# FLEX 4.0

## A Practical Instrument to Assess the Adaptive Capacity of Buildings

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

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**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.

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

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).

| FLEX 4.0: GENERALLY APPLICABLE INDICATORS | | | | |
|---|---|---|---|---|
| **Layer** | **Sub-layer** | **Flexibility Performance** | **Assessment Values** | **Remarks** |
| **1. SITE** | | **1. Expandable site / location**<br>Does the site have a surplus of space and is the building located at the centre? | 1. No, the site has no surplus of space at all (Bad)<br>2. 10-30% surplus (Normal)<br>3. 30-50% surplus (Better)<br>4. The site has a surplus space of more than 50% (Best) | The more surplus space on site, the better the building is expandable. |
| **2. STRUCTURE** | **Measurement** | **2. Surplus of building space / floor**<br>Does the building or the user units have a surplus of the needed usable floor space? | 1. Not oversized (Bad)<br>2. 10-30% oversized (Normal)<br>3. 30-50% oversized (Better)<br>4. > 50% oversized (Best) | The more the building space/surface is oversized (for instance by the use of a zoning system with margin space), the more easily a building can be rearranged or transformed to other functions. |
| | | **3. Surplus of free floor height**<br>How much is the net free floor height? | 1. < 2.60 m (Bad)<br>2. 2.60 - 3.00 m (Normal)<br>3. 3.00 - 3.40 m (Better)<br>4. > 3.40 m (Best) | The higher the free floor height, the better a building can be rearranged/transformed to other functions, the better a building can meet to changing user demands of facilities and quality. |
| | **Access** | **4. Access to building**<br>To what extend a centralized building access has been implemented? | 1. Decentralized/separated building entrance/core (Bad)<br>2. Decentralized/combined building entrance/core (Normal)<br>3. Building divided in different wings, each with centralized entrances/cores (Better)<br>4. 1 centralized building entrance and different wings with separate entrances/cores | The more a building entrance system can be used for a more independent use by different user groups the more easily a building can be rearranged. |
| | **Construction** | **5. Positioning obstacles / columns**<br>Is the adaptation of the building obstructed by load bearing obstacles or columns? | 1. Adaptation completely obstructed by difficult to replace load bearing obstacles<br>2. < 50% of the building adaptation is obstructed by load bearing obstacles (Normal)<br>3. < 10% of the building adaptation is obstructed by load bearing obstacles (Better)<br>4. No building space is obstructed by difficult to replace load bearing obstacles (Best) | The less obstructing parts of the load bearing construction, the more easily a building can be rearranged or transformed to other functions and is able to meet to changing user demands. |
| **3. SKIN** | **Facade** | **6. Facade windows to be opened**<br>Can windows in the façade be opened per planning grid size? | 1. No or < 10% of the windows can be opened (Bad)<br>2. 10 - 30% (Normal)<br>3. 30 - 80% (Better)<br>4. 80 - 100% (Best) | The more windows can be opened per planning grid size, the more easily a building can be rearranged/transformed to other functions, the better the building can meet changing demands. |
| | | **7. Daylight facilities**<br>What is the daylight factor for the spaces in the building? | 1. Daylight factor < 1/20 (Bad)<br>2. Daylight factor 1/20-1/10 (Normal)<br>3. Daylight factor 1/10-1/5 (Better)<br>4. Daylight factor > 1/5 (Best) | The higher the daylight factor for spaces in the building, the more easily a building can be rearranged/transformed to other functions; the better the building can meet changing demands. |
| **4. FACILITIES** | **Measure & Control** | **8. Customisability/controllability**<br>Is it possible to customize the facilities: temperature, ventilation, electricity, ICT? | 1. Bad/not customizable; monofunctional or fixed centralized use (Bad)<br>2. Limited customizable; after drastic interventions (Normal)<br>3. Partly customizable; after simple interventions (Better)<br>4. Good and easy customizable without any interventions (best) | The more facilities are customisable/controllable to respond to changing functional requirements, the easier a building can be rearranged/transformed to other functions; less vacancy/adaptation costs. |
| | **Dimensions** | **9. Surplus of facilities shafts and**<br>Do the facilities shafts and ducts have a surplus of space (heating, cooling, electricity, ICT)? | 1. Shafts and ducts have no surplus at all (Bad)<br>2. 10-30% surplus (Normal)<br>3. 30-50% surplus (Better)<br>4. Surplus of space of more than 50% (Best) | The more surplus facilities shafts and ducts have, the easier a building can be rearranged or transformed to other functions, the better a building can meet to changing user demands. |
| | | **10. Modularity of facilities**<br>Are the facilities assembled by modular components according to the facade planning grid? | 1. No facility is divided in modular components according to the façade planning grid<br>2. 1 of the 4 facilities is divided in modular components according to the grid (Normal<br>3. 2-3 of the 4 facilities are divided according to the façade planning grid (Better)<br>4. All of the 4 facilities are divided according to the façade planning grid (Best) | The more facilities are divided according to the facade planning grid (modularity), the more easily a building can be rearranged to other functions; the better the building can meet changing demands. |
| **5. SPACE** | **Functional** | **11. Distinction between support - infill**<br>To which degree deals the building with the division between support and infill? | 1. < 10% of the building is divided in a support and infill part (Bad)<br>2. 10 - 30% of the building is divided in a support and infill part (Normal)<br>3. 30 - 50% of the building is divided in a support and infill part (Better)<br>4. > 50% of the building is divided in a support and infill part (best) | The more construction components belong to the infill, the easier a building can be rearranged/transformed to other functions, the better a building can meet to changing demands. |
| | **Access** | **12. Horizontal access to building**<br>In what way is the horizontal access of the units in the building accomplished? | 1. Horizontal access is only by a single internal corridor (Bad)<br>2. Horizontal access is by a double internal corridor (Normal)<br>3. Horiz. access directly by a central core in the building with a surrounding corridor<br>4. Horizontal access is directly by a central core in the building, or an external gallery | The more the horizontal disclosure of the units is limited by a central core the more easily units in a building can be rearranged or transformed to other functions. |

Figure 2: The 'support' part of FLEX 4.0; 12 generally applicable flexibility indicators, including 4 assessment values for each indicator and some explaining remarks

### *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).

| FLEX 4.0: SPECIFICALLY APPLICABLE INDICATORS, PART 1 | | | | |
|---|---|---|---|---|
| LAYER | SUB-LAYER | Flexibility Performance | Assessment Values | Remarks |
| 1. SITE | | **1. Surplus of site space**<br>Does the site have a surplus of space and is the building located at the centre? | 1. No, the site has no surplus of space at all (Bad)<br>2. 10-30% surplus (Normal)<br>3. 30-50% surplus (Better)<br>4. The site has a surplus space of more than 50% (Best) | The more surplus space on site, the better the building is expandable (horizontal). |
| | | **2. Multifunctional site/location**<br>Is the location capable to support more functions, like offices, living, care and shops? | 1. Just one function; suited for offices or living or care or shops (Bad)<br>2. Two functions (Normal)<br>3. Three functions (Better)<br>4. > Three functions; suited for offices, living, care and shops as well (Best) | The more a location around a building supports more different functions of the building, the more easily a building can be rearranged or transformed to other functions. |
| 2. STRUCTURE | Measurement | **3. Available floor space of building**<br>Does the building or the user units have a surplus of the needed usable floor space? | 1. No, the building or user units have no surplus of floor space at all (Bad)<br>2. 10-30% surplus (Normal)<br>3. 30-50% surplus (Better)<br>4. The building has a surplus of floor space of > 50% (Best) | The more surplus space a building/user units have, the more easily a building can be rearranged or transformed to other functions, the better a building can meet to changing user demands. |
| | | **4. Size of floor buildings**<br>What is the size of the usable floor surface? | 1. The usable floor space < 400 m2 (Bad)<br>2. 400 - 600 m2 (Normal)<br>3. 600 - 1000 m2 (Better)<br>4. The usable floor space > 1000 m2 (Best) | The larger the size of the usable floor surface the more easily units in a building can be rearranged or transformed to other functions. |
| | | **5. Measurement system**<br>Have positioning/measurement modulare rules for construction components been used? | 1. Rules for modular coordination are not implemented (Bad)<br>2. <50% implemented (Normal)<br>3. >50% implemented (better)<br>4. Rules for modular coordination are > 90% implemented (Best) | The more project independent, demountable and replaceable construction components have been implemented, the more easily a building can be rearranged or transformed to other functions. |
| | | **6. Horizontal zone division/layout**<br>Has use been made of a horizontal zoning system, including intermediate margins? | 1. No zoning system of a zoning system without intermediate margins (Bad)<br>2.Yes, with 10-30% intermediate margins (Normal)<br>3. Yes, with 30-50% intermediate margins (Better)<br>4. Yes, with met > 50% intermediate margins | The more margins are used in the zoning system of the building, the more easily a building/units can be rearranged, extended or transformed to other functions. |
| | | **7. Presence of stairs/elevators**<br>Are sufficient stairs/elevators present in the building? | 1. Only one decentred located stairs/elevator core is available in the building (Bad)<br>2. There is one central located stairs/elevator core available in the building (Normal)<br>3. The building is divided into different wings each with a central stairs/elevator core<br>4. The building has one central and several decentred stairs/elevator cores per wing | The more stairs/elevators are available in the building the more easily a building/units can be rearranged, rejected, extended or transformed to other functions. |
| | | **8. Extension/reuse of**<br>Is there a possibility to add new stairs/elevators to the building and reusing the existing ones? | 1. No stairs/elevators can be added without drastic expensive measures (Bad)<br>2. A new stairs/elevators core can be accidently added and existing reused (Normal)<br>3. New stairs/elevators can be limited added and existing ones reused (Better)<br>4. New stairs/elevators can be easily without drastic expensive measures (Best) | The more stairs/elevators can be added to the building the more easily a building can be rearranged, rejected, extended or transformed to other functions. |
| | Construction | **9. Surplus of load bearing capacity**<br>How large is the load bearing capacity of the floors in the building? | 1. < 3 kN/m2<br>2. 3 - 3,5 kN/m2<br>3. 3,5 - 4 kN/m2<br>4. > 4 kN/m2 and several areas > 8 kN/m2 | The larger the load bearing capacity of floors, the easier a building can be rearranged, transformed to other functions, or vertical extended, the better a building can meet to changing user demands. |
| | | **10. Shape of columns**<br>How are the columns in the building shaped? | 1. The columns are shaped round and/or have vertical different sizes (Bad)<br>2. The columns are shaped octagonal (Normal)<br>3. The columns are shaped rectangular (Better)<br>4. The columns are shaped square (Best) | The less deviate from a square column, the better a building/units can be rearranged (standardized connection of inner walls). |
| | | **11. Positioning of facilities zones**<br>Are facilities zones and vertical shafts located at central building level and/or local unit level? | 1.All facility zones and vertical shafts are only located at central level (Bad)<br>2. Facility zones/shafts are located at central level and occasionally at local level<br>3. Facility zones/shafts are located at central level and limited at local level (Better)<br>4. Facility zones/shafts are located at central level and at local level as well (Best) | The more facility zones/shafts are located at unit level, the easier a building can be rearranged, transformed to other functions. |
| | | **12. Fire resistance main bearing**<br>How many minutes is the fire resistance of the main load bearing construction? | 1. The fire resistance of the load bearing construction is 30 minutes (Bad)<br>2. The fire resistance of the load bearing construction is 60 minutes (Normal)<br>3. The fire resistance of the load bearing construction is 90 minutes (Better)<br>4. The fire resistance of the load bearing construction is 120 minutes (Best) | The higher the fire resistance of the load bearing construction, the easier a building can be rearranged/transformed to other functions, the better a building can meet to changing demands. |
| | | **13. Extendible building/units horiz.**<br>Is it possible to expand the building horiz. for new extension to the building/user units? | 1. Horizontal extension of building/units is not possible at all (Bad)<br>2. Horizontal extension of building/units is very limited possible (only at one side)<br>3. Horizontal extension of building/units is limited possible (at more sides) (Better)<br>4. Horizontal extension of building/units is easily possible at all sides (Best) | The more a building/unit can be expanded, the easier a building can be rearranged or transformed to other functions or expanded, the better a building can meet the changing user demands. |
| | | **14. Extendible building/units vert.**<br>Is it possible to expand the building vertically, for adding new floors or a new basement? | 1. Vertical extension of building/units is not possible at all (Bad)<br>2. Vertical extension is limited possible; only for a few units in the building (Normal)<br>3. Vertical extension (added floor or basement) is possible after total rearrangement<br>4. Vertical extension (new floors/basement & individual user units) is possible (Best) | The more a building/unit can be vertically expanded, the easier a building can be rearranged or transformed to other functions or expanded, the better a building can meet changing user demands. |
| | | **15. Rejectable part of building/unit**<br>Is it possible to reject part of the building for selling/renting to third parties? | 1. It is not possible to reject part of building/units (Bad)<br>2. It is possible to reject 10-30% of the building/units (Normal)<br>3. It is possible to reject 30-50% of the building units (Better)<br>4. It is possible to reject >50% of the building/units (Best) | The more (part of) a building/unit can be vertically rejected, the easier a building can be rearranged/transformed to other functions, the better a building can meet changing user demands. |
| | | **16. Insulation between stories/units**<br>How is the thermal and acoustic insulation between the different storeys in the building? | 1. Insulation does not meet the current demands for office buildings anymore (Bad)<br>2. Meets the current demands for office buildings (Normal)<br>3. Also meets the current demands for housing and care (Better)<br>4. Meets 10% above the current demand for offices, housing and care (Best) | The better the thermal and acoustic insulation between the different storeys, the easier a building can be rearranged/transformed to other functions, the better a building can meet changing demands. |

Figure 3a: The 'infill' part of FLEX 4.0. 32 specifically applicable flexibility indicators, including 4 assessment values for each indicator and explaining remarks (part 1: indicator 1 - 16)

### *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).

| FLEX 4.0: SPECIFICALLY APPLICABLE INDICATORS, PART 2 | | | | |
|---|---|---|---|---|
| **LAYER** | **SUB-LAYER** | **Flexibility Performance** | **Assessment Values** | **Remarks** |
| **3. SKIN** | **Facade** | **17. Dismountable facade**<br>To what extend can facade components be dismantled in case of transformation? | 1. Facade components can not or hardly be dismantled without demolition (Bad)<br>2. A small part of the facade components can be dismantled (> 20 < 50%) (Normal)<br>3. A large part of the facade components can be dismantled (> 50 < 90%) (Better)<br>4. All facade components are easily dismountable (> 90%) (Best) | The more facade components are easily dismountable, the more easily a building can be rearranged or transformed to other functions. |
| | | **18. Location/shape daylight**<br>In what way are the facade/daylight openings positioned and shaped? | 1. There are large closed surfaces in the facade (Bad)<br>2. There are small horizontal open surfaces in the facade (Normal)<br>3. Large open surfaces in the facade, but with different height sizes (Better)<br>4. Large continuous horiz. open surfaces; connections according to planning grid | The more regular open surfaces in the facade according to the planning grid, the better a building can meet changing demands in functions, quality and finishing of the building. |
| | | **19. Insulation of facade**<br>How is the thermal and acoustic insulation quality of the facade of the building? | 1. Insulation does not meet the current demands for office buildings anymore (Bad)<br>2. Meets the current demands for office buildings (Normal)<br>3. Also meets the current demands for housing and care (Better)<br>4. Meets 10% above the current demand for offices, housing and care (Best) | The better the thermal and acoustic insulation of the facade, the easier a building can be rearranged or transformed to other functions, the better a building can meet the changing user demands. |
| **4. FACILITIES** | **Measure & Control** | **20. Measure & control techniques**<br>Is it possible to control/measure facilities on building level as well on user unit level? | 1. Control/measurement takes place only at central building level (Bad)<br>2. On central level and occasionally on unit level (Normal)<br>3. On central level and limited on unit level (Better)<br>4. As well central on building level as well completely on unit level (Best) | The more possibilities for measurement and control of the facilities on unit level, the more easily units in a building can be rearranged or transformed to other functions. |
| | **Dimensions** | **21. Surplus capacity of facilities**<br>Does the capacity of (the sources of) the facilities have a surplus capacity? | 1. The capacities of facilities have no surplus at all (Bad)<br>2. The capacities of facilities have a surplus of 10-30% (Normal)<br>3. The capacities of facilities have a surplus of 30-50% (Better)<br>4. The capacities of facilities have a surplus of > 50% (Best) | The more surplus capacity of the facilities, the easier a building can be rearranged or transformed to other functions, the better a building can meet to changing user demands. |
| | **Distribution** | **22. Distribution facilities**<br>Does the building have a specific distribution facility for hot/cold water, heating, cooling, gas? | 1. There is a specific distribution facility for all the different sources (Bad)<br>2. There is a specific distribution facility for some of the different sources (Normal)<br>3. There is a specific distribution facility for 2 of the different sources (Better)<br>4.There is no specific distribution facility one of the different sources (Best) | The less specific distribution equipment facilities have, the easier a building can be rearranged or transformed to other functions, the better a building can meet the changing user demands. |
| | | **23. Location sources facilities**<br>What is the location of the central facility sources? | 1. The facilities sources are located at only one central location in the building (Bad)<br>2. The facilities sources are located at several locations in the building (Normal)<br>3. The sources are located at a central location and a decentred location as well.<br>4. The sources are located at outside the building at city level (district heating) | The more facility sources are localized at decentred level, the easier a building can be rearranged or transformed to other functions, the better a building can meet the changing user demands. |
| | | **24. Disconnection of facility**<br>Can the components of the facilities be easily disconnected? | 1. Facility (parts) can not be disconnected or demounted; 'wet' connections (Bad)<br>2. Hardly be disconnected, demounted (Normal)<br>3. Partly be disconnected, demounted (Better)<br>4. Facility (parts) can be disconnected very easily (completely demountable) (Best) | The more facility parts can be disconnected or demounted, the easier a building can be rearranged/transformed to other functions, the better a building can meet to changing demands. |
| | | **25. Accessibility of facility**<br>To what extend are facility components good accessible? | 1. Hardly or not accessible (components on support level; concreted in) (Bad)<br>2. Limited accessible (partly on support and infill level) (Normal)<br>3. Good accessible (a lot of components on infill level) (Better)<br>4. Very good accessible; most components at infill level; completely demountable | The higher the accessibility of facilities components, the more easily units in a building can be rearranged or transformed to other functions. |
| | | **26. Independence of user units**<br>In what way are the user units independent related to services as pantry, toilet facilities? | 1. No services available at user unit level (Bad)<br>2. 1 - 2 services available (Normal)<br>3. 3 - 4 services available (Better)<br>4. > 4 services available (Best) | The more services are available at unit level, the more independent the units are opposite other units in the building, the more they meet to individual user demands. |
| **5. SPACE** | **Functional** | **27. Multifunctional building/Units**<br>Is the building capable to support different functions, like offices, living, care and shops? | 1. The building supports only one function (Bad)<br>2. The building supports 2 functions (Normal)<br>3. The building supports 3 functions (Better)<br>4. The building supports > 3 functions (Best) | The more a building supports more different functions of the building, the more easily a building can be rearranged or transformed to other functions. |
| | **Technical** | **28. Disconnectable, removable,**<br>To what extend are the user units in a building removable, relocatable? | 1. The user units in the building are not removable, relocatable (Bad)<br>2. The units are only relocatable with drastic expensive measures (Normal)<br>3. Units are easy relocatable; constructed with demountable components (Better)<br>4. Easy relocatable; constructed with 2D/3D modules, transportable by road (Best) | The more the units consist of demountable and reusable components, the better the units are relocatable to another location in or outside the building. |
| | | **29. Disconnectable, removable,**<br>To what extend are inner the walls in the building easily replaceable? | 1. Inner walls are not replaceable without drastic/expensive interventions (bad)<br>2. Inner walls are not replaceable, but good destructible (Normal)<br>3. Inner walls replaceable by dismantling and rebuilding at another location (Better)<br>4. Inner walls are easily replaceable without radical/expensive interventions (Best) | The more inner walls can be easily replaced, the more easily a building can be rearranged or transformed to other functions, the better a building can meet to changing user demands. |
| | | **30. Disconnectable connection detail**<br>Which detailed construction is applied between the interior walls and support structure and facade? | 1. The detailing connection consists of penetrating connections (Bad)<br>2. The detailing connection consists of wet connections (mortar, sealant, glue)<br>3. The detailing consists of specific project bound connection elements (Better)<br>4. The detailing consists of project unbound dismountable connections (Best) | The easier the connection of interior walls can be dismounted, the easier a building can be rearranged or transformed to other functions, the better a building can meet to changing demands. |
| | | **31. Possibility of suspended ceilings**<br>Is it possible to apply suspended ceilings (-0.20m) and to adapt these to the different user demands? | 1. Suspended ceiling results in free floor height of < 2.60 m (Bad)<br>2. Suspended ceiling results in free floor height of 2.60-2.70m (Normal)<br>3. Suspended ceiling results in free floor height of 2.70-2.80m (Better)<br>4. Suspended ceiling results in free floor height of > 2.80m (Best) | The higher the free storey height, the better the building can meet to changing demands concerning functions, facilities, finishing and quality of the building. |
| | | **32. Possibility of raised floors**<br>Is it possible to apply raised floors and to adapt these to the different user demands? | 1. Raised floor results in free floor height of < 2.6 m (bad)<br>2. Raised floor results in free floor height of 2.60-2.70m (Normal)<br>3.Raised floor results in free floor height of 2.70-2.80m (Better)<br>4. Raised floor results in free floor height of > 2.80m (Best) | The higher the free storey height, the better the building can meet to changing demands concerning functions, facilities, finishing and quality of the building. |

Figure 3b: The 'infill' part of FLEX 4.0. 32 specifically applicable flexibility indicators, including 4 assessment values for each indicator and explaining remarks (part 2: indicator 17 - 32)

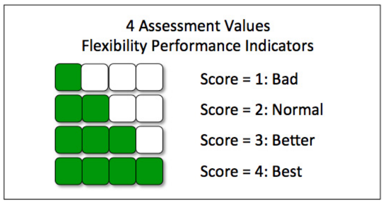


Figure 4: Visual representation of the four possible assessment values of the flexibility key performance indicators, from 1 = Bad to 4 = Best.

### *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).

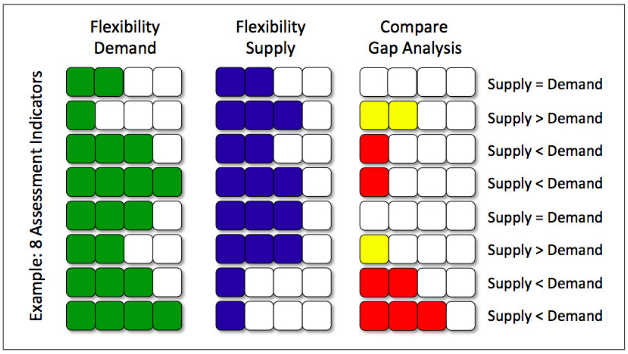


Figure 5: A gap analysis between a user flexibility demand profile and the supplied flexibility profile of a building; in this example based on 8 flexibility indicators (Geraedts 2015)

## *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 x 1 x 12 =) 12 and a maximum score of (4 x 4 x 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.

| Assessment Form 12 Generally Applicable Flexibility Indicators | | | | | | |
|---|---|---|---|---|---|---|
| **Layer** | **Sub-layer** | **Nr** | **Flexibility Performance Indicator** | **Weighting** | **Assessment** | **Score** |
| **1. SITE** | | 1. | Expandable site / location | 1 | 1 | 1 |
| **2. STRUCTURE** | **Measurements** | 2. | Surplus of building space / floor space | 4 | 3 | 12 |
| | | 3. | Surplus of free floor height | 4 | 2 | 8 |
| | **Access** | 4. | Access to building | 2 | 4 | 8 |
| | **Construction** | 5. | Positioning obstacles / columns in load | 3 | 1 | 3 |
| **3. SKIN** | **Facade** | 6. | Facade windows to be opened | 1 | 4 | 4 |
| | | 7. | Daylight facilities | 2 | 3 | 6 |
| **4. FACILITIES** | **Measure/Control** | 8. | Customisability/controllability facilities | 3 | 2 | 6 |
| | **Dimensions** | 9. | Surplus of facilities shafts and ducts | 4 | 3 | 12 |
| | | 10. | Modularity of facilities | 2 | 1 | 2 |
| **5. SPACE PLAN** | **Functional** | 11. | Distinction between support - infill | 4 | 1 | 4 |
| | **Access** | 12. | Horizontal access to building | 3 | 1 | 3 |
| | | | | | **Example of total Flexibility Score:** | **69** |
| | | | | | **Flexibility Class:** | **2** |

| CLASS TABLE FLEXIBILITY SCORES | Score range |
|---|---|
| Class 1: Not flexible at all | 12 - 48 |
| Class 2: Hardly flexible | 49 - 85 |
| Class 3: Limited flexible | 86 - 122 |
| Class 4: Very flexible | 123 - 159 |
| Class 5: Excellent flexible | 160 - 192 |

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 x 1 x 32 =) 32 and a maximum score of (4 x 4 x 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.

| Assessment Form 32 Specifically Applicable Flexibility Indicators | | | | | |
|---|---|---|---|---|---|
| LAYER | SUB-LAYER | Flexibility Performance Indicator | Weighting | Assessment | Score |
| 1. SITE | | 1. Surplus of site space | 4 | 1 | 1 |
| | | 2. Multifunctional site/location | 3 | 1 | 3 |
| 2. STRUCTURE | Measurements | 3. Available floor space of building | 4 | 3 | 12 |
| | | 4. Size of floor buildings | 3 | 4 | 12 |
| | | 5. Measurement system; modular coordination | 3 | 1 | 3 |
| | | 6. Horizontal zone division/layout | 1 | 3 | 3 |
| | | 7. Presence of stairs/elevators | 2 | 2 | 4 |
| | | 8. Extension/reuse of stairs/elevators | 1 | 4 | 4 |
| | Construction | 9. Surplus of load bearing capacity | 2 | 1 | 2 |
| | | 10. Shape of columns | 1 | 3 | 3 |
| | | 11. Positioning of facilities zones and shafts | 3 | 2 | 6 |
| | | 12. Fire resistance main bearing construction | 3 | 4 | 12 |
| | | 13. Extendible building/units horizontal | 2 | 1 | 2 |
| | | 14. Extendible building/units vertical | 4 | 3 | 12 |
| | | 15. Rejectable part of building/unit horizontal | 2 | 2 | 4 |
| | | 16. Insulation between stories and units | 2 | 4 | 8 |
| 3. SKIN | Facade | 17. Dismountable facade | 1 | 1 | 1 |
| | | 18. Location/shape daylight facilities | 2 | 3 | 6 |
| | | 19. Insulation of facade | 1 | 2 | 2 |
| 4. FACILITIES | Measure/Control | 20. Measure & control techniques | 4 | 4 | 16 |
| | Dimensions | 21. Surplus capacity of facilities | 4 | 1 | 4 |
| | Distribution | 22. Distribution facilities | 4 | 3 | 12 |
| | | 23. Location sources facilities (heating, cooling) | 3 | 2 | 6 |
| | | 24. Disconnection of facility components | 3 | 4 | 12 |
| | | 25. Accessibility of facility components | 3 | 1 | 3 |
| | | 26. Independence of user units | 1 | 3 | 3 |
| 5. SPACE PLAN | Functional | 27. Multifunctional building | 2 | 2 | 4 |
| | Technical | 28. Disconnectible, removable, relocatable units | 1 | 4 | 4 |
| | | 29. Disconnectible, removable, relocatable walls | 4 | 1 | 4 |
| | | 30. Disconnectible connection detail inner walls | 4 | 3 | 12 |
| | | 31. Possibility of suspended ceilings | 2 | 2 | 4 |
| | | 32. Possibility of raised floors | 2 | 1 | 2 |
| | | | | Example of total Flexibility Score: | 186 |
| | | | | Flexibility Class: | 2 |

| CLASS TABLE FLEXIBILITY SCORES | Score range |
|---|---|
| Class 1: Not flexible at all | 32 - 128 |
| Class 2: Hardly flexible | 129 - 225 |
| Class 3: Limited flexible | 226 - 322 |
| Class 4: Very flexible | 323 - 419 |
| Class 5: Excellent flexible | 420 - 512 |

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).

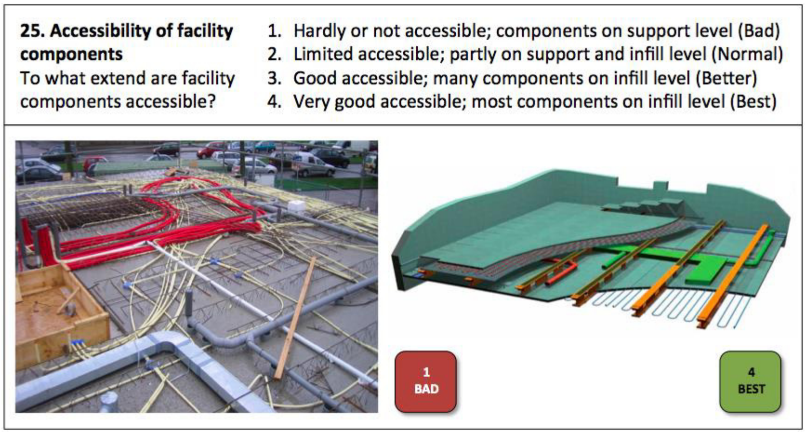


Figure 8: Example of flexibility indicator nr. 25: Accessibility of facilities components; left with the assessment value 1 (Bad) and right with the assessment value 4 (Best).

## 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?

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