Value-Driven Design Process: A Systematic Decision-Making Framework Considering Different Attribute Preferences From Multiple Stakeholders

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In general, architectural design is a loosely structured, open-ended activity that includes problem definition, representation, performance evaluation, and decision making. A number of approaches have been proposed in the literature to organize, guide, and facilitate the design process. The main objective of this paper is to seek a logical and rigorous means to aid in developing an optimized design that is acceptable to the customer or user of the product. The convention design approaches heavily involve decision making, which is integral to the architectural design process and is an important element in nearly all phases of design. There is a need to reframe the decision-making process to transform and improve the design process in order for finial building to achieve the performance goals. The first step in making an effective design decision is to understand the stakeholders' and team players' (architect, engineer, client, and consultant) different preferences based on their needs, experiences, and expectations of the project. In this paper, we first provide an overview about conventional decision-making method and process, identify the existing attributes that contribute to decision making in design, and outline the obstacles present in making optimized sustainable design decisions due to the uncertainty of different stakeholders' preferences. Then, we present one case study to identify and compare different preferences among engineering students, practicing architects, and the general public, and we analyze how the three groups attribute different weight to the major design attributes. This paper provides some novel insights into a value-driven sustainable design process, and it will be one of the building blocks for creating a framework to integrate game theory into the design decision-making process, considering multiple stakeholders' perspectives and preferences for building attributes as future research tasks. [DOI: 10.1115/1.4035059]

Introduction

Design is a process involving constant decision making. In the architectural design context, the role of decision making can be defined in several ways. The decision process is influenced by sets of conditions or contexts; some are controllable, such as the business context, and some are given and uncontrollable, such as market demand and users' preferences. The business context represents the long-term view of the developer/owner and is, in general, largely in the control of the developer/owner. Decisions such as capital investments, project programs, building performance goal, and marketing strategy are determined by the developer/owner. In a high-performance building design/construction case, the owner will have control over whether to pursue sustainable design objectives, such as receiving the Leadership in Energy and Environmental Design (LEED) or ENERGY STAR label. However, some aspects of business contexts, such as market share (which is influenced by competing design products), are somewhat uncontrollable. Correctly assessing the context for making a decision is important because it dictates the level of effort and long-term impact of the design decisions. Decisions with long-term impacts often are irreversible after implementation: Therefore, the decision maker must seriously analyze the context and impact of alternatives before arriving at a decision. For sustainable design, decisions that will have long-term impact are typically made in the early design stage by the design teams led by architects, engineers, developers, or owners. Understanding and proposing an effective design-making framework is essential to achieve sustainability.

In this paper, we define design decision making as the process of identifying and choosing an optimal alternative from a set of possible options. Various methods are commonly used to aid designers in decision making, such as the use of a decision matrix or a decision tree and quality function deployment. These methods are generally ad hoc and incorporate relatively high levels of subjective judgment, or so-called designer's intuition. An additional set of methods addresses variability, quality, and uncertainty in the design process, such as the Taguchi method [1] and Six Sigma [2]. These tools are more analytical and are typically coupled to the processes used to produce products. Design theories also exist, such as Suh's axiomatic design [3], which are less widely used but offer more rigorous analytical bases. Finally, certain other methods are used primarily in the fields of management science and economics, such as utility and game theory, which are being explored in the current research for feasibility and applicability to support decision making in design, mostly engineer and product design. Traditionally, architectural design has been viewed as intuitive or part of the subconscious thinking process. The methods mentioned above have not been applied to the real architectural design process, nor have they been studied and tested.

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The rest of the paper is organized as follows. "Existing Attributes and Obstacles" section defines the problem and lists the existing attributes to decision making in design and obstacles. "A Case Study" section provides a case study comparing preferences from three groups of users. "Conclusion and Future Research Directions" section concludes and provides some future research directions.

Existing Attributes and Obstacles

The traditional design and delivery method include design bid build, multiprime' construction management at risk, and design build [4]. The design of a building involves multiple stakeholders, such as designers (architectures and engineers), developers, members of the finance sector, regulators, contractors, manufacturers, and occupants. It also involves several main criteria, such as structural adequacy, utilities distribution, convenience, comfort, weather resistance, behavioral functionality, cultural expression and sensitivity, and regulatory compliance. This paper focuses on the following criteria: safety, comfort, sustainability, economics, flexibility, quality, functionality, and esthetics.

In this subsection, we list some existing obstacles in architecture design. Traditional design and delivery approaches contemplate separate silos of responsibility that, in practice, yield inefficiencies whenever there is a hand-off from one silo to another. Additionally, projects delivered traditionally suffer because participant success and project success are not necessarily aligned. Indeed, it is quite possible for one or more project participants to "succeed," even if the overall project fails, and the separate incentives that prevented the optimized design decision can be made based on achieving agreement among different design team members and stakeholders [5]. Tables 1 and 2 illustrate some misalignments of preferences among stakeholders during design and construction, where designers include both architects and engineers.

A Case Study

Architecture design includes various attributes [6]. In order to identify the exact misalignment of multiple team participants' preferences, we designed a case study to model the different participants' preferences using three steps: (1) create a mathematical prediction model; (2) identify the different weight sets of various players by conducting survey 1; (3) conduct a pictorial survey using an existing architectural project online database, and use the model created in step (2) to obtain different scores from various groups; and (4) compare the results and outline the next steps.

Setting. In the case study, we have three major players: practicing architects, engineering students, and the general public. They share the same eight main project concerns/attributes, including economics, safety, functionality, comfort, sustainability, flexibility, quality, and esthetic features of the building. The architects, engineers, and public typically are not aware of each other's priorities, preferences, and definitions of success at the beginning of the project. The case study aims to help us model and predict the preferences of each group.

We adopted a quantitative approach by using a multi-attribute utility function to represent each player's attribute utilities and values. We assumed that the utility of each attributes is additive independence. Hence, we applied an additive utility function $U(x_1, \ldots, x_6) = \sum_{i=1}^{6} w_i U_i(x_i)$ where $w_i \geq 0$ are the weights satisfying $\sum_{i=1}^{6} w_i = 1$. Then, we transferred the ordinal ranks into cardinal weight.

Step 1: Mathematic Model. The first step is to create a mathematical model. We created a small dataset using an existing online architectural project library. In Eq. (1), X_i is one of the existing designs in our database, Y_{ij} is the value of attribute j in design i, and w_j is the weight of attribute j. Finally, $U(X_j)$ is the utility of the existing design i. By finding the utility of existing designs, we can find the pertinent utility function for each group of participants and predict the behavior of each group according to their utility curve

$$U(X_i) = \sum_j w_j Y_{ij} \tag{1}$$

When considering the client's needs related to the architectural design of a building, we divided the needs into eight main categories. In this way, we attempted to cover the client's needs to the best of our knowledge. The attributes were inspired from Ref. [7]. Their investigation report established a checklist of different needs from which a client's specific requirements can be identified. We adjusted their attributes only for the design phase of the construction process.

Clients' needs. A need is a consumer's desire for a product's or service's specific benefit, which could be functional or emotional. A want is the desire for products or services that are not necessary but that consumers wish for. Clients can have three types of needs: (1) latent needs are needs that customers are not aware of, (2) direct needs are needs that customers tell you about, and (3) assumed needs are internal assumptions about what customers need [8]. In this project, we aimed to discover and measure the clients' wants and needs by designing a questionnaire in an architectural context. Also, we wanted to find the clients' preferences and priority of needs. The results would help architects design more efficiently and achieve greater customer satisfaction. The clients' needs typically are not documented. We considered three different groups—architectures, engineers, and the public—in the case study. We aimed to determine whether differences existed between the utility function of each group.

Step 2: Identify the Weight (Survey 1). The objective of survey 1 is to find w_j from Eq. (1). Thus, the second step is to design and use a questionnaire regarding the building attributes to identify each player's preference. We collected complete data from 15 people in the general public group, 10 people in the engineering students group, and 7 people in the practicing architects group. We classified the attributes into two levels: major attributes and their related subattributes. In total, we defined 41 preference attributes. Also, we asked all survey takers to list other potential attributes that we did not consider. Table 3 represents those attributes. First, we asked them to put their preferences score for each of the major attributes. Next, we defined the subattributes related to the main attributes and asked them to score their priorities for each of the subattributes. In this way, we could identify which attributes held the most importance from the perspectives of

Table 1 Who is incentivized to keep the cost down or reduce the schedule for the owner when changes occur? (source from Ref. [4])

	Owner	Designer	Builder	Trade
Design bid build	Yes	No	No	No
Multiprime (hard bid)	Yes	No	No	No
CM at risk	Yes	No	No	No
Design build	Yes	No	No	No

Table 2 Who is incentivized to improve building performance for the lifecycle (source from Ref. [4])

	Owner	Designer	Builder	Trade
Design bid build	Yes	No	No	No
Multiprime (hard bid)	Yes	No	No	No
CM at risk	Yes	No	No	No
Design build	Yes	No	No	No

different groups. The weights of each attribute (w_j) were computed by taking the average of each attribute, according to the results of survey 1. Then, we normalized the average score of each attribute, by dividing it with the summation of the average score of all attributes

$$w_j = \frac{\text{average score of attribute } j}{\sum_j \text{average score of attribute } j} \quad (2)$$

The main and subattributes' weights are represented in Table 3. The final weights for each attribute are equal to the multiplication of its weight with the weight of the main related attribute. For example, the weight of the attribute "color," according to Table 3, is equal to a product of 0.09 with 0.11.

Comparison of weight results from each of the groups. Figure 1 illustrates that the engineers' priorities regarding the main attributes are, respectively, safety, comfort, quality, and functionality. However, these priorities for architects are totally different (Fig. 2). The first three ranked main attributes, according to architects' opinions, are, respectively, functionality, comfort, and quality of building.

Table 3 Weight of attributes by practicing architects

Attributes		Architects' weights
Esthetic goals	0.11	
Beautiful interior	0.42	0.0478
Beautiful exterior	0.50	0.0573
Beautiful finishes/decorations	0.08	0.0096
Color	0.09	0.0104
Material	0.45	0.0521
Proportion/human scale	0.45	0.0521
Safety	0.11	
Fire egress	0.21	0.0230
Handicap accessibility	0.14	0.0156
Fire protection	0.20	0.0221
Occupant safety and health	0.18	0.0197
Natural hazard and security	0.12	0.0131
Security for occupant and assets	0.16	0.0172
Comfort	0.16	
Humidity	0.12	0.0192
Temperature	0.16	0.0261
Natural ventilations	0.14	0.0227
Daylight and lighting	0.22	0.0349
View	0.18	0.0288
Room size	0.12	0.0192
Convenience	0.07	0.0113
Sustainability	0.14	
Optimizing site potential	0.17	0.0236
Optimizing energy use	0.19	0.0275
Protect and conserve water	0.17	0.0236
Use greener material	0.13	0.0186
Enhance indoor environmental quality	0.19	0.0265
Optimize operational and maintenance practice	0.16	0.0226
Economic	0.09	
To reduce design cost	0.07	0.0057
To reduce construction cost	0.20	0.0171
To reduce planning cost	0.23	0.0200
Maximizing taxation benefit	0.16	0.0143
Price of product to meet a given budget	0.34	0.0299
Flexibility	0.06	
Account for functional needs in future	0.35	0.0205
Ensure appropriate product/system integration	0.27	0.0160
Meet performance objective	0.38	0.0228
Functionality	0.18	
Building to be operationally efficient with intended purpose	0.4	0.0711
Durable building	0.4	0.0711
Keeping existing building operational during construction	0.2	0.0356
Quality	0.15	
Quality of product to match current standards	0.31	0.0459
Innovative design incorporation high/test technology	0.20	0.0287
The building to reflect your activities and image	0.16	0.0229
Value of money, i.e., desired quality at appropriate price	0.33	0.0487

According to the computed weights of the public's preferences (Fig. 3), the most important attributes to this group are, respectively, operational efficiency based on intended purpose, occupant safety and health, and fire protection. These preferences change for the architect group (Figs. 4 and 5). Their top three ranked preferences are operational efficiency based on intended purpose and durability (which tied for first), beautiful exterior (second), and material and proportion/human scale (third).

We conducted ANOVA tests for eight hypothesis tests (for each of the eight attributes, respectively) with null hypotheses being that the mean weight of attribute i is the same across the three groups. For each of the eight tests, F test statistics are all greater than 10, which are higher than the critical value 3.37 (according to F distribution with degrees-of-freedom of 2 and 26, and alpha value of 0.05), which suggests rejecting the null hypothesis. This means that the between group variation is significantly larger than the within group variation, and thus, the results reported in this section are significant.

Step 3: Pictorial Survey (Survey 2). In this step, we used an online architecture library [9] to design a pictorial survey. We have 15 complete survey results. First, we narrowed down the artifact based on the following criteria: houses, built in the U.S., and built in 2015. Second, we selected the top ten rankings of buildings based on the Facebook users' votes. Third, we created a primary score for each selected design based on the following six attributes: beauty, safety, comfort, sustainability, flexibility, and functionality. Fourth, we used the weight from survey 1 to calculate the final score of each building. Finally, we found the utility of these selected projects according to Eq. (1), where Y_{ij} is the value of attribute j in project i. The amount of each Y_{ij} is defined by the pictorial survey. In this way, we identified the utility of each of the selected designs, and we then ranked them according to their utility amount.

From the results of survey 1, we found the related weight for each of the attributes. Thus, we calculated the utility of these selected projects according to the Eq. (1), where Y_{ij} is the value of attribute j in project i. The values for Y_{ij} are obtained from survey 2.

Finally, by finding w_j and Y_{ij}, respectively, from surveys 1 and 2, we determined the utility of each of the selected designs, and we ranked them according to their utility values. We call these utilities weighted ranks as shown in the right part of Table 4.

Results of survey 2. Table 4 summarizes the results of survey 2 and compares them with the data from the ArchDaily website. The first two columns show the number of Facebook likes and corresponding rank for each project. The third column demonstrates the average score ($\bar{Y}_{ij}$) for each project, based on the results of survey 2. The fourth column shows the related ranks for the third column. The fifth column presents the weighted score for each project based on the results of surveys 1 and 2. We defined

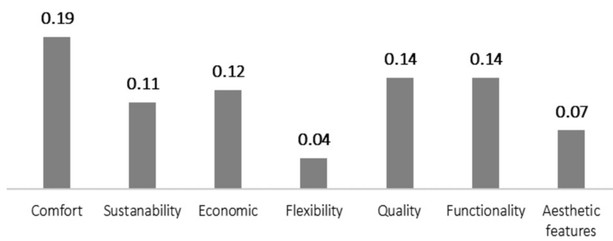

Fig. 1 Weight of general attributes according to engineering students' preferences

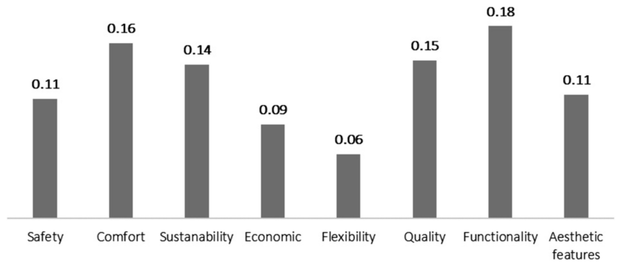

Fig. 2 Weight of general attributes according to practicing architects' preferences

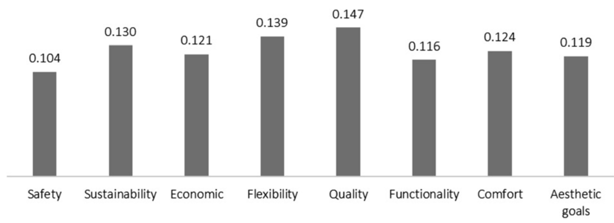

Fig. 3 Weight of general attributes according to public preferences

the weighted scores as a utility for each project. Thus, the values from the fifth column were computed according to Eq. (1), where w_j is the weight of each attribute based on survey 1, and Y_{ij} is the value of attribute j in project i based on survey 2. The sixth column contains the corresponding cardinal ranks for the values of the fifth column. For the fifth column, the weights w_j are for the general public population. The rest of the table presents similar results for the populations of practicing architects and engineering students.

Conclusion and Future Research Directions

Architectural design has been regarded as a service- and design-driven process for hundreds of years. With the recent development of computer design systems and smart-building techniques (e.g., energy simulation and building information modeling), there is a need to study a new performance-based and value-driven design process for architects. Several decision makers and stakeholders are involved in the architecture cycle, including designers, developers, members of the finance sector, regulators, contractors, manufacturers, and end users. Although those decision makers may have different (and often conflicting) perspectives, values, and resources, they often jointly and subconsciously determine the effectiveness and success of the design process through discussion, negotiation, and contracts. (We acknowledge that through those interaction processes, the

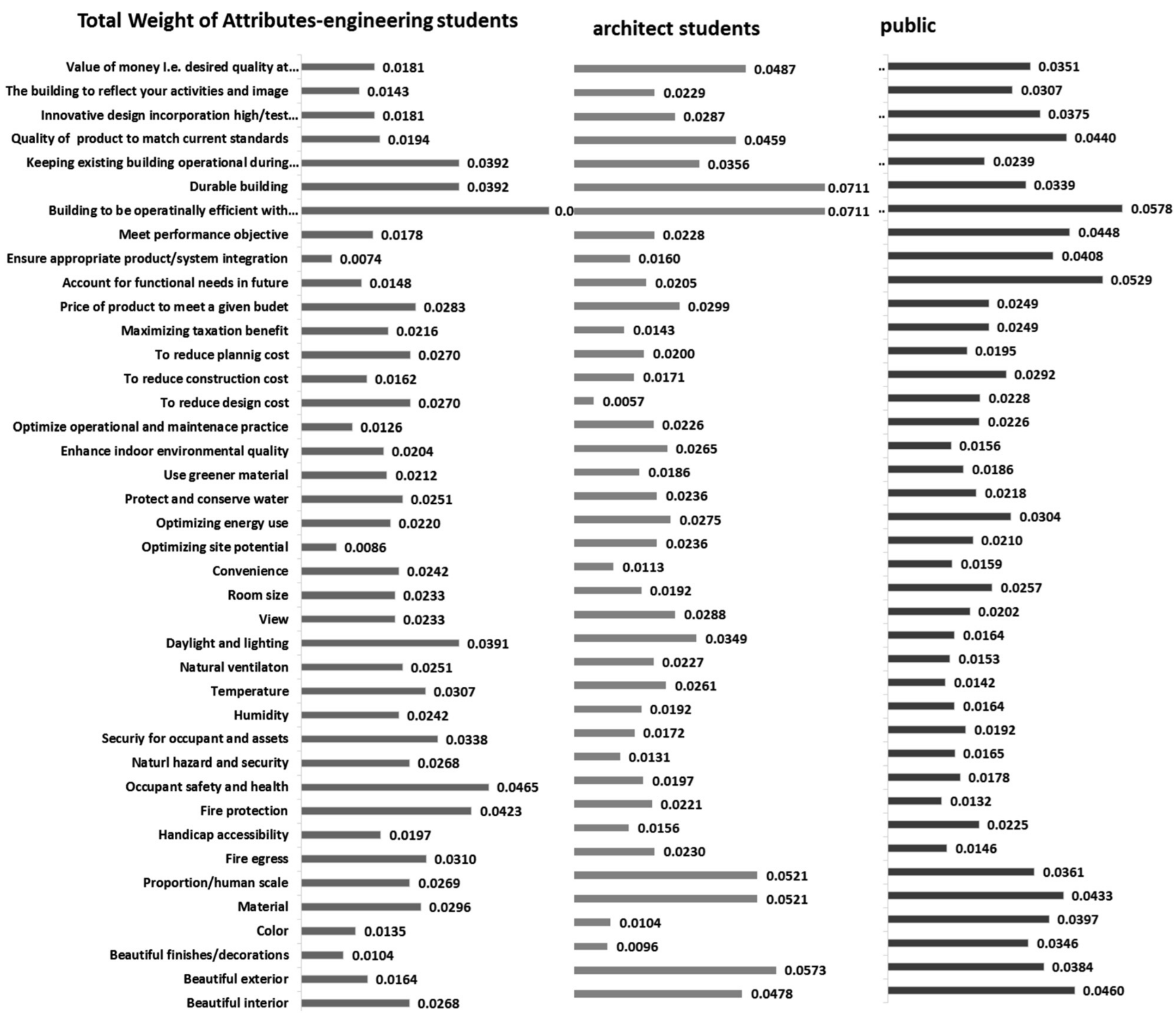

Fig. 4 Weight of all attributes for each group of participant

stakeholders' preferences and frames of understanding [10] could be altered or transformed.)

To the best of our knowledge, this paper is the first to formally empirically study different stakeholders' preferences regarding various attributes/criteria of architectural design. Our results show that, using the mathematic model that we proposed, there is certain consistence among three groups—the public, practicing architects, and engineering students—in terms of their preference for an existing built project. However, when we compared these consistent results to the actual public votes on Facebook, we found that a discrepancy exists. In the future, we build new mathematic models and conduct more surveys to study the discrepancy.

This paper provides a building block for integrating game theory and decision analysis into a sustainable architectural design process. In particular, with the identified user preferences, different utility models could be modeled for various stakeholders, considering potential utility dependence between attributes. Then, we could study the strategic interactions among those stakeholders to identify win-win cooperation strategies for architectural design between designers and clients, as well as between competing designers. In the case study provided in this paper, a single set of preferences is assigned to the practicing architects, engineering students, and general public groups. However, we acknowledge that in practice, architects or engineers may have different preferences than other architects or engineers, respectively; thus, a larger dataset with subgroups would be preferred. In general, more context-dependent approaches based in the social sciences could also be utilized to combine with mathematical models to study how group dynamics in the design process can lead to positive impacts and outcomes that reflect the interests of multiple competing social groups. In survey 2, the survey participants were asked to rate all attributes (including safety and comfort) of houses by looking at the pictures. This is a limitation of the survey, and in the future, we could provide additional information (e.g., building materials and structure) in order for the survey participants to provide more accurate judgment.

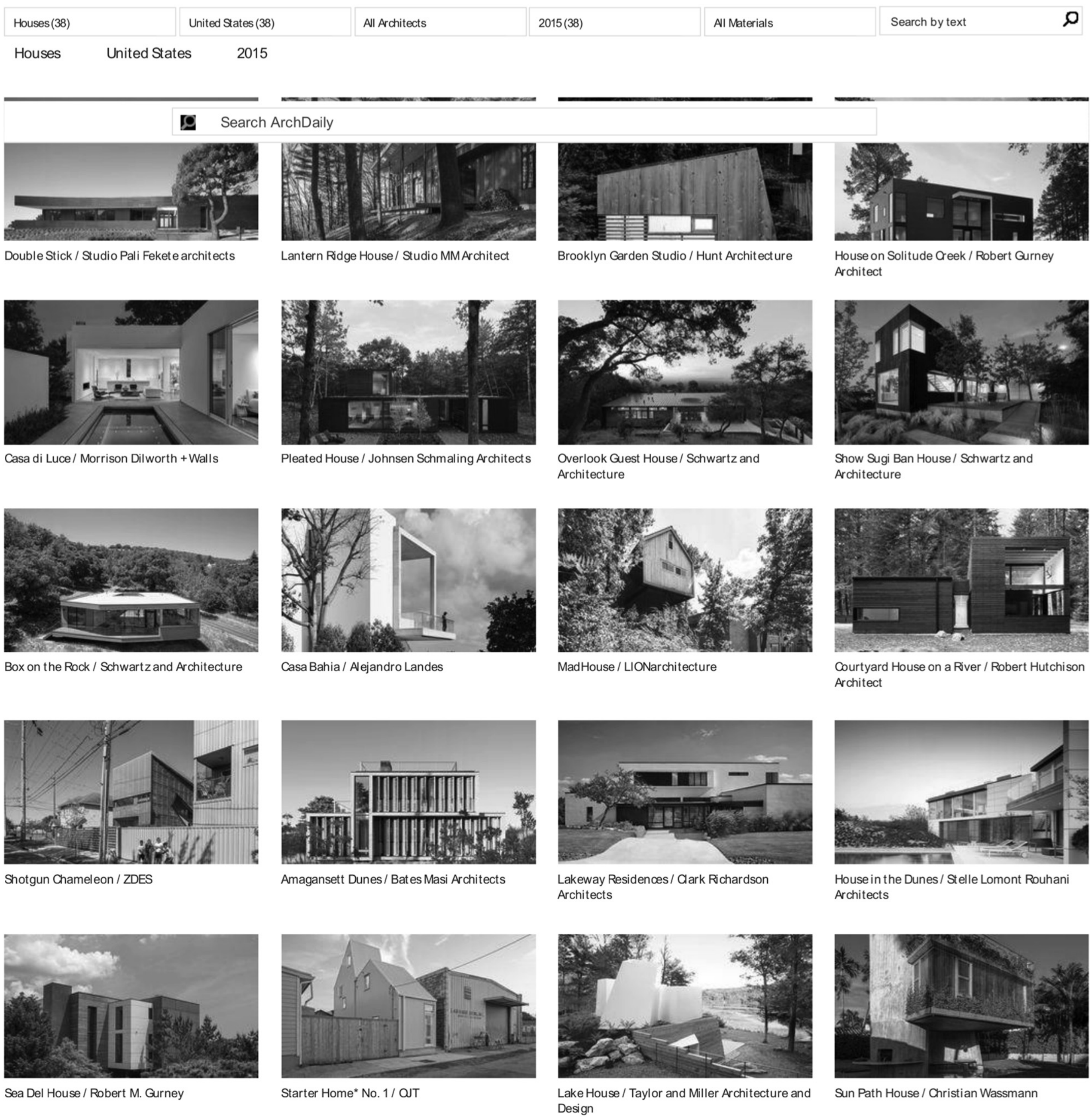

Fig. 5 Online architectural project library

Table 4 Comparison of the results of survey 2 with the Facebook results

	Facebook		Survey 2		Survey 2: weighted rank ($U(X_i)$)					
					Public w_j		Architect w_j		Engineer w_j	
	Rank	Likes	Average score = $\bar{Y}_{ij}$	Rank	$U(X_i)$	Rank	$U(X_i)$	Rank	$U(X_i)$	Rank
Project 1	1	3.9k	6.416	5	6.429	5	6.567	6	6.160	7
Project 2	2	2.7k	5.976	8	5.924	8	6.260	8	6.094	8
Project 3	3	1.7k	5.428	10	5.407	10	5.690	10	5.648	10
Project 4	4	1.5k	6.404	6	6.380	6	6.628	5	6.523	5
Project 5	5	1.4k	6.964	1	6.937	1	7.168	1	6.967	1
Project 6	6	1.1k	6.538	4	6.506	4	6.755	4	6.630	4
Project 7	7	924	6.897	2	6.912	2	7.140	2	6.762	3
Project 8	8	722	6.884	3	6.889	3	7.137	3	6.813	2
Project 9	9	640	6.166	7	6.165	7	6.429	7	6.213	6
Project 10	10	617	5.820	9	5.786	9	5.972	9	6.051	9

Value-driven design process will change the basic structure of design/build industry. In many project teams, there is a lack of integration of design and construction, and often poor collaboration among team members. This leads to risk-averse behavior as team members try to protect themselves from the impact of changes caused by error, omissions, and owner modifications. After identifying the team members' preference and pin point the problematic area, next step we could build decision support tools to help to reshape the design process. This tool could be used by architects, engineers, owners, and different stake hold as a collaboration tool and platform to make optimized design decision, save resources and energy, reduce the design cycle, and generate higher performance and more sustainable buildings.

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Nomenclature

$i =$ project 1,…, project 10
$j =$ beauty, safety, comfort, sustainability, flexibility, and functionality
$U(X_j) =$ the utility of the existing design i
$w_j =$ the weight of attribute j
$Y_{ij} =$ the value of attribute j in design i

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