FLEX 4.0, a practical instrument to assess the adaptive capacity of buildings

Rob Geraedts*

Abstract

Adaptive buildings are green buildings. But the question is: how to measure green? A direct connection can be made between adaptive building and sustainability. Market developments show increased demands for flexibility and sustainability by users and owners as well as a growing understanding of the importance of a circular economy. Since 2014 a research project at the Delft University has been investigating the adaptive capacity of buildings. As one of the results several versions of an instrument to assess the adaptive capacity of buildings have been developed since. The last version FLEX 4.0, amongst others based on the support and infill theory of Habraken [1], is described in detail in this paper, including all flexibility key performance indicators, the different default weighting factors, their assessment values and some examples to determine the flexibility class of buildings. This paper thus presents a complete assessment instrument that can be used in practice.

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Keywords: Assessment instrument; adaptive capacity; sustainable; open building; flexibility key performance indicators;

1. Introduction

Market developments show increased demands for flexibility and sustainability by users and owners as well as a growing understanding of the importance of a circular economy [2]. A direct connection can be made between adaptive building and sustainability [3]. The longer a building can keep its functional life cycle instead of becoming

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vacant or being demolished, the more sustainable that building will be. The more a building is flexible and able to
adapt to changing user demands, the longer it will keep its functional life cycle.

In 2014 a paper was presented at the International Union of Architects World Congress UIA2014 in Durban SA,
titled Adaptive Capacity of Buildings [4]. It reported on an extensive international literature survey and the
development of a method to determine the adaptive capacity of Buildings. In total 147 indicators with accompanying
assessment values were described.

In 2015 additional research led to a renewed assessment method with 83 indicators, clustered in five layers with
different life cycles. This method was called FLEX 2.0. It had a FLEX 2.0 LIGHT version with only 17 of the most
important indicators. This was presented in 2015 at the CIB Conference - Going North for sustainability in London
[5]. At the same time this method was used in two separate research projects for an evaluation with experts in
practice. One project concerned the development of school buildings [6]; the other project was related to the
development of office buildings [7]. The main conclusions and recommendations of both research projects
evaluating this method in practice with two different types of real estate, have led to the preliminary framework of
FLEX 3.0, which has been presented at the CIB World Building Congress in Tampere, May 2016 [8].

In this paper the final results and the renewed version of this practical assessment instrument FLEX 4.0 will be
elaborated on, described and presented in detail, including the 44 flexibility key performance indicators and the
associated different assessment values.

2. Fundamental ideas behind FLEX 4.0

The adaptive capacity of a building includes all characteristics that enable the building to keep its functionality
through changing requirements and circumstances, during its entire technical life cycle and in a sustainable and
economically profitable way. The adaptive capacity is considered a crucial component when looking into the
sustainability of the real estate stock [9]. The original method for determining the adaptive capacity of buildings was
developed in 2014 after an extensive survey of international literature on the characteristics, definitions and
assessment instruments of adaptive building and on boundaries of adaptive capacity, sustainability and financial
business cases for real estate. The literature survey resulted in a number of basic schemes with 147 flexibility
indicators and their mutual relationships. Next to the literature survey, a substantial number of experts from practice
were consulted. The basic schemes formed the input for discussions in two different expert panels: one with
representatives of the clients (demand side) and one panel with representatives of construction companies and
suppliers (supply side) in the construction process [9, 10].

The steering group behind this research project and the two already engaged expert panels played an important
role in addressing the next research aim: the translation of this initially developed instrument into a more accessible
and easy to use instrument in the daily construction practice, with less indicators to deal with. This resulted in a
renewed condensed method that was tested in practice with office buildings and schools. The final results led to a
new framework that formed the basic idea behind the development of the next updated version of the flexibility
assessment instrument called FLEX 4.0.

2.1. Framework for FLEX 4.0

The framework for FLEX 4.0 is based on three different instruments more or less derived from FLEX 2.0, the
model with the original 83 flexibility performance indicators, developed in 2015 and presented in 2016 (Geraedts
2016). In figure 1 these three instruments are presented and combined:

1. FLEX 2.0 LIGHT with 17 indicators and generally applicable [8],
2. An Assessment instrument for school buildings with 21 indicators [6],
3. An Assessment instrument for office buildings with 35 indicators [7].

The three instruments presented and combined with each other in figure 1 (FLEX 3.0) form the framework for
further elaboration into FLEX 4.0 (see column 2: Light, Schools and Offices). Next to the ‘Instrument’ column the
‘Dynamics’ column is shown. The ‘T’ stands for Transformation Dynamics, the capacity of a building to react to a
changed market demand of the building function from an owner’s point of view. The ‘U’ stands for Use Dynamics, the capacity of a building to react to changed user demands.

<table>
<thead>
<tr>
<th>FLEX 3.0: COMBINATION OF 3 ADAPTABILITY ASSESSMENT INSTRUMENTS</th>
<th>INSTRUMENT</th>
<th>DYNAMICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAYER Sub-layer Flexibility Performance Indicator</td>
<td>1. Light</td>
<td>2. Schools</td>
</tr>
<tr>
<td>1. SITE 3 Surplus of site space</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2 Expandable site / location</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3 Multifunctional site / location</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2. STRUCTURE Measurements 4 Surplus of building space / floor space</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>5 Available floor space of building</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>6 Size of building floors</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>7 Surplus free of floor height</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>8 Measurement system; modular coordination</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>9 Horizontal zone division / layout</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Access 10 Access to building: location of stairs, elevators, core building</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>11 Presence of stairs and/or elevators</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>12 Extension / reuse of stairs and elevators</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Construction 13 Surplus of load bearing capacity of floors</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>14 Shape of columns</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>15 Positioning obstacles / columns in load bearing structure</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>16 Positioning of facilities zones and shafts</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>17 Fire resistance of main load bearing construction</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>18 Extensible building / unit horizontal</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>19 Extensible building / unit vertical</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>20 Rejection part of building / unit horizontal</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>21 Insulation between stories and units</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3. SKIN Facade 22 Dimountable facade</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>23 Facade windows to be opened</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>24 Day light facilities</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>25 Location and shape of daylight facilities</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>26 Insulation of facade</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>4. FACILITIES Measure &amp; Control 27 Measure and control techniques</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>28 Customisability and controllability of facilities</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Dimensions 29 Surplus of facilities shafts and ducts</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>30 Surplus capacity of facilities</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>31 Modularity of facilities</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Distribution 32 Distribution of facilities (heating, cooling, electricity)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>33 Location sources of facilities (heating, cooling)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>34 Disconnection of facilities components</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>35 Accessibility of facilities components</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>36 Independence of user units</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>5. SPACE PLAN Functional 37 Multifunctional building</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>38 Distinction between support - infill (fin out)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Access 39 Access to building; horizontal routing, corridors, gallery</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Technical 40 Disconnectible, removable, relocatable units in building</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>41 Disconnectible, removable, relocatable interior walls</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>42 Disconnecting/detailed connection interior walls; hor/vert.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>43 Possibility of suspended ceilings</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>44 Possibility of raised floors</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Figure 1: FLEX 3.0, the integral combination of the three developed instruments to assess the adaptive capacity of buildings with 44 flexibility performance indicators in total, and basic framework for developing FLEX 4.0.

This framework has 44 flexibility performance indicators that are all applicable for assessing the transformation dynamics while 32 of them are also suited for assessing the user dynamics of a building. Figure 1 also shows the 7 generally applicable flexibility performance indicators (highlighted from 1 to 7 in the most right column). They can be used for each type of real estate. The 37 more specific indicators can be used for the assessment of specific real estate like schools or office buildings.
2.2. Layers with different life cycles

In order to structure and cluster the large number of different construction components with different functional life cycles, several possible arrangements were developed in the past. Duffy [11] and Brand [12] defined different functional levels within a building in order to identify functions with different changing life cycles in a building. Each layer and the components within have their own technical, functional and economic lifespan. In order to meet circularity, only construction components that are well suited to be reused using the different loops should be selected: site, structure, skin, services, space plan and stuff. In this research the layers space plan and stuff have been combined.

1. **Site**: the urban location; the legally defined lot whose context lives longer than buildings. According to Brand and Duffy, the site is eternal.
2. **Structure**: the foundation and load-bearing elements, which last between 30-300 years. However, few buildings last longer than 50 years.
3. **Skin**: the exterior finishing, including roofs and façades. These are upgraded or changed approximately every 20 years.
4. **Services**: the HVAC (heating, ventilating, and air conditioning), communication, and electrical wiring. They wear out after 7-15 years.
5. **Space plan & stuff**: the interior layout including vertical partitions, doors, ceiling, floors (and furniture). According to Brand, commercial space can change every 3 years.

2.3. Support - Infill theory for a generic assessment instrument

An additional point of view on the gained results so far for explaining the potential next development of the instrument in 2016 is the support-infill theory of Habraken. He developed in the sixties a theory to distinguish construction components by different life spans (long and short life cycles), by different decision levels (community or individual), by different building levels (urban tissue, support, infill), or by differences in dealing with components (fixed or variable components). This theory is also known as the support-infill theory [1] and afterwards elaborated on within the CIB Working Group W104: Open Building Implementation. According to this theory it could be possible to distinguish flexibility performance indicators that are generally applicable on ‘support’ level for each building type (the indicators in the right most column of figure 1) and the other 37 indicators on ‘infill’ level that are more specific for a special type of real estate; in this case school buildings or office buildings. In the next paragraphs this new instrument will be described in detail.

3. FLEX 4.0

3.1. Generally applicable indicators: 12

The 44 indicators from the basic framework for FLEX 4.0 (see figure 1) have been divided into two different categories. The first category consists of 12 flexibility performance indicators that are generally applicable, independent of the kind of real estate one is assessing: the so-called ‘support’ category of this instrument (see figure 2).
3.2. Specifically applicable indicators: 32

The second category consists of 32 flexibility performance indicators - the so-called ‘infill’ category - that are specifically applicable for a certain type of real estate. They are based on the underlying research in practice by Carlebur on school buildings and Stoop on office buildings [6, 7]. They can be used likewise according to the demands of the users of this instrument, like real estate owners or project developers. For the readability of this paper the 32 indicators are presented in two separate figures (see figure 3a and 3b).
3.3. Assessment values

Figures 2 and 3a,b also show the assessment values of all flexibility performance indicators, varying from 1 (Bad), 2 (Normal), 3 (Better) to 4 (Best). A visual presentation of these assessment values can be found in figure 4 and will be used to make a gap analysis between the requested flexibility by owners or users and the offered flexibility of buildings (figure 5).
5. SPACE

27. Multifunctional building elements that can also be used as support functions, like dressing rooms, lobbies, care and support?  
1. The building supports one support function (Bad)  
2. The building supports 2 functions (Normal)  
3. The building supports 3 functions (Better)  
4. The building supports > 3 functions (Best)  

The building supports more different functions of the building, the more easily a building can be rearranged or transformed to other functions.

28. Disconnection of buildings, to what extent are the units separate from the building?  
1. The units are collectively dethreed and isolated in the building area (Bad)  
2. The units are easily dethreeded and isolated from other buildings (Normal)  
3. The units are reconstructable (Better)  
4. The units are reconstructable and can be moved (Best)  

The more units are reconstructable and isolatable, the better the user can separate from other buildings or move to another location.
3.4. Flexibility profiles and gap analysis

With FLEX 4.0 and the corresponding 4 assessment levels of the different flexibility performance indicators, from 1 = Bad to 4 = Best, owners and users of buildings are able to assess the supplied building flexibility. They are also able to formulate their flexibility demand profile and compare both flexibility profiles with each other: the so-called gap analysis (see figure 5).

![Gap Analysis Diagram](image)

**Figure 5**: A gap analysis between a user flexibility demand profile and the supplied flexibility profile of a building; in this example based on 8 flexibility indicators (Geraedts 2015)

4. Assessment forms

To use FLEX 4.0 in practice, special assessment forms have been developed and use has been made of default weighting factors. Figure 6 and 7 show examples of a fictive assessment of a certain building with FLEX 4.0.

4.1. Default weighting

Each of the 12 generally applicable and 32 specifically applicable flexibility performance indicators has been given a weight relative to the other indicators, varying from weighting 1 (not important) to 4 (very important). In this case the weighting is given as a default setting by the author of the method. The users could change this default weighting, but as a result the next described minimum and maximum possible scores and the related flexibility classes would alter immediately.

4.2. Flexibility score and class; two examples

In the examples of figure 6 each indicator is assessed, varying from assessment level 1 (Bad) to 4 (Best). This leads to a score per indicator (weighting x assessment), which adds up to a total flexibility score. In the same way a theoretical minimum score of \((1 \times 1 \times 12 =) 12\) and a maximum score of \((4 \times 4 \times 12 =) 192\) can be found. With these two borders a class table can be made with five different flexibility classes ranging from 12 to 192. In the example of figure 6 the total Flexibility Score is 69. When looking up this score in the class table, the related Flexibility Class = 2. Or in other words: the building is hardly flexible.
Figure 6: Example of a fictive assessment of a building with the 12 generally applicable flexibility indicators, each with different weighting factors, the corresponding assessment value, the total flexibility score (69) and the corresponding flexibility class (2).

Similarly an assessment form is available for the 32 specifically applicable flexibility key performance indicators. Figure 7 shows a fictive assessment of a certain building with FLEX 4.0. Each of the 32 specifically applicable flexibility performance indicators has been given a weight relative to the other indicators, varying from weighting 1 to 4. Each indicator is assessed, varying from assessment level 1 (Bad) to 4 (Best). This leads to a score per indicator (weighting x assessment), which adds up to a total flexibility score. A theoretical minimum score of \((1 \times 1 \times 32 =) 32\) and a maximum score of \((4 \times 4 \times 32 =) 512\) can be found. With these two borders a class table can be made with five different flexibility classes ranging from 32 to 512. In figure 7 the total Flexibility Score is 186. Looking up this number in the class table, the related Flexibility Class = 2. The building is hardly flexible.
Figure 7: Example of a fictive assessment of a building with the 32 specifically applicable flexibility performance indicators, each with different weighting factors, the corresponding assessment value, de total flexibility score (186) and the corresponding Flexibility Class (2).

5. Example in construction

The next figure 8 shows an example from construction practice to illustrate the different assessment values connected to the flexibility performance indicators. In this case flexibility indicator nr. 25: *Accessibility of facilities components*. On the left a traditional concrete construction floor with facilities components located inside (assessment value 1: Bad) and on the right a prefab floor completely assembled with demountable components (assessment value 4: Best).
6. Conclusions and recommendations

The flexibility of buildings or their possibility to adapt to changing market and user demands is considered as a crucial component when looking into the sustainability of the real estate stock [9]. The original method for determining the adaptive capacity of buildings was developed in 2014 after an extensive survey of international literature on the characteristics, definitions and assessment instruments of adaptive building and on boundaries of adaptive capacity, sustainability and financial business cases for real estate. The literature survey resulted in a number of basic schemes with 147 flexibility indicators and their mutual relationships [9, 10]. The steering group behind this research project and the two expert panels played an important role in addressing the next research aims: the translation of this initially developed instrument into a more accessible and easy to use instrument in the daily construction practice, with less indicators to deal with. Through a number of intermediate versions of the instrument this finally resulted in a renewed condensed and easy to use method that was tested in practice with office buildings and schools. The final results led to the next and updated version of a flexibility assessment instrument called FLEX 4.0.

6.1. Next steps

In the near future a few important steps have to be taken to evaluate and implement this important instrument for formulating the demand for flexibility on the one hand and assessing the supplied flexibility of buildings on the other hand.

- First of all this renewed method has to be evaluated in practice with building owners, project developers and users, based on several case studies.
- Also needing evaluation are the formulated assessment values of the different flexibility performance indicators, varying from 1 (Bad) to 4 (Best), as showed in figure 2, 3 and 8. These were not taken into account in this follow-up research. It would be interesting to evaluate whether these values are still valid, or if they should be strengthened or expanded.
- The same counts for the proposed default weighting factors of the different flexibility performance indicators.
- For a better understanding of these different assessment values and in order to improve the user friendliness of this instrument, it is absolutely necessary to add a lot of examples (pictures) from construction practice to illustrate these different assessment values connected to the flexibility performance indicators, varying from ‘bad’ to ‘best’.
Finally it is not unlikely that professional owners and clients in construction feel the need for a uniform standard in construction describing the adaptive capacity of buildings, very much like the already existing energy labels and sustainability certificates like BREEAM and Greenstar. Would it be possible to develop a similar standard for the adaptive capacity of buildings?

References