

THE LIMITATIONS OF LEED: A CASE STUDY

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INTRODUCTION

The Xanterra houses are situated against the backdrop of one of America's most spectacular natural landscapes, just a few hundred yards from the north entrance to Yellowstone National Park. The project consists of two single-family homes for seasonal workers, approximately 2000 square feet each. They are mirrored east-to-west but otherwise identical (see Figure 1). The project was completed in 2003, and certified under LEED-NC v2.0, project #1353 on December 10, 2004—the first building project in the National Park system to receive LEED (Leadership in Energy and Environmental Design) certification from the USGBC (United States Green Building Council).¹

The houses were built with the explicit intent that they would become a model for future green building projects at Yellowstone and other national parks,² and the project team felt it was fitting that these houses be situated in the nation's first national park. Indeed, they were fundamentally well-designed and constructed, and they incorporated some of the latest technologies for saving energy and water, authentically earning the label "high-performance." Yet the project only earned the lowest possible rating ("certified") from LEED, meaning it is barely considered green. This paper documents the green design strategies through the design and construction process, with special attention paid to the influence of the LEED scorecard on collaborative decision-making and to the difficulties this project encountered during the LEED assessment process. Few academic studies have examined the process of LEED self-reporting and scoring within a professional setting,³ even though contingencies such as common business practices and human limitations clearly affect a project's LEED score.

This paper will show that the LEED scorecard turned out to be a poor assessment tool in this case study, because the reporting procedure inaccurately reflected the architectural design and construction. Furthermore, there have been a few important papers that conclude that a major problem of the LEED rating method is its failure to account for the building's performance over its projected life.⁴ This paper will verify those conclusions by showing that the lifespan of concrete construction was not considered by the LEED rating process.

The larger questions that stimulated this research are consistent with the problems that have motivated the current widespread interest in green design strategies: How can we design buildings that consume less energy? How can we use materials and construction practices more responsibly in terms of reducing pollution and waste? How should we evaluate our own practices to understand their true efficacy? These questions are particularly urgent for the American homebuilding industry, which has become increasingly extravagant and has lost sight of green design strategies in the design of its dwellings⁵ (and increasingly wasteful in energy consumption). Since the Xanterra houses were consciously developed as a positive alternative to typical homebuilding practices, an analysis of their performance—from design through assessment—may have implications for future projects of a similar type.

KEYWORDS

LEED, energy modeling, insulated concrete, passive solar heating, construction waste management

THE PROJECT

The principal members of the design team included Erik Hendrickson, an engineer for the National Park Service who functioned essentially as the client's representative. The actual commissioning agency was Xanterra Parks & Resorts, a pri-

vate company that holds a renewable license to operate hospitality services inside Yellowstone. The lead architect was Mark Headley of Overland Partners (Bozeman, Montana). Lastly, the client and architect agreed to retain a LEED consultant⁶ for the project: Dr. Kath Williams, one of the world's lead-

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Note: The authors are not affiliated with the project or project team.

FIGURE 1. Xanterra houses, view from south. (Photo: A. Denzer)



ing authorities in this area. She had recently completed seven years as vice-chair of the U.S. Green Building Council, and indeed she had been instrumental in developing the LEED system itself. Xanterra set the parameters for the houses' performance as "at least 40% more energy-efficient than a standard home."⁷ Hendrickson, an engineer and a sustainability enthusiast, took a more active role than a typical client's representative. He determined some of the major materials and systems selections, and enforced the 40% standard.

As the design process progressed (see below), and the pragmatic problem of balancing mass and glass became a primary concern, the personal experiences of some of the design team members were directly engaged. Both the client Hendrickson and the architect Headley had suffered the effects of overglazing and undermassing. According to Hendrickson, Headley had built his own passive solar house, which was 100% glazed on the south elevation but lacking thermal mass; it routinely overheated even in winter in Montana's cold climate. Hendrickson had a similar experience during childhood when he lived in an all-glass "House of Tomorrow" that had been designed by architect George Keck for the 1933 Chicago World's Fair.⁸ Keck claimed he discovered the possibilities of solar heat by accident; the tradesmen working inside in the dead of winter had to remove their coats because of the heat gain. The same overheating problem existed when Hendrickson lived in the house in the 1970s.⁹

SITE DESIGN ISSUES

Gardiner, Montana, located at 45° latitude, is a cold mountain climate with 7560 annual heating degree days. These characteristics suggested the need for a super-insulated building envelope. Due to its elevation of 5300 feet, high annual sun hours, and high atmospheric clearness numbers, the site also provided excellent conditions for passive solar heating, active solar power generation, and daylighting. The half-acre site also included a considerable north-facing slope—certainly

not an ideal condition for saving energy in a cold climate—which resulted in above-grade garage floors and north-facing walk-out basements (see Figures 2 & 3).

The specific building site was considered contaminated because it was formerly used as a fuel transfer station; it contained abandoned industrial tanks and other material (see Figure 4). Of course, *site repair* is one of the most fundamental and consequential aspects of sustainable development, as described by Christopher Alexander in *A Pattern Language*.

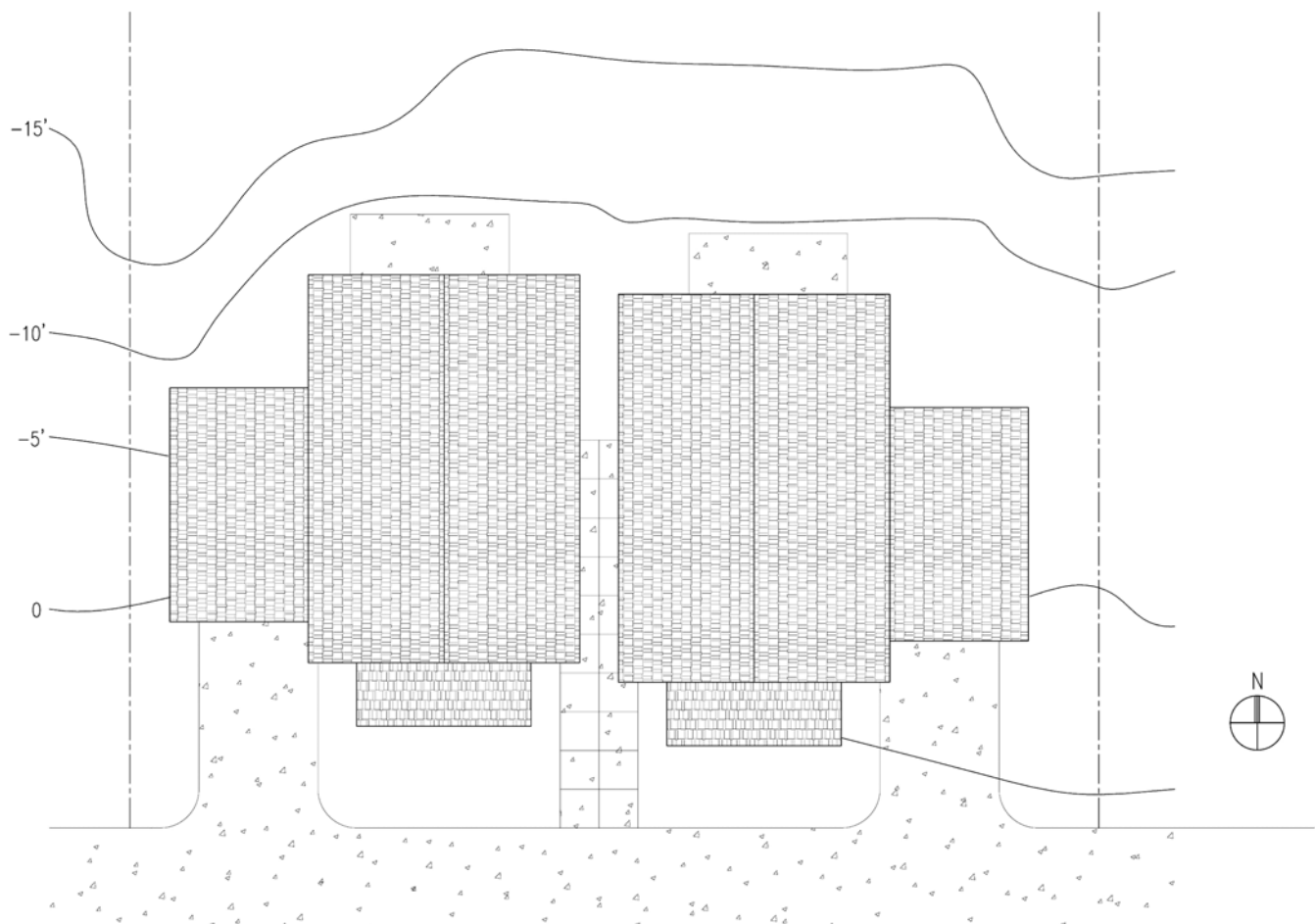
On no account place buildings in the places which are most beautiful. In fact, do the opposite. Consider the site and its buildings as a single living eco-system. Leave those areas that are the most precious, beautiful, conformable, and healthy as they are, and build new structures in those parts of the site which are least pleasant now.¹⁰

In the larger context of Yellowstone and its environs, the choice of a contaminated former industrial site in the town of Gardiner was clearly motivated by this notion of building on the worst part of the "place." Furthermore, the site was selected with the LEED scorecard in mind; Brownfield development and remediation of site contamination has been rewarded by LEED in all versions since its inception.

THE DESIGN PROCESS

The most significant aspect of the Xanterra houses' design in terms of energy efficiency is their super-insulated envelopes. From the outset, the design team narrowed their options to structural insulated panels (SIPs) and insulated concrete forms (ICFs), and there emerged a strong internal dispute between these two systems, with the architects favoring SIPs and Hendrickson the Park Service engineer insisting on insulated concrete for its mass. According to Hendrickson, who admired the use of thermal mass in ancient Native American dwellings in the Rocky Mountain region:

FIGURE 2. Site Plan. (Drawing: A. Denzer)



I regarded SIP panels as simply good insulation. Insulation is indeed a good thing, but our nation had been using good insulation since the 70s, and I felt strongly that insulation was not significant enough for a “leadership” house. I felt that LEED offered us an opportunity to incorporate thermal mass. . . . I was convinced that ICF was a superior system, and more appropriate for demonstrating leadership in sustainable design.¹¹

As the client’s representative, Hendrickson won the debate, and the homes were constructed with a wall system of 6” thick concrete walls, with an outside layer of 4-1/4” expanded polystyrene (EPS) and an inside layer 2-1/4” thick, providing an overall insulation value of R53 (see Figure 5).¹² By comparison, the 2003 International Energy Conservation Code (IECC) required R18.4 for mass walls in residential buildings in this climate zone.

Clearly the Xanterra houses demonstrate the benefits of insulated concrete construction. In general, energy modeling shows that a house with ICF walls of R15 will use 5.5 to 8.5% less heating and cooling energy than a house with conventionally wood-framed walls of R10.6.¹³ A typical ICF wall is

FIGURE 3. View from north-east showing sloped site. (Photo: A. Denzer)



FIGURE 4. Site conditions before project. (Photo: Erik Hendrickson)



FIGURE 5. ICF wall construction. (Photo: Erik Hendrickson)



FIGURE 6. ICF wall construction and SIP roof construction. (Photo: Erik Hendrickson)



rated much higher than R15, and will perform even higher than its rating.¹⁴ The use of ICF for residential construction in the United States is relatively small but growing rapidly. As of 2008, the technology accounted for 6% of residential construction nationwide, up from only 0.2 % in 1995, according to the Insulating Concrete Form Association. A barrier to the broad acceptance of ICF is economic. Using ICF rather than wood framing for above-grade walls will add 7.2 to 8.4% of the construction cost of a home, according to the National Association of Homebuilders' Research Center.¹⁵

Although SIPs were rejected for the wall system, they were a logical choice for roof construction (see Figure 6), and this decision contributed greatly to the high performance of the building envelope. These particular panels were constructed of oriented strand board (OSB) and 12-inch foam insulation, resulting in a roof that offered an insulation value of R45 versus the R30 required by IECC. In addition, the panels omitted the need for an attic, allowing additional ceiling height and increased daylighting on the upper level.

The architecture also sought to incorporate passive heating design, but interestingly, not to maximize it. Many solar homes mistakenly use too much glass and too little thermal storage, according to a leading reference book that the project team consulted.¹⁶ Both the client Hendrickson and the architect Headley had personal experience with overglazing and undermassing, as described above. Paradoxically, though, one of the major features that would come to aesthetically characterize the Xanterra houses was the sunspace (see Figures 7 & 8), a technique specifically not recommended in the literature.¹⁷ Again this suggests that the design process was not prescriptive, but instead marked by negotiation and compromise. Moreover, the sunspace was under-designed according to typical rules of thumb. It includes 53.44 square feet of glazing for a floor area of 85 square feet, resulting in a ratio of 0.629. The recommended ratio for a cold climate is 0.90-1.50 square feet of glazing per square foot of floor area.¹⁸ Perhaps in an effort to store more heat, the concrete slab floor of the sunspace was built 12-inches thick (see Figures 8 & 10), although the Sustainable Buildings Industry Council advises that any slab thickness above six inches has little effect on storage.¹⁹

The glazing design was considerably more sophisticated than in a typical American residence. Standard window technology is double pane, low-e glass, which, although good at helping hold heat inside a house, does not do a particularly good job of allowing radiant solar heat to enter. For passive solar architecture, it is critical to admit adequate solar gain, and so the architect's original design called for clear glass on the south windows. The design team then located a product with low emissivity and a high solar heat gain coefficient (SHGC) of 0.65. In order to mitigate the problem of excessive heat gain in the summer, the architects designed south-facing shades and overhangs according to typical passive-solar methodology with dimensions appropriate to the specific latitude (see Figure 9).

But the project team found that the practices of the American window industry created a significant barrier to those

FIGURE 7. Ground Floor Plan. (Drawing: A. Denzer)

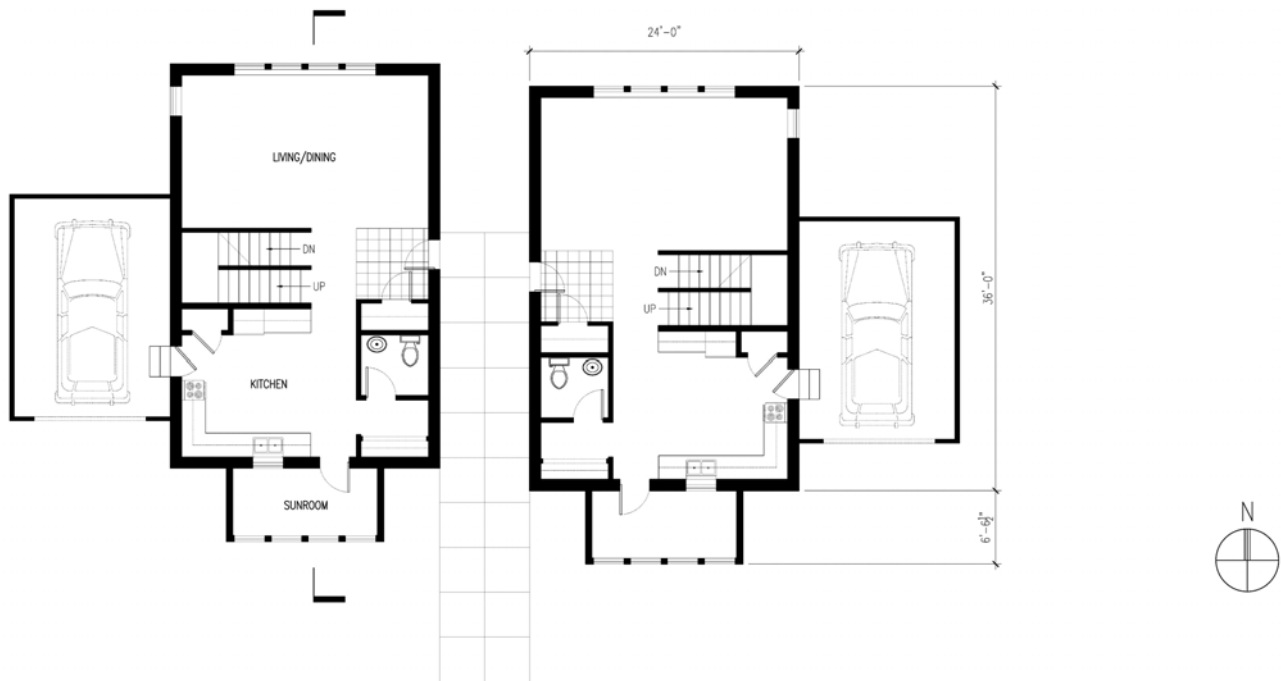


FIGURE 8. Section. (Drawing: A. Denzer)

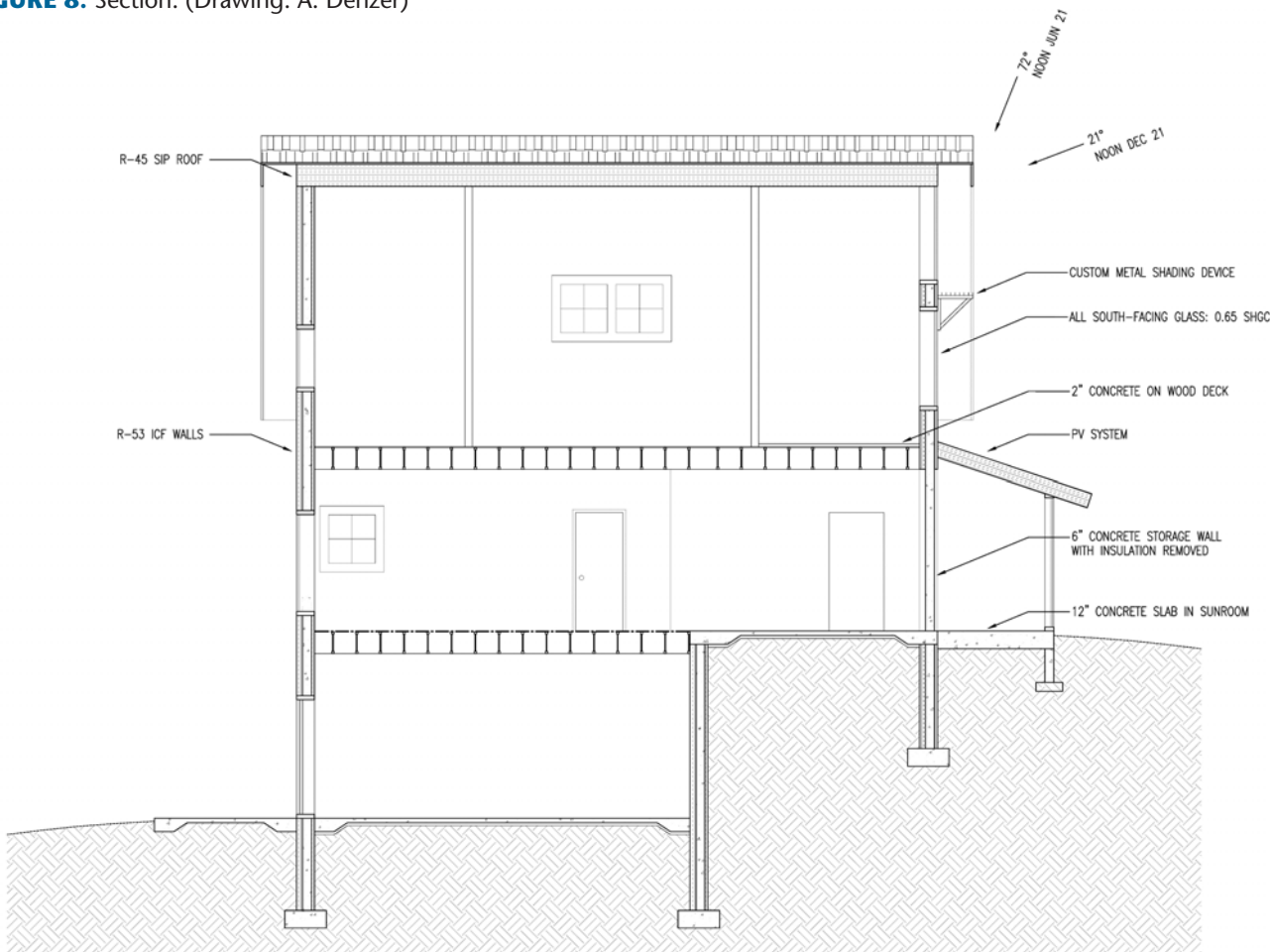


FIGURE 9. South windows showing shading at summer midday. (Photo: A. Denzer)



homebuilders interested in pursuing passive solar heating. At the time of construction, low-e glass with a high SHGC was labeled “northern glass” by the industry since it was recommended for northern climates. But Xanterra’s design team found this contradictory since it is best applied on the southern elevation. (Indeed since they planned to put “northern glass” on the south side, the window order was mishandled.) The major glass companies in America generally recommend using the same glazing on all elevations of a house, because they assume that homebuilders and consumers will be confused if attempting to pick special glazing for just the south windows.

Many other green features were incorporated into the houses in order to achieve LEED points. Photovoltaics (PV) were installed on the south-facing roofs of the sunspaces; the heating system incorporated an energy-recovery ventilator (ERV); dual-flush toilets were employed to reduce water consumption. Hendrickson would later come to question the appropriateness of these “gadgets” as these imply an after-thought rather than a holistic green design strategy. In this respect, the Xanterra houses reflect a larger trend in green building that Ted Shelton has described: “the superficial attachment of ‘green’ items . . . become signs announcing the building’s good intentions.”²⁰

THE CONSTRUCTION PROCESS AND PROJECT COSTS

The houses were built by Martel Construction (Bozeman, Montana), which specialized in commercial construction. The builders had not built with ICF before, and had no prior experience with LEED. One problem encountered during construction serves to illustrate the importance of effective communication between the designers and the builder, particularly when the builder may be unfamiliar with principles of sustainable construction. In this case the wall between the sunspace and the main body of the house was constructed of ICF, which would have tended to insulate the sunspace, keeping it hot and depriving the rest of the house of the benefits of the solar gain. Since a sunspace is only effective if its heat can be transferred laterally to the adjoining structure, Hendrickson argued correctly that it would be beneficial to remove the rigid foam insulation from this interior mass wall. The wall would become a thermal storage unit, collecting heat from the sunspace during the day and radiating it to the rest of the house at night. However, he had such difficulty convincing the builders of the importance of this detail that Hendrickson was compelled to conduct a “stealth” operation to remove the styrofoam formwork after hours, leaving a bare concrete wall 6-inches thick (see Figure 10).

The project was also notable for its aggressive recycling of construction waste, which is a major goal of the LEED system. Kath Williams developed a Construction Waste Management Plan for the project and worked with the builder to implement it. To obtain the maximum number of credits under the LEED system, at least 75% of construction, demolition, and land-clearing waste must be recycled. Moreover, it is a prerequisite requirement that there must be an area of the construction site dedicated to separation and collection of recyclables. Notably, the general contractor embraced the recycling practices, later employed it on all their projects, and even convinced other contractors to recycle their waste.

A commonly-asked question with regard to green buildings and LEED certification is: what are the added construction costs? Betsy del Monte, a LEED-certified architect, has argued: “There is a common misconception that . . . green buildings . . . are more expensive to construct than traditional buildings, [but] constructing a high-performance facility doesn’t necessarily mean using more costly materials or methods.”²¹ The most thorough scientific research on this subject, conducted for the State of California in 2003, concluded that the average premium for the green buildings that they studied was “slightly less than 2%,” or about \$3–5 per square foot. These costs, the report concluded, were “substantially lower than is commonly perceived.”²²

For the Xanterra houses, the parties involved were hesitant to share the actual project costs, although everyone admitted that the houses were considerably more expensive than typical houses of that size, and far more expensive than the typical housing for Park Service employees. The project most certainly exceeded the 2% premium that the California study

FIGURE 10. Sunspace construction. Note slab thickness at left, removal of wall insulation at right. (Photos: Erik Hendrickson)



has suggested. However, there were a few extraordinary contingencies in this project that triggered additional costs and justified the expense. First, the decontamination of the site, as described above, was unusual and expensive, particularly for residential design. Second, the site was steeply sloped, which offered the architectural advantage of a walk-out basement, but also necessitated the garages to be built above-grade. This undoubtedly led to a significant expenditure relative to slab-on-grade, which is typical for residential garage construction. The third and most important justification for a larger construction budget was the nature of Xanterra's relationship to the National Park Service as mentioned above.

LEED CERTIFICATION PROCESS

LEED is now essentially a self-reporting and self-policing certification process, but at the time this project was certified there was a fairly strong formal review process involving reviewers from the USGBC. Under this system, most of the review materials took the form of a written narrative; the reviewer did not visit the project and did not necessarily review plans or photographs. Thus, the certification depends largely on writing ability, which has frequently been acknowledged as a skill that many architects and engineers lack.²³ Moreover, the USGBC reviewer's judgment on any given point is able to be appealed, which places a further premium on the design team's ability to communicate persuasively. LEED has thus created a new market for professionals who have the ability to communicate and shepherd a project through this reporting and appeals process.

In this case, the LEED reporting paperwork was assigned to an intern architect, and some of the senior members of the design team never saw the final USGBC submittal.²⁴ In fact, there were several mistakes made during the reporting process. Despite the copious attention to the performance of the building envelope, the houses failed to get the proper number

of LEED credits for Optimizing Energy Performance. This category requires that a mathematical energy model be developed in order to analyze the building's theoretical performance compared to a "base case" of the same type and size. When a third-party energy model was commissioned, the modeler mistakenly used an insulated concrete envelope and southern orientation for the prescriptive house as well as the Xanterra houses. Even with the higher standard of comparison, the project received seven out of ten possible points for Optimizing Energy Performance because the model showed reduced energy costs of 42%. Hendrickson later showed that, if the base case had been modeled as a typical house according to ASHRAE 90.2, the Xanterra houses would have performed significantly better, likely earning all ten LEED credits for Optimizing Energy Performance.

Moreover, the Xanterra houses did not get full LEED credits for Construction Waste Management because the recycling process was documented incorrectly. In essence, an intern architect given responsibility for sending in the USGBC materials did not properly distinguish between *excavated material* and *land-clearing debris*. As a result, the project was improperly punished for not having recycled two large concrete cradles that, decades prior had held fuel tanks on the site.

Similarly, the project was denied a credit for Brownfield Redevelopment because of improper reporting, or the failure to make a persuasive argument, despite the fact that it clearly satisfied the sustainability goal of site repair. And the project received only one of three possible points for Renewable Energy, indicating that 5–10% of the buildings' energy use was supplied through the use of on-site renewable energy systems, when in fact the PV system produces 40–50% of the homes' electricity.²⁵ Other LEED credits were relatively easy to achieve and to document, but had little to do with architectural design or the sustainable characteristics of the building. For example, one point was earned in Alternative Transportation for providing bicycle storage in the garages.

The Xanterra houses received 30 out of a possible 69 points, qualifying it as LEED certified,²⁶ but it is clear that if the LEED reporting had been accurately and persuasively completed, the project should have received at least 38 points, enough for a silver medal and one point away from gold (although the client was satisfied with the certified rating).

DISCUSSION AND CONCLUSION

This study has several implications for future research and practice. One clear conclusion is that the (2004-era) process for LEED self-reporting was too complex for inexperienced and untrained personnel. (We are not suggesting that this is a problem USGBC should address.) Also the numerous third-party documentation problems (energy model, brownfield, construction recycling) lead us to conclude that LEED adds significant additional coordination and communication challenges for the project team (versus a non-LEED project). Perhaps most significantly, this case study suggests that LEED requires a difficult learning curve for clients and architects and difficult choices about trade-offs during the design process. In this case, the project team did not anticipate the significant added expense of energy modeling (approximately \$16,000), which would certainly discourage LEED certification for smaller projects.

The project's rating also suffered, to some degree, because LEED v2.0 did not consider life-cycle analysis or the usable life of a building, as Bunz, Henze, and Tiller noted.²⁷ (LEED 2009 introduced a credit-weighting system that incorporates life-cycle assessment by using the TRACI environmental impact categories developed by the U.S. Environmental Protection Agency. Still LEED does not directly reward buildings with an extended life span.) In this case, the ICF system employed by the Xanterra houses is assumed to have a longer projected life span than that of a conventional wood frame, a feature worthy of credit.

Then and now, the LEED system only recognizes positive sustainable elements and does not penalize for inappropriate use of non-sustainable design. The LEED scorecard gives a single point for positive achievement in each category and zero points for its absence. Since there is no method for losing points, neutral and negative performance are equivalent. So, at this time, if a project scored well enough in other areas, a building may contain vinyl products, have no recycled materials, have ozone depleting refrigerants, and still be rewarded with LEED certification and perceived as green. By contrast, the Japanese system (CASBEE) uses a five-point assessment scale for each category, and a score of level 3 indicates "average" performance.²⁸ Japanese buildings can therefore lose points due to negative performance in any given category. Taken together, the narrow perspective of sustainability based on positive scoring plus the failure to account for useful building life undoubtedly leads to an inadequate measure of true sustainability.

The Xanterra houses demonstrate yet another limitation of the LEED rating system: actual energy use is not required

to be measured and verified. (And hypothetical performance may be calculated in error, as shown above.) If LEED wishes to be a rigorous instrument of assessment, rather than a public-relations tool, why not require an actual performance measurement as a prerequisite to certification? In light of the fact that a hypothetical performance evaluation may cost approximately \$16,000 and the LEED process overall typically adds about \$40,000–50,000 to the project's bottom line,²⁹ it would seem difficult to argue that cost would be a prohibitive factor. Perhaps LEED should require a validation phase, where electricity, gas, and water usage are evaluated after one year of use. (LEED 2009 does offer 3 points for Measurement and Verification in EA Credit 5, and LEED 2012 may include additional verification measures.)

Different members of the Xanterra project team ultimately formed different opinions about the process of working within the LEED system. Jim Hanna, Xanterra's director of environmental affairs, remarked: "The good thing about LEED is that it gives you a comprehensive checklist of options. You get to choose. It is not a rigid standard that tells what you must do. You pick the ones you want to do. If you earn enough points, they will certify your project."³⁰ But Erik Hendrickson, the Park Service engineer, became rather disillusioned with the LEED system as a result of this project. He remained incredulous that the project received no points for ICF construction (because of the faulty energy model) yet did receive a point for the bicycle hooks. In Hendrickson's view, "LEED rewards 'gizmo' ideas and building practices" but does not emphasize strongly enough the fundamental principles of sustainable residential construction: solar orientation, super-insulated envelope design, and thermal mass. This highlights how green design and LEED procedures may be conflated concepts. Virtually all of the popular literature related to LEED is positive in nature and meant to endorse the system, and only a few academic studies address green architecture from a critical cultural perspective.³¹ Further work is needed to examine LEED's true effectiveness as a tool for measuring sustainability versus its (genuine) importance as a public relations tool.

Aside from the many critiques of the LEED system that arise from this research, this case study finally indicates that scoring and reporting in a collaborative professional environment is a contingent measure, rather than a definitive one. Any of the problems encountered here—a faulty third-party energy model, a contractor inexperienced in sustainable construction and its documentation, an intern architect given overwhelming responsibilities and perhaps lacking writing ability, no internal procedure for appealing the decisions of the LEED reviewer—are probably generalizable to many other examples of green architecture. Given these contingencies, how accurate should we regard LEED ratings? This question may loom particularly large for future historians assessing those early examples when the LEED process was unfamiliar. This single case shows a margin of error of at least 26% between the certified LEED score and the credits authentically earned. By extension, some examples of green architecture may be greener than we think.

NOTES

1. The LEED Rating System for Homes was introduced in September 2005.
2. Jim Hanna, Xanterra's director of environmental affairs, quoted in Carole McMichael, "LEEDing Yellowstone to a 'Greener' Future," *Concrete Homes* (January 2005).
3. Courtney France, "How to Successfully Implement LEED: Documentation Challenges and Solutions," *Journal of Green Building* 2, no. 4 (Fall 2007): 3–13.
4. Bunz, Henze, and Tiller, for example, emphasized that LEED and other systems do not quantify a building's life span. Kimberly R. Bunz, Gregor P. Henze, and Dale K. Tiller, "Survey of Sustainable Building Design Practices in North America, Europe, and Asia," *Journal of Architectural Engineering* (March 2006): 33–62. Furthermore, Trusty and Horst have concluded that life cycle assessment (LCA) techniques and LCA-based decision support tools should be better integrated in whole building rating and certification systems. Wayne B. Trusty and Scot Horst, "Integrating LCA Tools in Green Building Rating Systems," *ATHENA Sustainable Materials Institute* (2002). http://www.athenasmi.ca/publications/docs/LCA_Tool_Integr_Paper.pdf.
5. "Since 1950, the average new house has increased by 1,247 square feet. Meanwhile, the average household has shrunk by 1 person." See "This New House," *Mother Jones* (March/April 2005), 26–27.
6. In the United States, a "LEED Accredited Professional" (LEED-AP), is an emerging specialization of its own, since every project seeking to have official certification is required to have a LEED-AP on its design team, and most architects and engineers do not have this designation. Anyone is eligible to become a LEED-AP, regardless of education or professional experience, as long as he or she passes the exam. Indeed, Dr. Williams is an excellent example of this new field of practice since she is not trained as an architect or engineer, yet she was selected for this project due to her intimate knowledge of the LEED system.
7. Hanna, quoted in McMichael, *op. cit.*
8. See "The House of Tomorrow: America's First Glass House," in H. Ward Jandl, et al., *Yesterday's Houses of Tomorrow: Innovative American Homes 1850–1950* (Washington D.C.: Preservation Press), 1991, 127–139.
9. Erik Hendrickson, Project Engineer, National Park Service, "Building LEED Certified Houses in Yellowstone," manuscript provided by the author.
10. Christopher Alexander, et. al., *A Pattern Language: Towns, Buildings, Construction* (New York: Oxford University Press), 1977, 508.
11. Hendrickson, "Building LEED Certified Houses in Yellowstone," *op. cit.*
12. The ICF system was from Quad-Lock Building Systems Ltd. Hendrickson computed the value of R53.2, based on a given value of R38 with a factor of 1.4 applied, based on the principle that "the 'equivalent' R-value of insulated concrete walls can be significantly greater than the static R-value customarily used in energy analysis," according to Jan Kosny, et. al., "Energy Benefits of Application of Massive Walls in Residential Buildings." *ASTM, Performance of Exterior Envelopes of Whole Buildings VIII: Integration of Building Envelopes*, session IX-A. (2001).
13. Thomas W. Petrie, et. al., "How Insulating Concrete Form vs. Conventional Construction of Exterior Walls Affects Whole Building Energy Consumption: Results from a Field Study and Simulation of Side-by-Side Houses." *Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings* (2002).
14. See note 13.
15. "Concrete Homes Versus Wood Frame Homes – Installed Cost, Acoustic, and Thermal Performance," RP123, Portland Cement Association (1999).
16. "Overglazing and undermassing a home, common problems of the past, can cause severe overheating. Pay attention to the glass-to-mass ratio to achieve optimum comfort." Daniel D. Chiras, *The Solar House: Passive Heating and Cooling* (White River Junction, VT: Chelsea Green Publishing Co.), 2002, 110.
17. "In many cases, sunspaces provide their own heat, but not enough to be of great benefit to the rest of the house. Another significant problem is that it is often difficult to transfer heat generated inside a sunspace to neighboring rooms. Heat doesn't flow laterally very well." Chiras, *op. cit.*, 125.
18. Steven Winter Associates, *The Passive Solar Design and Construction Handbook* (Emmaus, PA: Rodale Press), 1983, 131.
19. Chiras, *op. cit.*, 104.
20. Ted Shelton, "Frugality and Robustness: Negotiating Economy and Ecology in Architecture," *Journal of Green Building* 2, no. 1 (Winter 2007): 109.
21. Betsy del Monte, "Counting the Costs of Going Green," (November 2005), <http://www.gostructural.com/article.asp?id=315>.
22. Greg Kats, et. al., "The Costs and Financial Benefits of Green Buildings," *California Sustainable Building Task Force* (2003).
23. See, for example, Dana Cuff and Elizabeth Robertson "Words and Images: The Alchemy of Communication." *Journal of Architectural Education* 36, no.2 (1982): 8–15.
24. It is fair to assume that many other projects of this type are managed in a similar fashion, where the responsibility for LEED documentation is given to an inexperienced designer who is enthusiastic and, from a business perspective, inexpensive. A very interesting scientific study of LEED projects could be constructed to document the average experience of the documenter versus the average experience of the architect-in-charge.
25. 40% was stated in McMichael, *op. cit.*; 50% was stated in Hendrickson interview, *op. cit.*
26. The project was certified under LEED-NC v2.0, project #1353, December 10, 2004. 26–32 points were required for "certified" status; 33–38 for silver; 39–51 for gold; and 52–69 for platinum.
27. Kimberly R. Bunz, Gregor P. Henze, and Dale K. Tiller, "Survey of Sustainable Building Design Practices in North America, Europe, and Asia," *Journal of Architectural Engineering* (March 2006): 61.
28. See <http://www.ibec.or.jp/CASBEE/english/method2E.htm>.
29. Information from Jim Cox, AIA, LEED-AP, Architecture Plus, Fort Collins, CO, October 17, 2006.
30. Hanna, quoted in McMichael, *op. cit.*
31. Sheila J. Bosch, "Green Architecture: Symbolic Sustainability or Deep Green Design," Technical report, *Sustainable Facilities and Infrastructure Program* (December 2000), <http://maven.gtri.gatech.edu/sfil/resources/pdf/TR/Symbolic%20sustainability.pdf>.