Koolhaas, Rem, and Bruce Mau. *S, M, L, XL*. New York: Monacelli Press, 1995.

“LEED Canada for New Construction 1.0 Credit Distribution as of February 2016.” PDF, *Canadian Green building Council*, February 2016. [https://www.cagbc.org/cagbcdocs/LEED\\_Canada\\_NC\\_v1-Average\\_Scorecard-Feb\\_2016-EN.pdf](https://www.cagbc.org/cagbcdocs/LEED_Canada_NC_v1-Average_Scorecard-Feb_2016-EN.pdf)

Li, Kaichang. “Formaldehyde-free lignocellulosic adhesives and composites made from the adhesives.” U.S. Patent No. 7,252,735. 2007. <https://www.google.com/patents/US7252735>



*Bibliography continued*

“Living Product Challenge.” *International Living Future Institute*, accessed November 14, 2016. <http://living-future.org/lpc>

Loughran, Patrick. *Falling Glass : Problems and Solutions in Contemporary Architecture*. Basel ; Boston, Mass.: Birkhauser, 2003.

Lyle, John Tillman. *Regenerative Design for Sustainable Development*. New York: J. Wiley, 1994.

MacBride, Samantha. *Recycling Reconsidered: the Present Failure and Future Promise of Environmental Action in the United States*. Cambridge, MA: MIT Press, 2012.

McDonough, William, and Michael Braungart. *Cradle to Cradle : Remaking the Way We Make Things*. New York: North Point Press, 2002.

McDonough, William, and Michael Braungart. *The Upcycle : Beyond Sustainability - Designing for Abundance*. New York: North Point Press, 2013.

McKaig, Thomas H. *Building Failures : Case Studies in Construction and Design*. New York ; Toronto: McGraw-Hill, 1962.

McKean, John. *Crystal Palace : Joseph Paxton and Charles Fox*. London: Phaidon Press, 1994.

McMillan, Michele. “Waste Management Industry Survey: Business and Government Sectors.” *Statistics Canada*, August 2013. <http://www.statcan.gc.ca/pub/16f0023x/16f0023x2013001-eng.pdf>

McNeill, John Robert. *Something New under the Sun : An Environmental History of the Twentieth-century World*. New York: W.W. Norton & Company, 2000.

Meadows, Donella H., Dennis L. Meadows, Jorgen Randers, and William W. Behrens III. *The Limits to Growth : A Report for the Club of Rome’s Project on the Predicament of Mankind*. New York: Universe Books, 1972.

Moe, Kiel. *Convergence : An Architectural Agenda for Energy*. London: Routledge, 2013.

Mostafavi, Mohsen, and David Leatherbarrow. *On Weathering : The Life of Buildings in Time*. Cambridge, MA: MIT Press, 1993.

“Nutrient Source Specifics: Ammonium Sulfate.” *International Plant Nutrition Institute*, accessed October 14, 2016. [http://www.ipni.net/publication/nss.nsf/0/A9E141566F664341852579AF007640CF/\\$FILE/NSS-12%20Ammonium%20Sulfate.pdf](http://www.ipni.net/publication/nss.nsf/0/A9E141566F664341852579AF007640CF/$FILE/NSS-12%20Ammonium%20Sulfate.pdf)

O’Connor, Jennifer. “Survey on actual service lives for North American buildings.” Paper presented at the Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, October 2004. [http://cwc.ca/wp-content/uploads/2013/12/DurabilityService\\_Life\\_E.pdf](http://cwc.ca/wp-content/uploads/2013/12/DurabilityService_Life_E.pdf)

Pfundstein, Margit. *Insulating Materials : Principles, Materials, Applications*. Basel ; Munich: Birkhäuser ; Edition Detail, 2008.

Ponsford, Matthew. “Shigeru Ban: Pritzker winner’s paper palaces could last forever.” *CNN*, November 2, 2015. <http://www.cnn.com/2015/09/29/architecture/shigeru-ban-pritzker-permanent/>

Qun, Zeng. “Focus on Livable Cities : Concern with Harmonic Development - Summary of the Expo 2010 Shanghai China.” *A + U: Architecture and Urbanism* No.478, July 2010: 10-93.

Ridgway, Allison. “Toronto exploring potential bid to host 2025 World Expo.” *Globe and Mail*, January 24, 2016. <http://www.theglobeandmail.com/news/toronto/toronto-exploring-potential-bid-to-host-2025-world-expo/article28367594/>

“ROCKWOOL Sustainability Report 2015.” *Roxul*. accessed December 13, 2016. [http://www.roxul.com/files/RX-NA\\_EN/pdf/Corporate/ROCKWOOL\\_Sustainability-Report\\_2015\\_web.pdf](http://www.roxul.com/files/RX-NA_EN/pdf/Corporate/ROCKWOOL_Sustainability-Report_2015_web.pdf)

Rogers, Robert P. *An Economic History of the American Steel Industry*. London ; New York: Routledge, 2009.

Rowell, Roger M., Bert Kattenbroek, Peter Ratering, Ferry Bongers, Francesco Leicher, and Hal Stebbins. “Production of Dimensionally Stable and Decay Resistant Wood Components Based on Acetylation.” Paper presented at the 11DBMC International Conference on Durability of Building Materials and Components, Istanbul, May 11-14th, 2008. <https://www.accoya.com/wp-content/uploads/2015/06/Roger-Rowell.pdf>

Seelye, Katharine Q. “Boston’s Bid for Summer Olympics Is Terminated.” *New York Times*, July 27, 2015. <http://www.nytimes.com/2015/07/28/sports/olympics/boston-2024-summer-olympics-bid-terminated.html>

Seliger, Günther. *Sustainability in Manufacturing Recovery of Resources in Product and Material Cycles*. Berlin: Springer, 2007.

Shamess, Albert. “Green Demolition Program Update.” City of Vancouver, November 16, 2015. <http://council.vancouver.ca/20151216/documents/cfsc5.pdf>

Shen, Li, and Ernst Worrel. “Plastic Recycling.” In *Handbook of Recycling*, edited by Ernst Worrel and Markus A. Reuter, 179-190. Amsterdam: Elsevier, 2014.

*Bibliography continued*

“Site and Legacy.” *Expo 2020 Dubai*. accessed December 11, 2016. <http://expo2020dubai.ae/content/legacy.aspx>

Slade, Giles. *Made to Break : Technology and Obsolescence in America*. Cambridge, MA: Harvard University Press, 2006.

Smil, Vaclav. *Making the Modern World : Materials and Dematerialization*. Chichester, West Sussex, UK: Wiley, 2014.

Song, Juliet. “The Phenomena of China’s Disposable Buildings.” *Epoch Times*, January 3, 2016. <http://www.theepochtimes.com/n3/1932144-the-phenomena-of-chinas-disposable-buildings/>

“Staff report on Toronto 2015 World Expo Bid.” *TEDCO and Toronto 2015 World Expo Corporation*, May 11, 2006. [urbantoronto.ca/forum/attachments/expo-it001-pdf.51944](http://urbantoronto.ca/forum/attachments/expo-it001-pdf.51944)

Staib, Gerald, Andreas Dörrhöfer and Markus J. Rosenthal. *Components and Systems : Modular Construction : Design, Structure, New Technologies*. Boston: Edition Detail, Institut Für Internationale Architektur-Dokumentation ; Birkhäuser, 2008.

Statistics Canada. *Table 379-0017 - Gross domestic product (GDP) at basic prices, by North American Industry Classification System (NAICS), annual (2007-2013)*, CANSIM (database). accessed: December 5, 2016. <http://www5.statcan.gc.ca/cansim/a26?id=3790017>

Statistics Canada. *Table 379-0029 - Gross domestic product (GDP) at basic prices, by North American Industry Classification System (NAICS), annual (1981-2006)*, CANSIM (database). accessed: December 5, 2016. <http://www5.statcan.gc.ca/cansim/a26?id=3790029>

Steele, Marion. “Section S: Construction and Housing.” *Historical Statistics of Canada*, Statistics Canada, 1983. <http://www.statcan.gc.ca/pub/11-516-x/sections/4057757-eng.htm>

Taleb, Nassim Nicholas. *Antifragile : Things That Gain from Disorder*. New York: Random House, 2012.

“The Private Sector IC&I Waste Management System in Ontario.” *RIS International Ltd.*, January 2005. <http://kelleherenvironmental.com/wp-content/uploads/2012/07/ICIPrivateSectorWasteStudy.pdf>

“The Red List.” *International Living Future Institute*. accessed December 13, 2016. <https://living-future.org/declare/about/red-list/>

“The Wrong Stuff Gets Built... Poorly.” *No Expo 2025*, accessed December 4, 2016. <http://www.noexpo2025.ca/2-the-wrong-stuff-gets-built.html>

Till, Jeremy. *Architecture Depends*. Cambridge, MA: MIT Press, 2009.

Timmer, John. “Bikes, bowling balls, and the delicate balancing act that is modern recycling.” *Ars Technica*, December 7, 2015. <http://arstechnica.com/science/2015/12/recycling-matching-high-tech-materials-science-with-economics-that-work/>

Wainwright, Oliver. “Beach cafe, billionaire’s retreat, wedding marquee: second lives of the Serpentine pavilions.” *The Guardian*, June 16, 2015. <https://www.theguardian.com/artanddesign/2015/jun/16/serpentine-pavilion-second-lives-zaha-hadid-toyo-ito-frank-gehry>

Wainwright, Oliver. “Expo 2015: what does Milan gain by hosting this bloated global extravaganza?” *The Guardian*, May 12, 2015. <https://www.theguardian.com/cities/2015/may/12/expo-2015-what-does-milan-gain-by-hosting-this-bloated-global-extravaganza>

Warren, Kathryn, and Adam Read. “Landfill Mining: Goldmine or Minefield?” *Waste Management World*, November 2, 2014. <https://waste-management-world.com/a/landfill-mining-goldmine-or-minefield>

Wilson, Rob. “Live Fast, Die Young - After the party at Hannover Expo 2000.” *Uncube Magazine* no. 32 (2015). <http://www.uncubemagazine.com/magazine-32-15358283.html#!/page51>

Woolley, Tom. *Building materials, health and indoor air quality: no breathing space?* Abingdon, Oxon ; New York, NY: Routledge, 2016.

“World Expo Canada 2025 Feasibility Study.” *World Expo Canada Bid Corporation*, Toronto, 2016. <http://www.expo2025canada.ca/world-expo-canada-2025-feasibility-study/>

Yeheyis, Muluken, Kasun Hewage, M. Shahria Alam, Cigdem Eskicioglu, and Rehan Sadiq. “An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability.” *Clean Technologies and Environmental Policy* no. 15 (February 2012). DOI: 10.1007/s10098-012-0481-6

Zumthor, Peter, Plinio Bachmann, Karoline Gruber, Ida Gut, Daniel Ott, Max Rigendinger, and Roderick Hönig. *Swiss Sound Box : A Handbook for the Pavilion of the Swiss Confederation at Expo 2000 in Hanover*. Basel ; Boston: Birkhäuser, 2000.



Appendix A

Sources and reasoning behind the building waste projections on page 16 and 17.

The goal of these three diagrams is to illustrate the inertia of waste designed into buildings.

The mass of waste designed into Canadian buildings was derived from construction expenditures collected by Statistics Canada going back to 1896.<sup>1</sup> By controlling for inflation, the floor area constructed each year can be estimated. The volume of waste generated by construction and demolition is based on disposing of 9% of buildings per year for a 110 year lifetime. The first 9% represents construction waste on site, with renovations generating more waste in the following years and an average lifetime of 85 years, as surveyed by Jenniffer O’Connor.<sup>2</sup> Estimated waste volumes were calibrated against a 2013 estimate of 9 million tons of construction and demolition waste created annually in Canada.<sup>3</sup>

Canada disposes of 25 million tons of waste a year, which leaves 16 million tons of non-building waste.<sup>4</sup> Consumer waste was derived from Canada’s gross domestic product. The lifetime of products was estimated at between one year for packaging, one decade for consumer durables, and thirty years for machinery.<sup>5</sup>

1.

Marion Steele, “Section S: Construction and Housing,” *Historical Statistics of Canada*, Statistics Canada, 1983, <http://www.statcan.gc.ca/pub/11-516-x/sections/4057757-eng.htm>

Statistics Canada, *Table 379-0017 - Gross domestic product (GDP) at basic prices, by North American Industry Classification System (NAICS), annual (2007-2013)*, CANSIM (database), accessed December 5, 2016. <http://www5.statcan.gc.ca/cansim/a26?id=3790017>

Statistics Canada, *Table 379-0029 - Gross domestic product (GDP) at basic prices, by North American Industry Classification System (NAICS), annual (1981-2006)*, CANSIM (database), accessed December 5, 2016. <http://www5.statcan.gc.ca/cansim/a26?id=3790029>

2.

Jennifer O’Connor, “Survey on actual service lives for North American buildings,” (paper presented at the Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, October 2004), [http://cwc.ca/wp-content/uploads/2013/12/DurabilityService\\_Life\\_E.pdf](http://cwc.ca/wp-content/uploads/2013/12/DurabilityService_Life_E.pdf)

3.

Muluken Yeheyis et al., “An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability” *Clean Technologies and Environmental Policy* 15 (February 2012), 83. DOI: 10.1007/s10098-012-0481-6

4.

Michele McMillan, “Waste Management Industry Survey: Business and Government Sectors,” *Statistics Canada*, August 2013. 7. <http://www.statcan.gc.ca/pub/16f0023x/16f0023x2013001-eng.pdf>

5.

Vaclav Smil, *Making the Modern World : Materials and Dematerialization* (Chichester, West Sussex, UK: Wiley, 2014), 113.

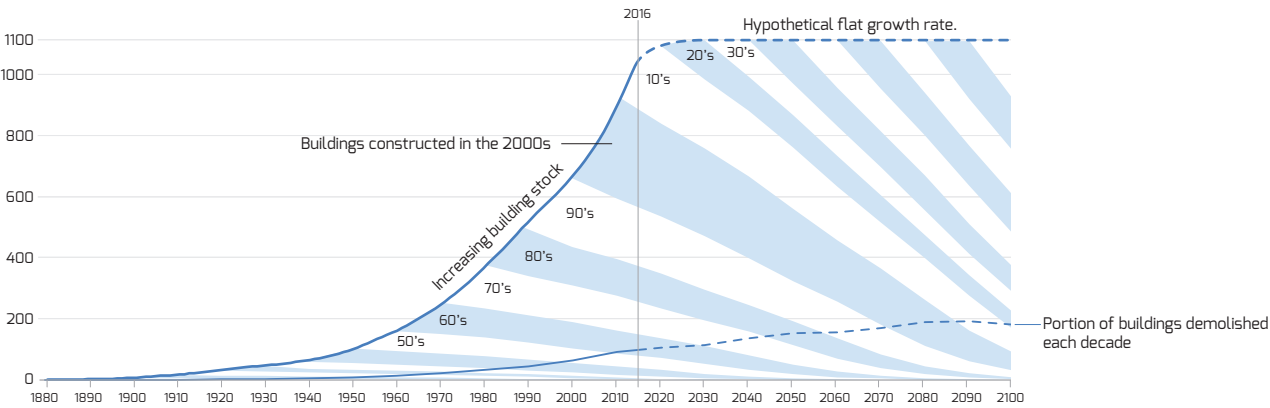


Figure 7.2 Weight of materials in Canada’s buildings by decade and projected into the future. (millions of tons)

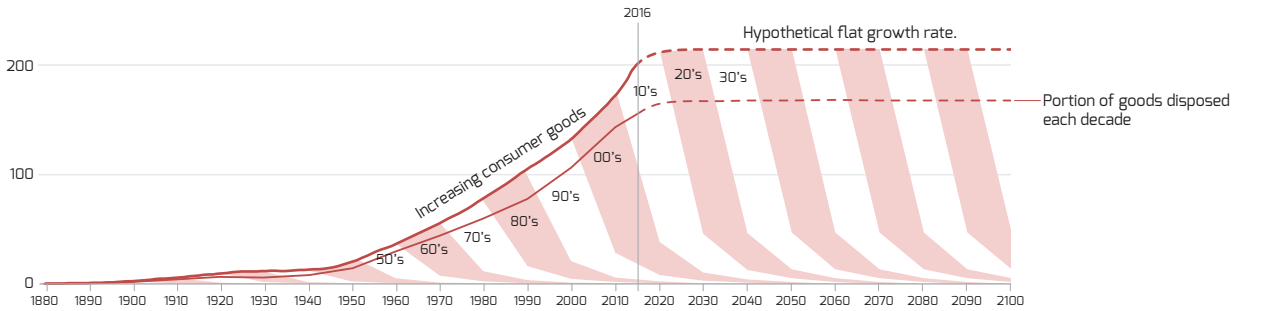


Figure 7.3 Weight of consumer products in Canada, by decade and projected into the future. (millions of tons)

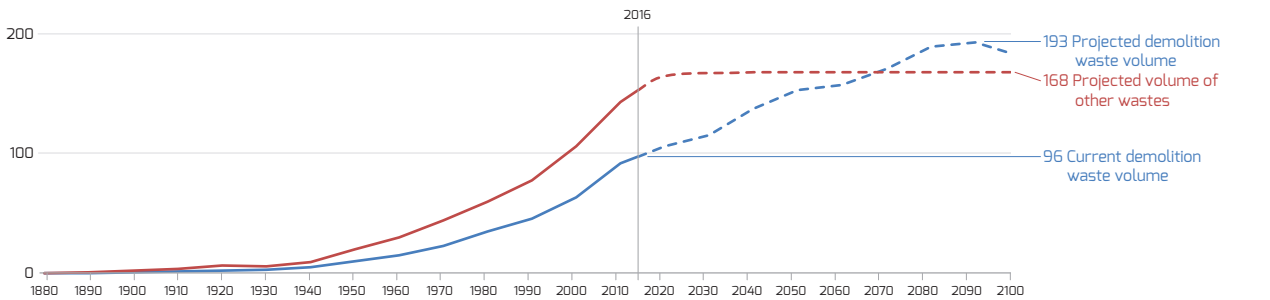


Figure 7.4 Canadian landfill waste projected into the future assuming flat growth. Construction and demolition waste will overtake all other waste sources combined.

Appendix B

Sources for the white-list of building materials.

Material	End of life
<div>Concrete</div> <div>Concrete is commonly reused in bulk as clean fill or ground into aggregate for mixing into new concrete. However the reactive portland cement portion must be replenished with each use. “How Concrete is Recycled,” CDRecyclingAssociation, accessed September 15, 2016, <a href="http://www.cdrecycling.org/how-to-recycle">http://www.cdrecycling.org/how-to-recycle</a></div>	<div>Downcycled</div>
<div>Mortared masonry</div> <div>There is a long tradition of stone and brick reuse, though cleaning mortar off is labour intensive.</div>	<div>Reusable</div>
<div>Glued masonry</div> <div>Plastic adhesives are tenacious, refusing to release from masonry and plugging up surface pores so a subsequent adhesive will not stick.</div>	<div>Inseparable</div>
<div>Toxic glazes, pigments</div> <div>Heavy metal pigments, including chromium, antimony and cadmium are present in some ceramic glazes. Until testing of the glaze can be done, coloured ceramics should be treated as dangerous waste. Bjørn Berge, <i>The Ecology of Building Materials</i> (Oxford ; Boston: Architectural Press, 2000), 324.</div>	<div>Toxic</div>
<div>Steel</div> <div>Aluminum</div> <div>Copper</div> <div>Steel, aluminum, and copper are commonly recycled building materials.</div>	<div>Recyclable</div> <div>Recyclable</div> <div>Recyclable</div>
<div>Stainless steel</div> <div>Galvanized steel</div> <div>Stainless and galvanized steels are recyclable, but with greater environmental damage from chromium and tin fumes. Berge, <i>The Ecology of Building Materials</i>, 80.</div>	<div>Recyclable</div> <div>Recyclable</div>
<div>Lead</div> <div>Mercury</div> <div>Lead and mercury appear on the Living Buildings Red List as materials unsafe for exposure at any level. “The Red List,” <i>International Living Future Institute</i>, accessed December 13, 2016, <a href="https://living-future.org/declare/about/red-list/">https://living-future.org/declare/about/red-list/</a></div>	<div>Toxic heavy metal</div> <div>Toxic heavy metal</div>
<div>Wood</div> <div>Pressure treated lumber</div>	<div>Compostable</div> <div>Toxic arsenic and creosote</div>

Most wood treatments are toxic, and appear on the Red List.	
<div>Polyethylene</div> <div>Polyethylene is one of only two plastics that are widely recycled. Jefferson Hopewell, Robert Dvorak and Edward Kosior, “Plastics recycling: challenges and opportunities,” <i>Philos Trans R Soc Lond B Biol Sci.</i> July 27, 2009; No. 364: 2115–2126. DOI: 10.1098/rstb.2008.0311</div>	<div>Recyclable</div>
<div>Polyvinyl chloride</div> <div>Neoprene</div> <div>Chlorinated plastics</div> <div>Epoxy</div> <div>Formaldehyde glues</div> <div>Many of the most common construction plastics appear on the Living Future Institute’s Red List. The weather resistant properties of chlorinated plastics also make them persistent environmental pollutants. Epoxies are made from the pseudo-hormone bisphenol A, and most construction adhesives contain formaldehyde. “The Red List,” <i>International ...</i></div>	<div>Toxic chlorine</div> <div>Toxic chlorine</div> <div>Toxic chlorine</div> <div>Toxic bisphenol A</div> <div>Toxic</div>
<div>Composites</div> <div>Any materials bonded together are generally un-recyclable as they cannot be separated to make high quality feed-stocks. Composites can sometimes be downcycled. Biodegradable composites are the exception as soil bacteria are happy to compost mixed wastes.</div>	<div>Inseparable</div>
<div>Tyvek (spun polyethylene)</div> <div>Polyethylene film</div> <div>Surprisingly, Tyvek is a mono-material of polyethylene strands. Poly vapour barrier is even more recyclable, as it does not contain any ink for marketing. “Product Handbook for DuPont Tyvek,” Dupont. accessed December 13, 2016. <a href="http://www.dupont.com/content/dam/dupont/products-and-services/fabrics-fibers-and-nonwovens/industrial-fabrics/documents/DPT_Tyvek_Product_Handbook.pdf">http://www.dupont.com/content/dam/dupont/products-and-services/fabrics-fibers-and-nonwovens/industrial-fabrics/documents/DPT_Tyvek_Product_Handbook.pdf</a></div>	<div>Recyclable</div> <div>Recyclable</div>
<div>Cellulose fibres</div> <div>Straw</div> <div>Insulation materials derived from plants are compostable and of low embodied energy. Composting is an especially good end of life for insulation, whose bulk and low weight makes transportation to a recycling site uneconomical.</div>	<div>Compostable</div> <div>Compostable</div>
<div>Rockwool</div> <div>Rock wool is currently recovered in small quantities from consumers for recycling. “ROCKWOOL Sustainability Report 2015,” <i>Roxul</i>, accessed December 13, 2016, 17. <a href="http://www.roxul.com/files/RX-NA_EN/pdf/Corporate/ROCKWOOL_Sustainability-Report_2015_web.pdf">http://www.roxul.com/files/RX-NA_EN/pdf/Corporate/ROCKWOOL_Sustainability-Report_2015_web.pdf</a></div>	<div>Recyclable</div>



<del>Polystyrene foam</del>	<del>Landfilled</del>
Polystyrene and other plastic foams are bulky and difficult to recycle, they contribute significantly to plastic pollution.	
<del>Flat roofing products</del>	<del>Toxic, inseparable</del>
Flat roofing relies on a watertight membrane, which can be toxic PVC or less damaging but no less disposable rubber or tar.	
<del>Painted metal roofs</del>	<del>inseparable</del>
Durable paints for steel may resist peeling outdoors, but that same property makes separation before recycling nearly impossible.	
<del>Caulking</del>	<del>inseparable</del>
The tenacious, grippy properties of a good sealant make it impossible to separate from surfaces at end of life. Caulking may mar substrates, contaminating their recycling process.	
Aluminum and steel frames	Recyclable
<del>Vinyl frames</del>	<del>Toxic chlorine</del>
Metal and wood frames are recyclable, but toxic PVC is the only plastic frame material used for windows.	
Glass	Recyclable
Float glass is readily recyclable, but in practice the low cost of sand makes competing glass scrap uneconomic to transport for recycling.	
<del>Coated glass</del>	<del>inseparable</del>
<del>Laminated glass</del>	<del>inseparable</del>
<del>Tinted glass</del>	<del>inseparable, possibly toxic</del>
<del>“Smart windows”</del>	<del>inseparable, possibly toxic</del>
When assembled into sealed glazing units and doped with mineral tints and electric layers, glass ceases to be recyclable and becomes another complex waste to be shredded and downcycled.	
Berge, <i>The Ecology of Building Materials</i> , 101.	
<del>Plaster</del>	<del>Downcycled</del>
Wet applied materials such as plaster cure irreversibly and can not be recycled in a closed loop.	
<del>Gypsum board</del>	<del>Downcycled</del>
Gypsum board is manufactured from a mix of minerals and additives which cannot be fully separated. A Canadian company accepts gypsum board for paper recovery and grinding the centre into aggregate for new boards.	
“Recycling Process,” <i>New West Gypsum</i> , accessed December 13, 2016. <a href="http://www.nwgypsum.com/our-process/recycling-process/">http://www.nwgypsum.com/our-process/recycling-process/</a>	
Fastened panelling	Recyclable or compostable

Mechanically fastened panels are the logical extension of design for disassembly for interior finishes.	
<del>Tile</del>	<del>Downcycled</del>
Ceramic tiles may be reusable, but they are fragile and cannot be recycled. Coloured tiles may contain toxic pigments and go obsolete as popular styles change.	
Bjørn Berge, <i>The Ecology of Building Materials</i> , 324.	
<del>Concrete flooring</del>	<del>Downcycled</del>
Concrete topping slabs are not recyclable or compostable. They can be recovered for downcycling as aggregate in new concrete production.	
Wood flooring	Sometimes recyclable
Wood is eminently compostable, but many varnishes and sealants are toxic. Non-toxic coating options include wax, soap, plant oils and bare wood.	
Lizanne Dirkx and Pietro Galgani, “Wood Finishing,” <i>WoodGuide.org</i> , accessed September 23, 2016, <a href="http://www.woodguide.org/guides/finishing/">http://www.woodguide.org/guides/finishing/</a>	
<del>Vinyl flooring</del>	<del>Toxic</del>
Plastic flooring is generally un-recyclable due to pigments and fillers, but PVC is toxic as well.	
“The Red List,” <i>International ...</i>	
<del>Fluid applied flooring</del>	<del>inseparable</del>
Wet applied products that cure onto the building are difficult to separate and generally cannot be recycled.	
Carpet	Some are recyclable
Carpet manufacturers are leading the construction industry with life cycle assessments and take back programs, but their products use a mix of different plastics and a rainbow of pigments, making recycling difficult.	
<del>Most paints</del>	<del>inseparable</del>
Thin layers of paint cure chemically and are impossible to recover from substrate materials. At the same time, pigments and plastics in paint may contaminate the substrate, making it un-recyclable.	