Chapter 6
Quantifying Adaptability of College Campus Buildings

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Abstract While much has been written about adaptable buildings, quantification of adaptability is still in its nascent stage. Little has been published toward validation of quantitative adaptability models. This paper proposes a scoring system for evaluating the design-based adaptability of college campus buildings. This system was created to be a tool to guide future designs. Different physical features (i.e., floor-to-floor height and structural span lengths) of the buildings are considered in the scores. Adaptability scores are calculated for four buildings on Clemson University’s campus. Scores are compared to those from an earlier study of the same buildings; the earlier study quantified adaptability by surveying experts through an Analytic Hierarchy Process (AHP). Both approaches rank the subject buildings in the same order with respect to adaptability. Additionally, scores from both approaches are linearly correlated. These encouraging results suggest that the proposed scoring system is a starting point for quantifying the adaptability of college campus buildings.

Keywords Design-based adaptability · Empirical comparisons · Analytic hierarchy process · Quantitative model

6.1 Introduction and Background

6.1.1 Adaptability and Design-Based Adaptability (DBA)

Adaptability has been defined as the ease with which a building can be physically modified, deconstructed, refurbished, reconfigured, repurposed and/or expanded [1]. Similar definitions are presented in books by Schmidt and Austin [2] and Cowee and Schwehr [3]. Physical, economic, functional, technological, social, legal and political factors all impact a building’s adaptability [4]. Physical factors that impact adaptability include a building’s age and state of repair, as well as the features of its design. The portion of adaptability based on design features has been described as
Design-Based Adaptability (DBA) [5]. While DBA is only one contributor to overall adaptability, it is critical because it is the only portion that can be directly impacted (intentionally or otherwise) by design decisions. This paper proposed a quantitative model for scoring DBA of college campus buildings. The model is intended as the first step toward a tool for architects and engineers who are seeking to design more adaptable buildings.

Few models and methods have been proposed to quantify adaptability, and even fewer have been empirically validated [6]. Existing models for measuring DBA [5, 7–9] have been created using weighted-sum approaches. In weighted-sum models, a building is first scored for a variety of different parameters (e.g., floor plan openness). Scores are then multiplied by weighting values based on the scale and importance of the parameters, and then products are summed to determine an overall score. The proposed scoring system is also created using the weighted-sum approach, but is distinct from previous models in its use of research data for development and validation.

### 6.1.2 DBA Strategies

This section briefly reviews relevant strategies for increasing a building’s DBA. Words in **bold** are used as shorthand for describing the strategies. More detailed reviews can be found in the works by Ross et al. [1] and Heidrich et al. [10] and detailed practical examples of each strategy are listed in Table 6.1.

The strategy of **Layering** building systems was examined by Duffy [11] and Brand [12]. Duffy proposed that buildings should be analyzed as they are built and maintained: in layers such as “shell, services and scenery.” Brand observed that building layers are replaced at different rates (Fig. 6.1). He suggested that the layers be designed with physical and functional separation so each layer can be modified without impacting the others.

Large floor-to-floor heights and wide structural grids are part of the **Open** strategy. For example, floor-to-floor height dictates if “ample space for HVAC equipment, etc.” [13] is available. Small floor heights can constrain the possibility of future changes. Similarly, wide open structures present more options for future change than do densely located structures.

**Reserve capacity** is providing additional capacity beyond needs for the original building function. Future changes to a building may result in additional technical requirements, these changes can be facilitated by reserve capacity [1]. This idea is typically described in terms of structural capacity, but the strategy can also be applied to building services and space plans.

**Plan depth** is related to the proximity of interior spaces to exterior walls. In the context of adaptability, access to exterior walls is desirable because many potential building functions, particularly those on college campuses, benefit from exterior windows. While plan depth has been reported as being beneficial to adaptability, other building characteristics are reported more frequently [14].
Simple designs can reduce uncertainty associated with adaptation projects. Easy to understand load paths, repeating elements and details, orthogonal walls, stacking floor plates all contribute to simplicity [1].

Table 6.1 Examples of DBA strategies

| Strategy          | Practical example                                                                                           | Picture |
|-------------------|-------------------------------------------------------------------------------------------------------------|---------|
| Layering          | Use of non-bearing facades or demountable walls to separate the skin and structure layers The picture shows demountable walls in an office [15] | ![Layering Example](image1.jpg) |
| Open              | Increasing structural grid size or floor-to-floor heights The warehouse in the picture has large spans and tall ceilings [16] | ![Open Example](image2.jpg) |
| Reserve capacity  | Increasing design live loads or providing overly sufficient services for multiple potential occupancies The picture shows the construction of the raised plenum floors in the Watt Family Innovation Center on Clemson University’s campus [17] | ![Reserve Capacity Example](image3.jpg) |
| Plan depth        | Creating a building footprint that allows interior spaces to be in close proximity to exterior walls and windows The building on the right has a shallow plan depth [18] | ![Plan Depth Example](image4.jpg) |

(continued)
Table 6.1 (continued)

| Strategy | Practical example |
|----------|-------------------|
| Simple   | Use of standard member sizes or similar grid patterns. Buildings shown to the right have repetitive plans and elevations [19] |

![Fig. 6.1 Building layers (after Brand [12])](image)

6.1.3 Becker et al. 2020

Becker et al. quantitatively measured DBA of four buildings from the Clemson University campus using an Analytic Hierarchy Process (AHP) [14]. The four buildings were the Watt Family Innovation Center (WFIC), Academic Success Center (ASC), Lee Hall and Stadium Suites (Fig. 6.2). These buildings were selected for study because of their similar size, age, and quality of materials.

AHP is a method that separates multifaceted decisions into a series of pairwise comparisons. Pairwise results are aggregated to determine an overall best option. Experts in the Becker study used AHP to compare the subject buildings according to their relative suitability for different potential adaptation schemes. After aggregating the individual pairwise scores, the buildings’ overall adaptability scores were 0.3 for WFIC, 0.23 for ASC, 0.27 for Lee Hall, and 0.2 for Stadium Suites. Higher scores mean that a building is more suited for potential adaptation.

Becker et al. also qualitatively evaluated the buildings’ adaptability by asking experts to describe the physical features that made the buildings more or less suitable for potential adaption. Open floor plans and high floor-to-floor heights were the most frequently mentioned features. Some of the other features, listed in order of most-to-least frequently mentioned, included: flexible HVAC systems, overdesigned structure, ease of access/plentiful circulation and building footprint/plan depth that
suits creative uses. Becker et al. engaged separate groups of experts to conduct the qualitative and quantitative portions of their study.

### 6.2 Scoring System Description

The proposed scoring system measures the DBA of college campus buildings. Previous work by Becker et al. [14] measured DBA of existing campus buildings, whereas the scoring system aims to guide the design of future buildings. The choice to evaluate college campus buildings was made partially for the practical reason that the current researchers had access to detailed drawings and information about the buildings. More importantly, campus buildings were chosen because the stakeholders tend to be long-term owners who are interested in an elongated life for their facilities.

College campuses are always evolving based on new student and faculty needs. The recent transition to classrooms with increased social distancing due to COVID-19 is one example. Since abundant land area for new construction is not always a viable asset in these necessary evolutions, the buildings located on these campuses must be able to adapt to new occupancies quickly in order to further the success of
the university. The four buildings analyzed using the system proposed were chosen based on their similar sizes and ages.

6.2.1 Parameters and Parameter Score

Eight physical features (parameters) are considered in the proposed scoring system. These parameters are similar to the DBA strategies cited in the literature (Sect. 1.2) and observed in the qualitative data collected by Becker et al. (Sect. 1.3). Separate scales are proposed to relate the value of each parameter to an adaptability score between 0 and 10. Individual adaptability scores are then multiplied by weighting factors, and the products are summed to determine an overall DBA score. This section discusses the parameters and their adaptability scales.

It has been theoretically argued that there is a limit to the degree to which DBA strategies should be applied [20]. For example, just because reserve structural strength can increase a building’s adaptability, it would be wasteful to design all buildings to the highest and most stringent structural requirements. Scores for the individual parameters reflect this notion. Most of the parameter scores have diminishing returns as the parameters increase in value. Relationships between parameter scores and values are based on the authors’ professional opinions and reasoning. They are presented as a first step but are far from definitive. The authors intend to conduct additional research on this topic in the near future.

To the extent possible, relationships between parameter scores and values are continuous mathematical functions. Continuous functions are used in lieu of checklist scoring systems. In a recent conference on adaptable buildings, checklist systems were criticized for promoting “checklist fatigue,” facilitating “gaming” or scores, and for dulling designer’s critical thinking [20].

**Structural spacing.** Structural spacing is related to the open DBA strategy. Scores for this parameter are determined using Fig. 6.3. It is reasoned that spacings below 10 ft (3 m) severely restrict the types of college campus functions that could be used in such spaces. Accordingly, the scoring for structural spacing begins at 10 ft (3 m). The score increases with increasing structural spacing with slope changes at 30 ft (9 m) and at 60 ft (18 m). The 30 ft spacing is based on the size of a typical classroom. After a structural spacing of 60 ft, the score remains constant because 60 ft is large enough

![Fig. 6.3 Adaptability scores associated with structural spacing. (1 ft = 0.3 m)](image-url)
for two typical classrooms and most other occupancies on college campuses. The scale is based on typical structural spacing. If structural spacing varies throughout the building, then the average spacing should be used.

**Floor-to-floor height.** Adaptability score for floor-to-floor height is defined by Fig. 6.4. This parameter is related to the open DBA strategy. The scale begins at 9 ft (3 m) for a floor-to-floor height. Values below this height are impractical and deemed to restrict adaptability. Increasing floor-to-floor height between 9 and 15 ft improves adaptability; this is represented by the relatively steep slope between these heights. A floor-to-floor height of 15 ft (4.5 m) is considered ample for most campus occupancies. Adaptability scores increase more gradually for floor-to-floor heights between 15 and 30 ft. The score reaches the maximum value of 10 for a floor-to-floor height of 30 ft. At this value, the story could be split into two well-heighted floors.

The floor-to-floor height used to determine the adaptability score is taken as the average for the building. It is calculated as the elevation difference between top of first floor and top of the roof structure divided by the number of stories.

**Wall deconstructability.** Wall deconstructability refers to how easy it is to remove an interior wall [21]. Adaptability increases as walls are easier to deconstruct. The schedule in Table 6.2 lists the deconstructability score associated with different wall types. Bearing walls are considered the hardest to remove and are assigned a score of 0. Non-bearing walls are easier to remove and have higher scores. The highest score is for “removable” walls that are intentionally detailed to facilitate removal. The wall deconstructability score is based on the average wall deconstructability score across all interior walls in a building (Eq. 6.1). For example, the WFIC (Fig. 6.2) has a combination of bearing, light, and removable walls and has a wall deconstructability score of 7.5. Wall deconstructability is associated with the layer and open DBA strategies.

| Wall type        | Deconstructability score (D) |
|------------------|------------------------------|
| Bearing          | 0                            |
| Heavy non-bearing| 3                            |
| Light non-bearing| 7                            |
| Removable        | 10                           |

**Table 6.2** Unweighted score values associated with different wall types
WDAS = \frac{\sum L_j D_j}{\sum L_j} \quad (6.1)

where:

WDAS  Wall deconstructability adaptability score

\( L_j \)  Total length of wall type \( j \)

\( D_j \)  Deconstructability score of wall type \( j \)

\( J \)  Index for wall type.

**HVAC accessibility.** Accessibility refers to how readily an HVAC system can be inspected, updated or modified. This parameter is related to the layer DBA strategy; HVAC systems that are highly integrated with or embedded in other building layers tend to be more difficult to adapt. The adaptability score for this parameter is more subjective than for the other parameters. Systems with embedded/rigid designs have a score of 0 while fully exposed/flexible designs have a score of 10. Scores given to the buildings in Fig. 6.2 are demonstrative. The WFIC is given a score of 8. It has raised floors that house the HVAC ductwork. Segments of the floor can be easily removed to inspect, replace or modify the ductwork. Lee Hall is given a score of 6. The ground floor of Lee Hall has a hydronic heating tubes in embedded in a concrete slab-on-grade. Ductwork for cooling is fully exposed below the upper floor and roof structure. The score for Lee Hall reflects the lack of accessibility of the in-slab heating, on the one hand, and positive accessibility of the ductwork on the other. HVAC systems for Stadium Suites and the ASC are typical of many buildings on the Clemson campus. HVAC ducts and chases are in wall/ceiling cavities that are covered by gypsum board. This condition is assigned a 5 and is considered a typical level of HVAC accessibility.

**Design live load.** Design live load is associated with the reserve DBA strategy. Standard 7 from the American Society of Civil Engineers [22] lists uniform design live loads between 20 and 300 psf (1–14 kN/m²) for different occupancies. Live loads for most college campus occupancies fall between 20 and 100 psf, and these values form the first segment of the adaptability scale for live loads shown in Fig. 6.5. Live loads over 100 psf have increasing adaptability scores, but with diminishing returns (lower slope on figure) because design loads over 100 psf are only needed for special conditions such as data centers and libraries.

![Fig. 6.5](image-url)  
**Fig. 6.5** Adaptability scores associated with design live load. (1 psf = 0.048 kN/m²)
Different design live loads are typically applied across different portions of a building. In these situations, the weighted average design live load is used to determine the adaptability score. For example, the majority of areas in the Stadium Suites building is designed for 40 psf. Common rooms and corridors have higher design loads. The weighted average is 47.5 psf; therefore, the design live load adaptability score is 3.8.

**Plan depth.** The percentage of a floor plate area that is within 12’ (3.7 m) of an exterior wall is an indicator of the plan depth strategy. A relatively skinny building has low plan depth and high percentage of area close to exterior walls. A “big box” store is an example of a building with high plan depth and a corresponding low percentage of space near exterior walls. While interior spaces in “big box” buildings can be adapted for a variety of uses, experts from the Becker et al. [14] study preferred shallower plans. This is because shallow plans provide greater proximity to exterior walls and windows which is desirable for many college campus occupancies. Shallow plan depths facilitate more occupancies making them more adaptable.

The scale for determining the plan depth adaptability score is shown in Fig. 6.6. A score of 0 is associated with large plans depths in which 10% or less of the floor area is within 12’ of exterior walls. The score increases with increasing up to a peak at 50%. Scores decrease for percentages above 50% as the plan depth becomes “too thin.” When 100% of the plan area is within 12’ of the exterior, the plan depth is 24 ft (7.3 m). Such plans can facilitate a limited number of campus occupancies and are assigned an adaptability score of 6.0.

**Orthogonal walls.** The adaptability score for this parameter is linearly related to the percentage of walls in a building that are oriented in orthogonal directions (Fig. 6.7). In the Stadium Suites building, there are diagonal wall segments that form the corner tower (Fig. 6.2). The remaining 90% of walls are orthogonal which results
in an adaptability score of 9. Orthogonal walls are taken as an indicator of the simple DBA strategy.

**Stacking floor plates.** Stacking floor plates are also related to the simple DBA strategy; stacking floor plates are indicators of simple structures and details. This parameter is calculated as the overall percentage of floor plate areas in a building that match. This percentage is linearly related to the floor plate adaptability score using the same scale as the orthogonal wall adaptability score (Fig. 6.7). An example of this indicator is found in the WFIC in which floor plates get smaller with each story. The floor plate adaptability score is 6 because 60% of the floor plate area stacks. While this indicator is very simple to calculate and apply, the authors are currently considering more rigorous methods for calculating stackability. From an adaptability perspective, it is reasoned that some portions of buildings (i.e., plumbing chases) are more critical to stack vertically than others. More rigorous models could consider which portions of a building stack.

### 6.2.2 Overall Adaptability Score

Adaptability scores for the individual parameters are aggregated to determine the overall adaptability score. This is done by multiplying each parameter score by a weighting factor representative of its level of importance then summing the products:

$$OAS = \sum PW_iPAS_i$$

where:

- **OAS** Overall adaptability score
- **PW** Parameter weighting factor
- **PAS** Parameter adaptability score
- **I** Index for parameters.

Parameter weighting factors are based on the qualitative data collected from building professionals in Becker et al. [14]. The professionals listed physical features of the subject buildings that would facilitate or impede adaptation. Parameters in the model were assigned to the most similar physical features mentioned by the professionals. Parameters (features) that were more frequently listed are assigned higher weights than those listed less frequently (Table 6.3). The parameter weighting factors are set such that they sum to 1.0. Hence, the overall adaptability score ranges from 0 to 10.
Table 6.3 Physical features, scoring system parameters and parameter weighting factors

| From Becker et al. [14] | Associated parameter       | Parameter weighting factor |
|-------------------------|-----------------------------|---------------------------|
| Frequency in data       | Physical features cited by professionals | Structural spacing | 0.20 |
| Most frequent           | Open/closed floor plans     | Floor-to-floor height     | 0.20 |
| Most frequent           | Floor-to-floor height       | Structural spacing        | 0.20 |
| Frequent                | Reconfigurable floor plans  | Wall deconstructability   | 0.14 |
| Frequent                | Flexible HVAC systems       | HVAC accessibility        | 0.14 |
| Least frequent          | Overdesigned structure      | Design live load          | 0.08 |
| Least frequent          | Floor plan facilitates     | Plan depth                | 0.08 |
|                         | creative uses               | Orthogonal walls          | 0.08 |
|                         |                             | Stacking floor plates     | 0.08 |

6.3 Comparison of Scoring System and AHP Study

Overall adaptability scores for the four subject buildings were calculated (Table 6.4) and were compared to the results of the Analytic Hierarchy Process (AHP) study presented by Becker et al. [14]. The scoring system and the AHP study resulted in the same rank order from most to least adaptable. As seen in Fig. 6.8, there is a high degree of linear correlation \( R^2 = 0.84 \) between the scoring system and the results of the AHP study. The favorable comparison is encouraging and suggests that the proposed scoring system may have practical value for measuring and comparing adaptability.

Table 6.4 Adaptability scores of case study buildings

| Parameter                  | Weighting factor | WFIC | ASC | Lee Hall | Stadium Suites |
|----------------------------|------------------|------|-----|----------|----------------|
| Structural spacing        | 0.20             | 8.0  | 8.2 | 8.5      | 6.5            |
| Floor-to-floor height     | 0.20             | 7.0  | 6.2 | 7.3      | 4.2            |
| Wall deconstructability   | 0.14             | 7.5  | 5.6 | 7.0      | 3.3            |
| HVAC accessibility        | 0.14             | 8.0  | 5.0 | 6.0      | 5.0            |
| Design live load          | 0.08             | 8.0  | 5.0 | 7.0      | 3.8            |
| Plan depth                | 0.08             | 3.5  | 6.8 | 3.0      | 8.8            |
| Orthogonal walls          | 0.08             | 8.0  | 9.0 | 9.0      | 9.0            |
| Stacking floor plates     | 0.08             | 6.0  | 9.0 | 5.0      | 9.5            |
| **Total Unweighted Score** | **56.0**         | **54.8** | **52.8** | **50.3** |
| **Overall Adaptability Score** | **7.21**       | **6.75** | **6.91** | **5.82** |
| **AHP score (Becker et al. [14])** | **0.30**       | **0.23** | **0.27** | **0.20** |
of college campus buildings. Caution is advised, however, as the comparison with the AHP study is a relatively small degree of validation.

### 6.4 Summary and Conclusions

A system is proposed for scoring and comparing the design-based adaptability (DBA, the portion of adaptability associated with a building’s physical design) of college campus buildings. The system considers eight different physical parameters, such as floor-to-floor height and design live load, which can be readily measured. Adaptability scores for the individual parameter scores are aggregated to determine a building’s overall adaptability score. The system is intended as an aid for designing new buildings for adaptability and also for evaluating adaptability of existing buildings.

Four case study buildings from the Clemson University campus were used to evaluate the proposed scoring system. DBA of these same buildings has previously been quantitatively determined by Becker et al. [14] using the Analytic Hierarchy Process (AHP). Results from the proposed scoring system and the earlier AHP study are in good agreement ($R^2 = 0.84$). While these results are encouraging, more research on a larger, more diverse group of buildings is recommended to further develop and validate the proposed system. Traditional office buildings and multi-family residential buildings could be a starting point for a new group to test.

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