Chapter 7.
Conclusions and Recommendations

Summary: Findings of all previous chapters are summarized and combined, organized by research question. Overall results are discussed for what design teams most value in sustainable design practices, leading to hypotheses for how these results may save time and money for design teams, and how different design practices might be hybridized to improve value. Limitations of the study are discussed, and directions for future research are suggested. Finally, design professionals are invited to apply the insights of this study in their practice.

7.1 Summary of Results by Research Question

As Chapter 1 described, this study was the first to deconstruct sustainable product design practices into their constituent activities and mindsets to characterize them and hypothesize their potential synergies and redundancies. Other studies have identified mindsets in sustainable design practices (Brink et al. 2009a), (Telenko et al. 2008), (Telenko and Seepersad 2010), (Oehlberg et al. 2012), or have deconstructed general engineering design practices into activities (Smith 1998), (Kudrowitz 2010), (Vallet et al. 2013). However, none have done both for sustainable design practices and used the information to recommend hybrid practices to maximize sustainable design effectiveness. Such analysis is important because most designers do not follow design methods to the letter, but opportunistically skip or combine components from various methods (Homans 1949), (Pahl et al. 1999), (Cross 2001), (Jensen et al. 2010). As one interviewee said, *"formal design methods are like musical scales; real design practice is jazz."*

This study was also the first to empirically test what activities and mindsets practitioners value within three of these design practices (The Natural Step, Whole System Mapping, and Biomimicry). It did so by providing 29 workshops on these design methods to 520 participants and surveying them. There were 376 survey respondents: 172 professionals from over 30 different companies and 204 Berkeley students, totaling 778 pre- and post-workshop survey responses, due to many people participating in multiple workshops. This approach was new because most literature on sustainable product design either treats all sustainable design the same (Sherwin and Bhamra 1999), (Spangenberg et al. 2010), (Behrisch et al. 2011), (Molenaar et al. 2010), (Cheng et al. 2014), (Bocken et al. 2014), (Keskin et al. 2013), (Storaker et al. 2013), (Anttonen et al. 2013), (Hansen and Große-Dunker 2013), (Kiron et al. 2013) (Hopkins et al. 2009), or proposes a specific new design method and studies it (Ameli et al. 2016), (Wisthoff and DuPont 2016), (Uang and Liu 2013), (Kobayashi 2006), (Ölundh 2006). The empirical testing of what people value exposed the "golden tools" in these green design toolkits; this

enabled hypotheses to be formed suggesting new practices to maximize sustainable design effectiveness.

The specific goals of this study were to answer four overarching research questions (RQs):

- RQ1: What activities & mindsets exist within sustainable design methods, and how do they depend on each other?
- RQ2: What do design teams value in design methods generally?
- RQ3: In these green design methods, which activities & mindsets drive sustainability, innovation, and other value for students?
- RQ4: In these green design methods, which activities & mindsets drive sustainability, innovation, and other value for professionals?

RQ1 was answered by Chapter 2's analyses of fourteen different design practices, from Human-Centered Design (d.school 2013) to green design methods such as The Natural Step (Robèrt 1991), (Baxter et al. 2009), Whole System Mapping (Faludi et al. 2010), (Faludi 2015), and Biomimicry (Benyus 1997), (Baumeister et al. 2013), to certifications such as EPEAT (IEEE 2009) and Cradle to Cradle (MBDC 2012), to design guides such as the Living Principles (Brink et al. 2009b) and Lunar Field Guide (LUNAR 2008). The chapter deconstructed the design practices into their component activities and mindsets, then categorized activities similarly to Roschuni (2015) or Vallet (2013b), and categorized mindsets similarly to Brink (2009), Shedroff (2009), Telenko (2008) and Oehlberg (2012). Results found that for activities, most sustainable design methods were dominated by Analysis activities, while certifications and design guides contained mostly Goal-Setting activities; for mindsets, some design practices contained only Abstract Predetermined Goals while others contained Concrete Predetermined Goals or helped designers set their Own Goals. Design practices with significantly different categories of activities and mindsets are likely to complement each other (e.g., a laptop designer might pull a computer-specific Predetermined Goal mindset from EPEAT Certification to help guide the Goal-Setting or Ideation activities in The Natural Step method). Conversely, design practices with large overlaps in activity or mindset categories may be redundant. Chapter 2 hypothesized that some design practices would be favored by designers, some would be favored by engineers, and some by managers. However, Chapter 6's empirical tests with professionals did not support this hypothesis. Still the breakdown of design practices into their component activities and mindsets, and categorizing the types of each, should help design teams to universally hybridize sustainable design methods to maximize their effectiveness, or to tailor different hybrid practices for different circumstances.

RQ2, "What do design teams value in design methods generally?" set the background for design workshops, and was answered by Chapter 3's interviews with professional designers, engineers, managers, and sustainable design educators. Practitioners valued a wide range of design practices; some were valued highly by all interviewees, such as Human-Centered Design and its components, but highly-valued sustainable design practices, such as Green Goals / Strategies (any eco-design outcomes such as recyclability, energy efficiency, material use reduction, non-toxic materials, etc.), LCA (Guinée 2002), the Cradle to Cradle book (McDonough and

Braungart 2002), and others were only valued by interviewees with sustainability experience. This emphasized the specialized nature of sustainable design, implying design teams wishing to practice it should learn sustainability-specific skills, not merely use standard design practices while thinking green thoughts. Design practices were most often valued for the results they provided; in addition, some were valued for providing a new lens in approaching problems, focusing or clarifying thought, broadening scope, collaboration, and other benefits more specific to particular practices, such as LCA helping to balance tradeoffs. Some design practices were valued for both sustainability and innovation: systems thinking (any generic reference to thinking at the system level), The Natural Step, Whole System Mapping, and Natural Capitalism / Factor Ten Engineering (Hawken et al. 2013), (Lovins et al. 2010); possibly also the Cradle to Cradle book and Biomimicry. Multiple respondents mentioned the value of combining green design practices with both each other and traditional design practices (*"none of those frameworks are complete and they all have to be augmented."*) Such statements reinforced the purpose of this study.

The interviews described in the chapter also investigated how practitioners define innovation, what possible business values of sustainability might be, who can drive sustainability in their companies, and overall the major drivers of sustainability in the companies represented. The results caused the research plan of quantifying innovation to be abandoned as unpromising (it proved both difficult and low-value or zero-value to practitioners); however, the interviews provided encouraging results for the other questions. Possible business values of sustainability were cost savings and marketability, a result that was more extreme but similar to those found in other studies (Hahn and Scheermesser 2006), (Brønn and Vidaver-Cohen 2009), (Windolph et al. 2014). For who could best lead sustainability, there was not widespread agreement, similar to disagreement in the literature (Epstein and Buhovac 2014), (Chick and Micklethwaite 2011), but the most convincing arguments suggested that both designers and managers / executives (as well as clients, for consultancies) needed to work together, with designers providing creative solutions and practical implementations, but managers or clients giving designers the time and resources they need to pursue such improvements. For overall major drivers of sustainability, interviewees did not agree enough for statistical significance, but often-mentioned were arguing the business case for sustainability and changing company culture, which other studies have also found to be primary drivers for sustainability in companies (Lozano 2015), (Post and Altma 1994).

RQ3, "In these green design methods, which activities & mindsets drive sustainability, innovation, and other value for students?" was answered by Chapter 5's workshops with students performing The Natural Step, Whole System Mapping, and Biomimicry design methods. As hypothesized, there were "golden tools" in these toolkits—some activities and mindsets were valued far more than others. The Draw System Map activity from Whole System Mapping was by far the most often valued from any design method, even beyond its reported value for innovation or sustainability. Many valued it for the general design process benefits of focusing / organizing thought and broadening scope. Biomimicry's Discover Model Strategies Online ("AskNature.org") and Nature as Mentor were also highly valued, but there was not a statistically significant winner for Biomimicry as there was for Whole System Mapping; similarly for the Natural Step, Backcasting and Creative Solutions were highly valued, but not significantly more than others. The two activities most often mentioned for innovation were

Biomimicry's AskNature.org and Whole System Mapping's Brainstorm to Eliminate Steps; surprisingly, the latter was also the most mentioned for driving sustainability. The Natural Step's Four System Conditions mindset was most often criticized, with students calling it hard to understand. The primary criticism for all activities / mindsets of all design methods was being unactionable; this is a common industry criticism of all sustainability practices.

In addition to these specific activities and mindsets being valued, some whole categories of activities and mindsets were valued differently: Research and Ideation activities were valued more for innovation, while Goal-setting and Analysis activities were valued more for sustainability; however, the difference was smaller than expected, especially for Ideation activities, which were valued as highly for sustainability as Goal-Setting or Analysis activities. Popularity of ideation activities for not just innovation but also sustainability may explain why, in the author's experience, so many people believe that thinking about sustainability while brainstorming is all that is needed for sustainable design.

RQ4, "In these green design methods, which activities & mindsets drive sustainability, innovation, and other value for professionals?" was answered by Chapter 6's workshops with professional design teams performing workshops on the same design methods as students. Again as hypothesized, there were "golden tools" in these toolkits: Backcasting in The Natural Step, Draw System Map in Whole Systems Mapping, and a combination of Nature as Mentor and AskNature.org in Biomimicry. Backcasting was valued largely for the strategic benefit of focusing thought to accomplish goals, and providing a new lens. Draw System Map was valued for broadening scope, visually showing the larger system, and aiding collaboration. Nature as Mentor was valued as a new lens to approach problems, and for being inspiring. AskNature.org was valued for providing new ideas and for being interesting / engaging. AskNature.org was the most valued for innovation of all activities or mindsets of all three design methods. Ideation activities from the other design methods also scored well (The Natural Step's Creative Solutions and Whole System Mapping's Brainstorm All System Nodes), but The Natural Step's Awareness / Vision and Whole System Mapping's Draw System Map also scored well for innovation, because participants said they were so valuable for framing the later ideation activities. For sustainability value, no activity or mindset was statistically significantly more valued than others, but LCA scored highly. Most practices from The Natural Step and Whole System Mapping scored well for sustainability, but no practices from Biomimicry did so. Post-workshop interviews immediately after workshops and follow-up interviews three to eight months after workshops verified these and the other conclusions.

Neither Backcasting nor Draw System Map were remarkably high for either sustainability or innovation; this implied their values (accomplishing goals, broadening scope, collaboration, etc.) were primarily for overall design process. This is encouraging, as it implies these green design methods could provide business value to design teams beyond sustainability. In fact, one followup interviewee described using Draw System Map for managing cost rather than environmental impacts. Such motivators are important, since interviews suggested that building the business case for sustainability would be a major driver for design teams pursuing green design—much more important than providing innovation.

7.1.1 Comparing Student and Professional Results

Professionals overall agreed with students about which activities and mindsets were most valued. However, there were differences—professionals were much more united in their favorite design practices, and many more professionals valued practices for sustainability than students. For professionals' united choice of golden tools, they statistically significantly valued Nature as Mentor and AskNature.org most in Biomimicry, while students did not have a clear winner. Similarly, for The Natural Step, students also lacked a clear favorite, while professionals by far valued Backcasting most. In Whole System Mapping, students and professionals agreed on Draw System Map being by far the most valued practice. When more professionals valued these design practices than students, they generally described valuing them for reasons similar to students; it may be that professionals' experience made them place more value on those same reasons.

For sustainability, professionals valued LCA more highly than students, perhaps because those receiving four-hour workshops received a more in-depth LCA activity than students received; participants valued it for the same reasons non-workshop interviewees highly valued LCA: for helping set sustainability priorities and balance tradeoffs. For innovation, professionals most highly valued AskNature.org (more highly than any other activity or mindset in any of the design methods); while it was also popular with students for innovation, professionals listed it significantly more often.

Again surprisingly, both students and professionals valued some ideation activities (The Natural Step's Creative Solutions and Whole System Mapping's Brainstorm All System Nodes) as often for sustainability as they valued other activities and mindsets whose whole purpose is to drive sustainability (such as the Natural Step's Four System Conditions, or Whole System Mapping's Decide). Qualitative analysis suggests this was because ideation activities are where sustainability become concrete, as teams generate possible solutions. Ideation acitvities were, however, rated more highly for innovation than analysis and goal-setting activities, as expected. The only exception was Draw System Map from Whole System Mapping, which for professionals was within confidence intervals of Brainstorm on System Map. It may have been valued for innovation because of it broadening the scope of the later brainstorm.

7.2 Overall Results: Golden Tools for Green Design

Combining the results of all four research questions above, the “golden tools” (activities and mindsets that were most valued) were The Natural Step’s Backcasting, Whole System Mapping’s Draw System Map, and Biomimicry’s AskNature.org and general idea of Nature as Mentor. Presumably other golden tools exist within the ten other green design methods, certifications, and guides analyzed in Chapter 2 but not workshopped, as well as other green design practices not studied here.

Surprisingly, these golden tools were close to universal. Analysis by demographic divisions of both students and professionals found almost no significant differences for any findings in any of the three design methods. Chapter 2's hypothesis that engineers, designers, and managers would value different design methods was disproved. For professionals, the demographic divisions tested were job role, company type, company size, industry sector, and gender. For students, the demographic divisions tested were major, industry sector, and gender. Sample sizes were limited, so these results had high uncertainties, but if differences exist, they are subtle. Even software teams in student populations did not show statistically significantly different values or criticisms than other industry sectors, despite researcher concerns that the design methods taught were intended for physical products only. The most significant demographic difference was that few professional engineers rated Biomimicry useful for sustainability, though professional designers, managers, and sustainability strategists, as well as all students, valued it for sustainability roughly as much as the other design methods. (Professionals at consultancies shared engineers' skepticism of Biomimicry for sustainability compared to manufacturers, but this is likely due to the high demographic overlap between engineers and consultancies in the population sampled.) Another statistically significant difference was that participants receiving the four-hour version of Whole System Mapping valued its LCA activity more, because the longer workshop allowed a qualitatively different activity that provided more analytical depth. Overall, despite proving Chapter 2's hypothesis wrong, this lack of demographic differences is encouraging, because it suggests there is no need to teach different sustainable design methods by demographic, or to hybridize sustainable design practices differently by demographic. Individual responses varied greatly, so different individuals will tailor design practices to themselves, but when teaching and promoting green design methods, a universal approach can be taken, much as Design Thinking is taught as a universal tool.

7.2.1 Saving Time and Money with Golden Tools

Finding these golden tools in green design practices may help designers, engineers, managers, and students of product development to optimize their sustainable design process by spending time on the most valuable activities and mindsets, while eliminating time spent on less-valuable practices, or spending only as much time as is needed to support the high-value practices. For example, those without time to perform all activities in the Biomimicry method might only use AskNature.org, since it does not depend on any other activities, or spend much more time on it than other activities. For Whole System Mapping, practitioners might perform only Draw System Map and Brainstorm on System Map, without LCA, which was criticized for being time-consuming. For The Natural Step, Backcasting is the combination of four activities in sequence, thus all activities should be used together, but they could be used with other mindsets to guide them, since the Four System Conditions was sometimes criticized. These should not be considered canonical recommendations, but suggestions to aid the critical thinking of design professionals in their own choices.

Such time and money savings may help mainstream sustainable design practice, by reducing its cost in the design process and increasing its effectiveness. These are important motivators because, as mentioned above, interviews suggested that building the business case for sustainability is much more important than providing innovation.

7.2.2 Hybridizing Green Design Practices

Besides some design practices being more valued than others, this research examined how different design activities and mindsets have different purposes; thus design practices could be hybridized to create better design methods. Many interviewees described their own practice this way (*"none of those frameworks are complete and they all have to be augmented"*). Chapter 2 categorized design activities by research, analysis, ideation, building, communicating, decision-making, and goal-setting; it also categorized design mindsets by systems thinking, checklists, prioritizing, determining own goals, and predetermined goals (environmental, social, abstract, and concrete). In addition, post-workshop surveys and interviews found participants valued different activities and mindsets for different reasons, such as broadening scope, focusing thought, providing a new lens, etc.

Some suggestions for hybridizing design methods based on the golden tools in this study's empirical results, plus the theoretical analysis of Chapter 2, include the following:

- The Natural Step's Backcasting could be used without the Four System Conditions, replacing it instead with a set of concrete predetermined goals, such as EPEAT or Cradle to Cradle Certification, or design guides such as the Living Principles or Lunar Field Guide. This could also be thought of as supplementing any green design guide or certification with Backcasting to help achieve the listed goals.

- For teams with more time and skill, The Natural Step's Four System Conditions could be replaced with an activity to determine and prioritize one's own goals, such as LCA and Priorities from Whole System Mapping, or D4S's SWOT Matrix, Development Capacity Questionnaire, Identify D4S Drivers, and other analysis activities.

- Biomimicry's AskNature.org activity could help drive innovation in any green design method, since it was so often valued for innovation. For example, it could be used during the other method's ideation activity, or used to ideate solutions to goals set by design guides and certifications that contain no ideation activity of their own.

- Engineers wishing to improve Biomimicry's sustainability value could combine it with LCA to provide quantitative environmental prioritization of what problems to solve, and scoring of new design ideas.

- Whole System Mapping's LCA activity could be replaced by a set of concrete predetermined goals, such as EPEAT or Cradle to Cradle Certification, or design guides such as the Living Principles or Lunar Field Guide. These would be faster and require less expertise than LCA, though they might be of less help setting priorities for Brainstorm on System Map.

- Whole System Mapping's Draw System Map activity could help drive systems thinking in any green design method, since it was so often valued for broadening scope and being visual.

For example, it could be used as the basis to apply 12 Leverage Points, Factor Ten Engineering, the Cradle to Cradle book, or others, to make the system in question more concrete and wholly visible.

Again, these should not be considered canonical recommendations, but suggestions to aid mindful design professionals in their own choices. As one interviewee said, *"Each designer has their own special tool belt or toolkit that they'd like to carry with them to every project."* Further research should ask sustainable design experts for their recommended combinations of practices, and empirically test combinations of practices like these.

7.3 Limitations

As mentioned in the previous chapters, readers should not generalize the results of this study, because design practitioners' values and criticisms differ by context, and this study only accessed a limited set of contexts. Limitations of recruitment meant sample sizes were relatively small, especially for interviews, and especially when divided by demographics. Limitations of staffing meant all workshops and interviews were performed by this author. Another limitation is self-reporting of value, including sustainability and innovation value. In addition, workshops are artificial; how design methods are used in situ in companies' product development processes will differ. Future studies could address all of these limitations.

7.4 Directions for Future Research

Given the limitations above, future research should test more practitioners in more industries and different countries, with different instructors and other context changes to test generalizability of results. The ten sustainable design methods, certifications, and guides analyzed in Chapter 2 but not tested empirically should be tested as The Natural Step, Whole System Mapping, and Biomimicry were in Chapters 5 and 6. To overcome limitations of participants self-reporting sustainability and innovation value, future studies should have third parties rate the sustainability and innovation of workshop ideas to validate participants' self-perceptions. To overcome the artificiality of workshops, studies should test design practices in situ in companies as they integrate them into product development processes, or study the successes and failures of companies who have already integrated them into product development. Obviously, future studies should test the variations of design practices hypothesized in the sections above, "Saving Time and Money with Golden Tools" and "Hybridizing Green Design Practices", to test whether they actually maximize value to design teams, and how their results differ. Expert practitioners could also be interviewed for their recommendations on such hybridization, and those suggestions could be tested empirically.

In addition to future research optimizing sustainable design practices, future research should also investigate how these design practices can prove the business value of sustainability, how design

practices can drive company cultures toward sustainability, and/or what green design practices are easiest for various company cultures to adopt. Since the ten follow-up interviews found almost no product ideas or design practices from the workshops were still used several months later, despite all interviewees being enthusiastic about the workshops, future research should investigate what drives adoption of sustainable design practices, integrating this work into the larger literature of organizational change for sustainability. Effective green design methods are important, but are not the only requirement to drive the complex systems of industrial production towards sustainability.

7.5 Conclusion

Finding the golden tools in green design methods—the practices most valued by professionals—can help optimize design practices for sustainability, innovation, and other business value, just as user testing of prototypes helps optimize product designs. We who are designers, engineers, or product managers, are the people who create the material world we live in, and who shape our material culture. Thus, we carry a great share of the power and responsibility to make the world more healthy, abundant, equitable, and beautiful. Let us use these insights, along with others, to create and spread better design practices to build a better world.