Leveraging streamlined building life cycle assessment and machine learning to determine critical and flexible building design parameters

The CSHub-developed **Building Attribute to Impact Algorithm (BAIA)** allows building designers to understand which design attributes will ultimately have the most significant environmental and economic impacts during the building's life including the *use phase*, which comprises the operation of the building throughout its life. The use phase is a dominant source of environmental impacts for most buildings in the U.S. today.

- BAIA, which takes less time and uses less data than traditional methods, makes it possible for designers to identify key influential factors and make changes earlier in the design process when decisions can have a bigger impact.

Life cycle assessment (LCA) is a method that building practitioners can use to analyze the environmental performance of a proposed building design. CSHub surveys of building practitioners have shown that LCA tools are not widely used because traditional methods are time-consuming, require burdensome data collection, and are poorly integrated with the design process.

BAIA was originally designed to calculate environmental impacts, but recent updates allow users to understand financial impacts of decisions as well, including incorporation of **life cycle cost assessment (LCCA**) modeling that accounts for material and labor costs for components already included in the environmental impact calculations.

- Costs include the foundation, exterior walls, windows, interior walls, floors, ceiling, and roof, but exclude interior finishes, appliances, electrical/lighting systems, and plumbing.
- Also included in the costs are an estimate of the HVAC system cost and the estimated cost of energy consumption over the lifetime of the building, taking fuel type (electricity or gas) and price variations by state into account.

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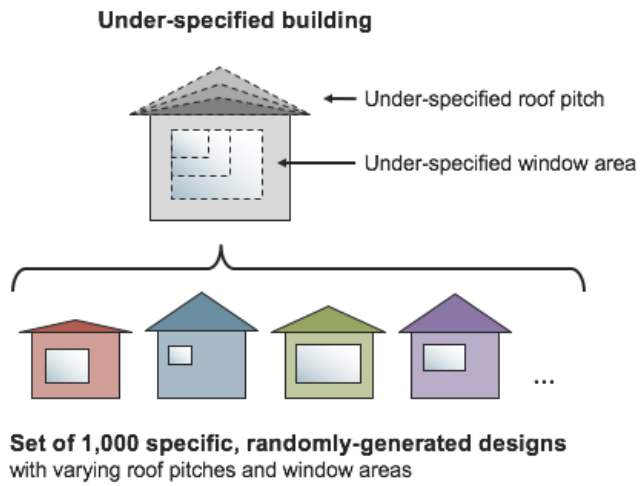
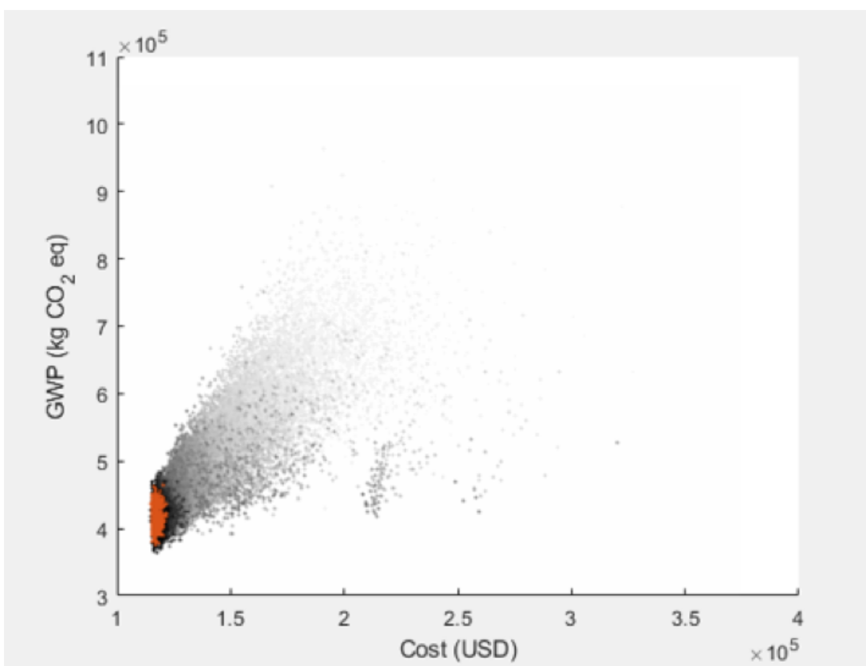
The updated optimization method uses a **genetic optimization algorithm,** inspired by natural selection, which is designed to identify a near optimum, or *quasi-optimum,* design. It can be used to define which aspects are flexible and which aspects are critical to determining the cost and environmental impacts of the building.

The algorithm starts with a random set of designs (within ranges set by the user). Through an automated process, the program samples thousands of possible designs before picking a subset with the lowest BAIA-calculated costs and impacts to use as "parents" for calculating impacts in the next generation.



- Each design in the following generation is created by combining random design parameters from two randomly-selected parents.
- BAIA learns from each generation and the optimization continues until the average impacts and costs have similar values for several consecutive generations, suggesting a design approach.
- The process also balances trade-offs between environmental impacts (i.e., global warming potential) and costs, so that the suggested approach incorporates consideration for both factors.
- The tool expresses results by defining the range of values for a parameter in the optimum and near-optimum sets of designs. Parameters with a wide range of values are flexible, whereas those with a narrow range are critical.



Lighter dots represent early generations
Darker dots represent later generations that have improved on their "parents"
Orange dots are the final (optimized) generation (lowest cost and impacts)
GWP = global warming potential (a climate change metric)

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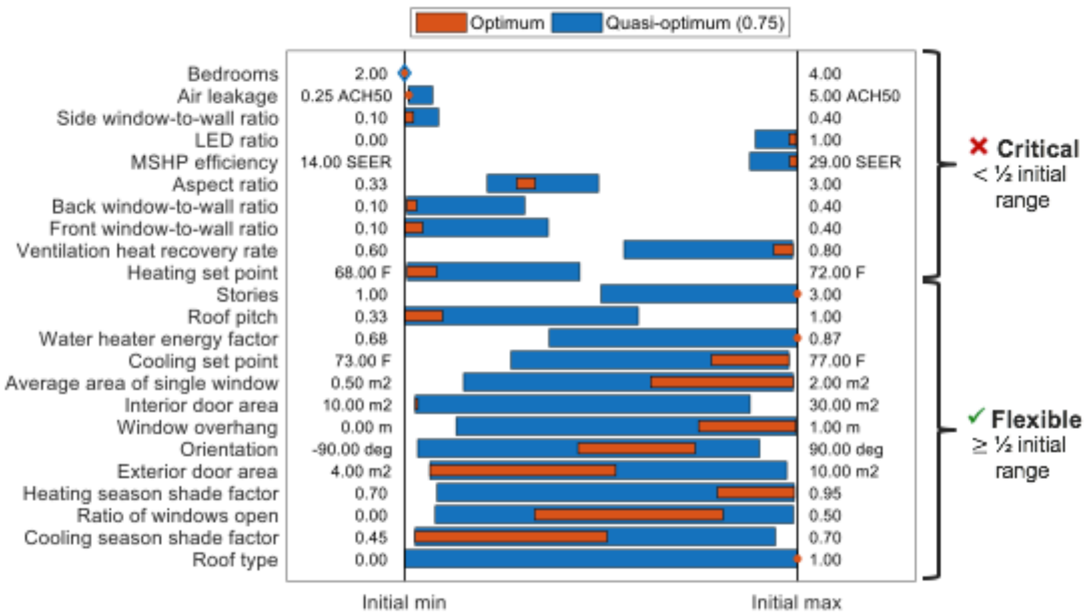
By exploring methods for identifying quasi-optimum solutions for building design guidance, CSHub researchers are adding a new dimension to LCA-based design optimization. The team's current work examines single family homes, but this method of analysis may also be useful for the design of other complex products in the future.

Case Studies

Researchers used the BAIA genetic optimization algorithm approach to identify a range of near optimal, high-performance designs for a series of case studies using a baseline design of a 2,400 square-foot single family residential building in Chicago. Parameters explored include the impacts of changes in climate, analysis period, environmental impacts of energy generation, and weighting of costs compared to environmental impacts.



Larger blue bar indicates more flexibility gained

- Researchers found that quasi-optimum designs (those representing at least a 75% reduction in life-cycle impacts and costs from the initial generation) can be associated with a 40% increase in flexibility over the optimum design (meaning a larger range of options for a given parameter).
- For example, optimum designs all had an air leakage of 0.25 ACH50 and quasi-optimum designs had a range that extended only slightly higher, so that parameter is considered critical because the range of values in quasi-optimum designs was similar to optimum designs.
- By contrast, the water heater energy factor was 0.87 in all optimum designs, whereas the range of acceptable values in quasi-optimum designs was over half of the initial range allowable in the analysis (0.68-0.87). Thus, the water heater energy factor is quite flexible.

Researchers also noted that flexibility is influenced by contextual parameters such as climate. In addition to the case studies conducted using Chicago, a cold climate, researchers also studied the impact of design decisions for similar structures in San Francisco (mild climate), and Phoenix (hot climate).

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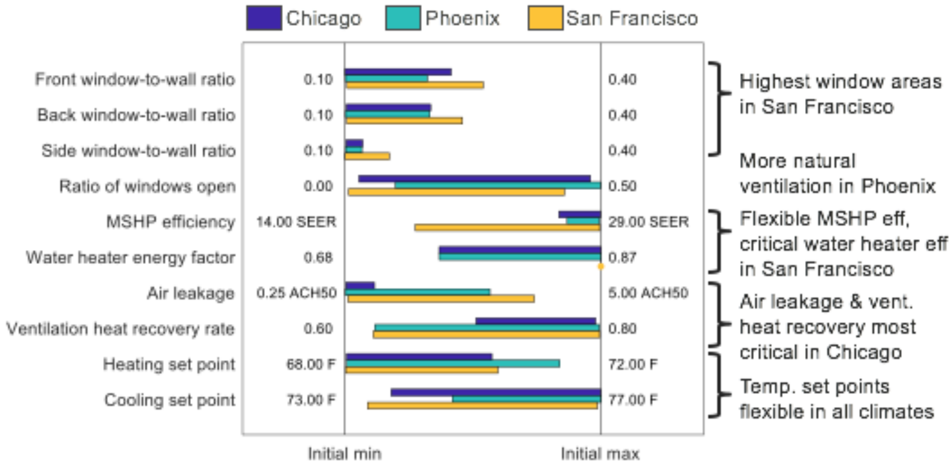

For other factors, they observed lowered flexibility with:

- Longer analysis periods, because the algorithm seeks and encourages higher-performing designs
- Higher energy-related environmental impact factor variability, because the design must be more conservative to account for uncertainty in use-phase impacts.
- Higher weights of environmental impacts over costs in the genetic optimization, due to the added emphasis on reducing energy consumption beyond what is required to minimize costs.

The building aspect ratio and window-to-wall ratio proved to be critical factors in lowering impacts, while seven other factors (including orientation, number of stories, and window overhangs) were flexible in all cases. Most occupant-related attributes (including window shading and natural ventilation) were also flexible in all cases. Among the systems-related attributes, mini-split heat pump efficiency, air leakage, and ratio of LED lighting fixtures were critical in most or all cases.

Additional information may be found at: http://cshub.mit.edu/

Publications

- Hester, J., Gregory, J., Ulm, F.J., Kirchain, R. "Building design-space exploration through quasi-optimization of life cycle impacts and costs" *Building and Environment*, Volume 144, 15 October 2018, Pages 34-44.
- Tecchio, P., Gregory, J., Ghattas, R., and Kirchain, R. "Structured Under-Specification of Life Cycle Impact Assessment Data for Building Assemblies" *Journal of Industrial Ecology* (2018).
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- Rodrigues, C., Kirchain, R., Freire, F., Gregory, J. "Streamlined environmental and cost life-cycle approach for building thermal retrofits: A case of residential buildings in South European climates" *Journal of Cleaner Production*, Volume 172, 20 January 2018, Pages 2625-2635 (2018).
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