Typology of person-environment fit constellations: a platform addressing accessibility problems in the built environment for people with functional limitations

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Abstract

**Background:** Making the built environment accessible for all regardless of functional capacity is an important goal for public health efforts. Considerable impediments to achieving this goal suggest the need for valid measurements of accessibility and for greater attention to the complexity of person-environment fit issues. To address these needs, this study aimed to provide a methodological platform, useful for further research and instrument development within accessibility research. This was accomplished by the construction of a typology of problematic person-environment fit constellations, utilizing an existing methodology developed to assess and analyze accessibility problems in the built environment.

**Methods:** By means of qualitative review and statistical methods we classified the person-environment fit components covered by an existing application which targets housing accessibility: the Housing Enabler (HE) instrument. The International Classification of Functioning, Disability and Health (ICF) was used as a conceptual framework. Qualitative classification principles were based on conceptual similarities and for quantitative analysis of similarities, Principal Component Analysis was carried out.

**Results:** We present a typology of problematic person-environment fit constellations classified along three dimensions: 1) accessibility problem range and severity 2) aspects of functioning 3) environmental context. As a result of the classification of the HE components, 48 typical person-environment fit constellations were recognised.

**Conclusions:** The main contribution of this study is the proposed typology of person-environment fit constellations. The typology provides a methodological platform for the identification and quantification of problematic person-environment fit constellations. Its link to the globally accepted ICF classification system facilitates communication within the scientific and health care practice communities. The typology also highlights how relations between aspects of functioning and physical environmental barriers generate typical accessibility problems, and thereby furnishes a reference point for research oriented to how the built environment may be designed to be supportive for activity, participation and health.

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Introduction

For health promotion and public health efforts, it is vitally important to foster physical environments supportive of activity, participation and health [1]. One aspect which deserves specific attention in this regard concerns the relationship between the person and the built environment [2]. In particular, this relationship concerns the degree to which access to utilities in the environment is facilitated or obstructed, depending on the functional capacity of individuals. Due to the rapidly ageing population more people will live for a longer period of their lives with limited functional capacity. Therefore, accessibility issues can be expected to gain in importance for societal policies concerning the built environment. According to internationally approved policies [3, 4], housing, public buildings and public transportation should be accessible for all citizens, regardless of functional capacity. Nevertheless, serious deficiencies can still be observed, even in countries where legislation is characterized by foresightedness with regard to accessibility problems. To rectify these shortcomings calls for a great variety of measures to be undertaken, but a fundamental condition for such measures to be adequate and efficient is that systematic and objective methods for problem identification are utilized. With the use of reliable and valid methods, the conditions for achieving the goal of making the built environment accessible for all could be improved [5–7].

Theoretically, the concept of accessibility is underpinned by the ecological theory of ageing (ETA) [2], also referred to as the competence-press or person-environment fit model. The ETA defines the person in terms of a set of competencies, and the environment in terms of its demands, labelled environmental press. With the addition of the docility hypothesis [8], stating that those with lower personal competencies are more vulnerable to environmental press whereas those with higher competencies can withstand greater environmental press, the ETA has become one of the most influential person-environment fit theories. Based on the ETA and originating from the so-called Enabler Concept [9], an internationally recognized and research-based methodology for assessing and analyzing accessibility problems in housings [10] is now well established. The Enabler methodology (EM) treats accessibility as a quantifiable person-environment fit measurement, where the personal component consists of functional limitations and the environmental component of barriers in the physical environment. It is thus a composite measurement attaching varying degrees of severity to different person-environment fit constellations [10]. Thereby the measurement permits an analysis that is detailed as well as sensitive to any variation in either of the two components. Methodological research results indicate good predictive value for this measurement, where varying characteristics of the personal component produce different sets of improvement priorities [11, 12]. For example, for groups where limitations in movement are prevalent, the measurement particularly indicates environmental barriers that obstruct mobility as prioritized for removal. Up to now however, the EM has mainly been applied to the housing environment [13]. In order to explore the potential for valid extension of the EM to other environmental arenas, this study aimed to provide a methodological platform useful for further research and instrument development within the field of accessibility research. More specifically, we constructed a typology of problematic person-environment fit constellations, addressing accessibility problems in the built environment for persons with functional limitations.

Background

The enabler methodology

The principal idea of the EM is that a quantitative measurement of accessibility problems can be produced by juxtaposing systematic and structured checklists of environmental features with certain personal characteristics. The environmental checklist is comprehensive in coverage of features that are potentially limiting or hindering access in a given context, such as narrow door openings, high thresholds, absence of handrails etc. The checklist of personal characteristics is delimited to limitations in the functional capacity of an individual [14], such as poor balance, incoordination, limitations of stamina etc., relevant for activities implying access to the environment. Considered as indicators of more severe functional limitations, the personal component also includes use of mobility devices. When juxtaposing the two checklists, the intersections between each personal characteristic and each environmental feature are assigned pre-defined scores on a scale, grading the severity in terms of accessibility problems. For a description of the process of how the severity scores were originally defined by means of expert panels, see [9]. By summing up the scores, an aggregate measure is computed, representing the magnitude of accessibility problems in a particular case [10]. Based on the original scoring of the Enabler Concept [9], the scoring has been successively validated over the years, taking advantage of the results of empirical research as well as expert opinions from different professions, such as occupational therapy and architecture [13].

This methodology has been successfully applied in an instrument targeting accessibility of the housing environment (which is here considered as one environmental arena), the Housing Enabler (HE) [10]. That means one essential element needed for an extension of the
methodology to other environmental arenas is already in place. That is, the HE checklist for identification of functional limitations is appropriate regardless of the environmental arena. On the other hand, the HE checklist for environmental barriers only covers the housing environment arena, and to adequately assess for example public buildings, shopping malls, theaters, bus stops etc., new lists of barriers have to be compiled (see e.g. [15]). Moreover, to establish valid scores of severity when juxtaposing each new environmental barrier to each functional limitation is challenging and requires additional methodological efforts. This is one of the most important reasons why despite of considerable research efforts throughout several years (see e.g. [16]), results are still not comprehensive enough for a valid extension of the EM to other environmental arenas. As a methodological approach that could provide a valid basis for a scoring rationale in a simplified manner, we therefore opted for the construction of a classification system. That is, to sort out and classify the dimensions essential to capture accessibility problems on a general level. The severity scores for new environmental barriers could then ideally be established just by finding its proper classification.

Methods
Typology construction as a methodological approach
A multi-dimensional classification system based on conceptual similarities is commonly referred to as a typology [17]. As dimensions essential to capture accessibility problems we considered: 1) the range and severity of problems generated, 2) the implied aspects of functioning of the individual (vision, mobility etc.), and 3) the environmental contexts where the barriers may occur (the kitchen, the bathroom etc.). We made use of the inherent elements and properties of the HE for the classification of these three dimensions. The HE comprises a checklist of 161 environmental barrier items [10]. Each barrier item has a descriptive label attached, designating barrier characteristics, such as “Paths narrower than 1.5 m”, “High thresholds at entrance more than 15 mm” etc. Further, for each barrier item there is a 14-position scoring pattern, where the scores denote severity of accessibility problems related to 14 functional limitations of the individual. Table 1 shows the 14 functional limitations of the HE that the scoring patterns are related to.

The scoring positions of the patterns are graded from 0 to 4 (0 = no problem, 1 = potential problem, 2 = problem, 3 = severe problem, 4 = impossibility). When constructing the typology the scoring patterns and the pool of the 161 environmental barrier specifications constituted the data to be classified. That is, we did not use any empirical data but only the content and scoring

| Functional limitation | Position of scoring pattern |
|-----------------------|----------------------------|
| Difficulty in interpreting information | 1 |
| Severe loss of sight | 2 |
| Complete loss of sight | 3 |
| Severe loss of hearing | 4 |
| Prevalence of poor balance | 5 |
| Incoordination | 6 |
| Limitations of stamina | 7 |
| Difficulties in moving head | 8 |
| Difficulty in reaching with arms | 9 |
| Difficulty in handling and fingering | 10 |
| Loss of upper extremity skills | 11 |
| Difficulty in bending, kneeling, etc. | 12 |
| Reliance on walking aids | 13 |
| Wheelchair user | 14 |

*The Housing Enabler instrument [10]

1/ Classification of the accessibility problem range and severity
To classify the accessibility problem range (i.e., based on the functional limitations involved) and severity (i.e., as indicated by the scoring patterns), we first applied a statistical approach using Principal Component Analysis (PCA) (see e.g. [18, 19]) to the pre-defined severity scores of the HE instrument. We thus ran a PCA on the scoring patterns of the 161 environmental barrier items, that is, the bivariate between-barrier correlations of the barriers’ 14 severity scores. In simple terms we thereby aimed to identify groups of similar scoring patterns inherent in the HE. PCA is well suited for this task, as it basically adopts a purely data descriptive algorithm, which decomposes the overall covariation of the scoring patterns comprised in the correlation matrix into unique orthogonal components and does not imply distributional assumptions. Notably, PCA is based on a kind of grouping of the items analyzed according to their similarity in terms of correlation. A high correlation of the scores assigned to each of a given pair of environmental barriers means that they have a similar pattern of range and severity in generating accessibility problems across the 14 functional limitations. That is, both environmental barriers would provide relatively high or low risks of accessibility problems across the same functional limitations. Note however, that this does not necessarily mean that they generate problems of equal severity, as we did not intend to analyze the environmental barriers due to the absolute equality of the pre-defined severity scores.
Hence, the loadings obtained from the Varimax rotated factor solution (for computational details, see [18]) was used to group barriers with similar patterns of their scores across the 14 functional limitations. Each group of similar scoring patterns thus constitutes a class of this dimension of the classification system.

Though this statistical approach provided an initial classification, it was considered to need an additional qualitative review, as the component output, by the inherent rationale of the procedure, would not be distinct enough to to be valid for our particular purpose. That is, in statistical terms the similarities in a typology should demonstrate minimum within-group variance and maximum between-group variance [20], which is not entirely the case regarding the PCA output. Therefore we proceeded in a second, complementary analytic step. Principal components that included scoring patterns which we considered as too varied were further subdivided by means of qualitative review. The classification was finalized during consensus discussions.

Further, in order to achieve the unified scoring patterns needed for generalizability, we made a final balancing of the original scoring patterns included. For example, if there were five scoring patterns included in a class and three of them had a severity grade 2 for a certain position, while the others had a severity grade 3, we needed to choose between these. This was done by calculating the mean scores (rounded to integer values) for each position of the scoring patterns. Mean scores were chosen because they designate minimum deviance (i.e., variance) of the scoring patterns subsumed.

2/ Classification of the aspects of functioning

Since components of functioning and disability such as “Body Function and Structures”, “Activities and Participation”, “Environmental Factors” and “Personal Factors” are relevant in this context, we decided to use the International Classification of Functioning, Disability and Health (ICF) [21] as a conceptual framework. The underlying idea of problematic person-environment fit constellations is the assumption that environmental barriers as such do not generate accessibility problems, but may do so when connected to certain aspects of physical functioning [22]. For instance, high kerbs may constrain walking and too high/low seats may constrain sitting for people with difficulties bending and kneeling, and hence generate accessibility problems. In other words, the accessibility problems are specific to an individual; what hinders one person might not be an issue for someone else.

The classification of aspects of functioning was carried out in an iterative process, by means of qualitative...
review and consensus discussions. Four researchers with documented practical and scientific experience of accessibility assessments and methodological development were engaged (see e.g. [13, 23–25]). In the first step of the process one of the researchers reviewed a list where the 161 barrier items were sorted according to the PCA output (as described above). Doing so aided the classification of aspects of functioning, as similarities in scoring patterns often, though not always, imply similar functioning. The guiding classification principle was to find the ICF classification that most closely corresponded to the aspect of functioning implied by the barrier specification, together with the functional limitations involved, as indicated by the scoring patterns. If more than one aspect of functioning was involved, the predominant aspect—in terms of severity—was noted first in order. Following this step, the other researchers reviewed the proposed classification, and suggested alterations and adjustments. After repeated consensus discussions, the classification was finalized when all classifications were agreed upon.

3/ Classification of the environmental contexts
Classification by environmental contexts was done in parallel and independently of the other two dimensions. Although the ICF also considers environmental factors as something external that may influence the individual’s capacity [21], the categories specified therein are not related to detailed features of the built environment. That is why the ICF was not used for this dimension. Instead, we basically used the headings and subheadings from the HE instrument manual to classify the environmental barriers according to environmental context. For reasons of parsimony some headings were merged (such as entrance doors and ramps) when forming the classes. The HE checklist of barriers in the housing environment is to some extent general with respect to the environmental context in which the barriers occur. Barriers such as the width of door openings, insufficient maneuvering space, controls placed too high or too low, etc., contain features that evidently occur also in other environmental arenas [16].

The typology of person-environment fit constellations
Finally, the typology of person-environment fit constellations was constructed by combining the classifications of all three dimensions. The groups with common characteristics thus generated are the types of the typology [26]. In this study the types are the particular combinations of aspects of functioning as related to the environmental contexts that generate accessibility problems of a certain range and severity. The types were sorted according to the ICF framework, and labelled by the order in which they appear in the typology, beginning with T1.

Results
By use of the PCA we first arrived at 13 principal components (as each barrier got scores for 14 functional limitations), that accounted for the total variation of the scores across the functional limitations. After further subdivision and final balancing of the scoring patterns included in these 13 initially identified principal components, the classification of accessibility problem range and severity (as quantified by the scoring patterns) ended up with 48 different classes, labeled T1 to T48. Five of these classes of scoring patterns covered ten or more environmental barriers, while fifteen covered just one.

As a result of the classification according to the ICF, five different blocks of functioning—all under the “Activity and Participation” component of the ICF—were recognized as predominant. They represented “Learning and Applying Knowledge”, “Communication” and “Mobility”, either alone or in combination. “Purposeful sensory experiences” was predominant for types T1-T4, “Applying knowledge” for T5-T6, “Changing and maintaining body position” for T7-T17, “Carrying and handling objects” for T18-T33 and “Walking and moving” for T34-T48. Three additional ICF blocks of functioning occurred as subordinated. In total the functioning blocks covered 28 different functioning categories. The classification of the environmental context dimension resulted in nine different classes. The contexts with the highest frequencies of environmental barrier items were “Hygiene area” (28 items), “Kitchen/Laundry/Utility kitchen” (24 items) and “Stairs” (22 items). Table 2 gives an overview of the 48 types with regard to the two dimensions aspects of functioning and environmental contexts.

The functioning blocks “Walking and moving” and “Purposeful sensory experiences” were represented in all environmental context classes. “Applying knowledge” and “Changing and maintaining body position” were represented in all classes except “Sitting out place/balcony/supplementary housing facility” and “Parking”, respectively.

Combining all three dimensions into a typology highlights their complex internal relations. In Table 3 the typology of the 48 typical person-environment fit constellations is provided, and each type is exemplified with an environmental barrier of the HE.

Most of the types, even those that cover ten or more environmental barrier items, showed a high degree of homogeneity in the aspects of functioning implied. However, many types were represented in several environmental contexts, as exemplified in Fig. 2. Eight environmental barrier items were covered by T17, occuring
in three different environmental contexts. Accessibility problems generated by T17 all have the severity grade scored 1, related to “Poor balance”, “Incoordination”, “Limitations of stamina” and “Reliance on walking aids” (positions 5, 6, 7 and 13 of the scoring pattern). That is, several functional limitations are involved, but the severity grade is low. For T28 three items were covered, all identical in the aspects of functioning implied, but each recognized in a different environmental context. Accessibility problems scored 3 in T28 were related to “Limitations of stamina” and “Reliance on walking aids” (positions 7 and 13 of the scoring pattern), while accessibility problems scored 1 were related to “Difficulty in handling and fingering” and “Wheelchair use” (positions 10 and 14 of the scoring pattern).

**Discussion**

By the construction of a typology of person-environment fit constellations we have provided a novel platform for further studies and instrument development within the field of accessibility research. This was achieved by classifying the inherent elements and properties of an existing instrument targeting housing accessibility. Similarities as well as differences in how typical accessibility problems are manifested as physical barriers in the environment are made more easily recognized.

As evidenced by Table 3, the typology of person-environment fit constellations covers accessibility problems of a varied range and severity, within the ICF framework stretching from “Purposeful sensory experiences” to “Moving around using equipment. Even though the housing environment—constituting only one out of several different environmental arenas where people live their lives—can not be presumed to cover all possible person-environment fit constellations that creates accessibility problems, the typology provides a basis for the extension of the EM to other environmental arenas. The scoring of accessibility problems, generated by juxtaposing each environmental barrier with each functional limitation, is thereby connected to general person-environment fit constellations. Hence, when creating new checklists for other environmental arenas, providing the severity scores is ideally only a matter of finding the proper classification. By tracing which aspects of functioning that can be related to the new barriers, it should be possible to recognize similarities and find existing scoring patterns that are already present in the typology.

A practical example of the relevance and usability of the typology might be that an instrument applicable for assessing the accessibility of entrances at public facilities is sought for. First environmental barriers in that context should be determined, for instance “Visual information signs that are difficult to read at an appropriate distance”. Next, the implied aspects of functioning in terms of the ICF classification should be identified, in this case “Purposeful sensory experiences” and “Applying knowledge”. Finally, by scrutinizing aspects of functioning, range and severity of the accessibility problem and with the help of existing examples of environmental barriers given in the typology, an appropriate scoring pattern can ideally be established. In this example, “Purposeful sensory experiences” and “Applying knowledge” are predominant aspects in types T2-T3 and T5-T6. The barrier

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**Table 2** Overview of the 48 types with regard to aspects of functioning and environmental context, as they are represented in the HE checklist for the housing environment. The types are listed by their predominant aspect of functioning.

| Type     | Aspect of functioning, ICF blockb | Environmental contexta |
|----------|----------------------------------|-------------------------|
|          |                                  | Paths & roadway/ seating places | Parking doorway/ ramps | Entrance door/ ramps | Stairs | Lifts | Hygiene area | Kitchen/ laundry/ utility kitchen | Indoor, except hygiene/ kitchen | Sitting out place/balcony/ suppl housing facilities |
| T1 - T4  | Purposeful sensory experiences    | X (X)                    | X X X (X)             | X (X)             | X X (X) | X | X (X)       | X (X)       | X | X |
| T5 - T6  | Applying knowledge               | (X) (X)                  | (X) (X)               | X X X X           | X | X | X | X | X | X |
| Subordinated | Communicating, receiving        | (X) (X)                  | (X) (X)               | (X) (X)           | (X) | (X) | (X) | (X) | (X) |
| Subordinated | Conversation and use communication devices | (X) (X)                  | (X) (X)               | (X) (X)           | (X) | (X) | (X) | (X) | (X) |
| T7 - T17 | Changing and maintaining body position | X (X)                    | X X X X               | X X X X           | X | X | X | X | X |
| T18 - T33| Carrying, moving and handling objects | X (X)                    | X X X X               | X X X X           | X | X | X | X | X |
| T34 - T48| Walking and moving               | X X X                   | X X X X               | X X X X           | X | X | X | X | X |
| Subordinated | Moving around using transportation | (X) (X)                  | (X) (X)               | (X) (X)           | (X) | (X) | (X) | (X) | (X) |

**Note:** crossmark in parenthesis indicates occurrence only where aspect of functioning is subordinated

bBasically headings/subheadings from the Housing Enabler instrument [10]

aInternational Classification of Functioning, Disability and Health [21]

*N* = 161 items
Table 3: Typology of 48 typical person-environment fit constellations, with the ICF as conceptual framework and scoring patterns that quantify range (i.e. functional limitations/use of mobility devices involved) and severity of accessibility problems.

| Type | Accessibility problem | Aspect of functioning$^b$ | ICF block | ICF category | Environmental context | Environmental barrier example$^c$ | No of items |
|------|-----------------------|---------------------------|-----------|--------------|-----------------------|----------------------------------|-------------|
| T1   | 0400000000000000      | Purposeful sensory experiences | Watching | Stairs, Kitchen/laundry room/utility kitchen | Poor illumination of walking area and/or handrails. | 3 |
| T2   | 1300000000000000      | Purposeful sensory experiences/Applying knowledge | Watching/Focusing attention | Paths and roadways/Seating places Stairs | Visual pattern on the surface of stair treads camouflages edges of treads. | 5 |
| T3   | 1330001000000111      | Purposeful sensory experiences/Applying knowledge/Walking and moving | Watching/Focusing attention/ Walking short distance | Entrance door/ramps Lifts Kitchen/laundry room/utility kitchen Paths and roadways/ Seating places Indoor, except hygiene/ kitchen Entrance door/ramps Stairs | Complicated/illogical routes to/from entrance. | 9 |
| T4   | 0003003000000111      | Purposeful sensory experiences/ Changing and maintaining body position | Listening/Maintaining a standing position | Lifts | No visual signal when the lift arrives. | 1 |
| T5   | 4230000000000000      | Applying knowledge/Purposeful sensory experiences/Communicating, receiving/ | Applying knowledge, other specified/ Watching/Non-verbal messages | Lifts/Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/ kitchen | Illogical design of controls. | 4 |
| T6   | 333003000110000      | Applying knowledge/Purposeful sensory experiences/Use of communication devices/Carrying, moving and handling objects | Applying knowledge/Watching/Using communication device Manipulating | Entrance door/ramps Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/ kitchen | Complicated/illogical opening procedure. Also includes entry phone. | 4 |
| T7   | 000000030000000      | Changing and maintaining body position | Standing | Kitchen/laundry room/utility kitchen | Low working surfaces | 1 |
| T8   | 000000030000000      | Changing and maintaining body position | Sitting/Standing | Hygiene area | Wash-basin placed at a height for use only when standing | 2 |
| T9   | 000000000000010      | Changing and maintaining body position | Maintaining a standing position | Hygiene area | Grab bars in low position. | 1 |
| T10  | 0000000000000110     | Changing and maintaining body position | Maintaining a standing position | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Controls in low position | 3 |
| T11  | 000020100000023      | Changing and maintaining body position | Sitting/Standing/Maintaining a sitting/standing position/ | Kitchen/laundry room/utility kitchen Hygiene area Sitting out place/balcony/ suppl housing | No surface at a height suitable for sitting while working. | 5 |
| T12  | 000100000000332      | Changing and maintaining body position | Sitting/Standing/Maintaining a sitting/standing position | Hygiene area | Insufficient space for stool, bath board, or equivalent, or other problem in shower/bath. | 3 |
| T13  | 000000000000001      | Changing and maintaining body position | Transferring oneself while sitting | Hygiene area | Toilet 48 cm or higher. Including seat. | 2 |
| T14  | 001001012100000      | Changing and maintaining body position/Purposeful sensory experience | Maintaining a sitting position/ Watching | Hygiene area | Toilet roll holder in inaccessible position | 1 |
| T15  | 111033300000141      | Changing and maintaining body position/Purposeful sensory experiences/ Applying knowledge | Maintaining a standing position/ Watching/Focusing attention | Hygiene area Stairs | No grab bar at shower/bath and/or toilet. | 3 |
| Table 3 Typology of 48 typical person-environment fit constellations, with the ICF as conceptual framework and scoring patterns that quantify range (i.e. functional limitations/ use of mobility devices involved) and severity of accessibility problems (Continued) |
|---------------------------------------------------------------|
| T16 000032300000030 Changing and maintaining body position/Walking and moving | Maintaining a standing position Walking | Lifts Paths and roadways/Seating places | No seat in lift. | 2 |
| T17 000011100000010 Changing and maintaining body position/Walking and moving | Maintaining a sitting/standing position/Climbing stairs | Stairs Lifts Paths and roadways/Seating places | Handrails placed too high/low | 8 |
| T18 00000000320000 Carrying, moving and handling objects | Carrying in the hands | Kitchen/laundry room/utility kitchen | Hobs with ordinary rings. Also includes gas stoves, coil stoves, etc. | 1 |
| T19 00000000024000 Carrying, moving and handling objects | Grasping/Manipulating/Releasing Turning or twisting | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen Lifts | Use requires fingers (i.e. isolated grip, e.g. pinch and lateral grip). | 10 |
| T20 00000000034010 Carrying, moving and handling objects | Hand and arm use, other specified | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Use requires hands. | 3 |
| T21 02200000032000 Carrying, moving and handling objects/Purposeful sensory experiences | Manipulating/Turning or twisting/Watching | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Very small controls. | 3 |
| T22 01101101300013 Carrying, moving and handling objects/Purposeful sensory experiences/Changing and maintaining body position | Reaching/Watching/Maintaining a sitting/standing position | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Inappropriate design of wardrobes/clothes cupboards. | 2 |
| T23 0304332434334 Carrying, moving and handling objects/Purposeful sensory experiences/Changing and maintaining body position | Reaching/Watching/Maintaining a sitting/standing position | Kitchen/laundry room/utility kitchen | Wall-mounted cupboards and shelves placed high | 1 |
| T24 10000300010010 Carrying, moving and handling objects/Applying knowledge | Grasping/Manipulating/Releasing/Focusing attention | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Use requires intact fine motor control. | 3 |
| T25 20100200011010 Carrying, moving and handling objects/Applying knowledge | Grasping/Manipulating/Releasing/Applying knowledge, other specified | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Complex manoeuvres (more than one operation/movement) and good precision required. | 3 |
| T26 10000200014030 Carrying, moving and handling objects/Applying knowledge | Hand and arm use, unspecified/Focusing attention | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Use requires two hands. | 3 |
| T27 00000002311024 Carrying, moving and handling objects/Changing and maintaining body position | Reaching/Maintaining a sitting/standing position | Lifts Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | Controls placed too high/low. Refers to both outside and inside the lift | 5 |
| T28 0000030010031 Carrying, moving and handling objects/Changing and maintaining body position | Grasping/Manipulating/Maintaining a body position, other specified | Kitchen/laundry room/utility kitchen Hygiene area Indoor, except hygiene/kitchen | High force required to activate controls. | 3 |
| T29 00033330304033 Carrying, moving and handling objects/Changing and maintaining body position | Pushing/Pulling/Maintaining a sitting/standing position | Entrance door/ramps Lifts | Heavy doors without automatic opening. | 2 |
| T30 0000001004414 Carrying, moving and handling objects/Changing and maintaining body position | Pushing/Pulling/Maintaining a sitting/standing position | Kitchen/laundry room/utility kitchen | Door swings (inner doors) which impede accessibility to storage units. | 1 |
| T | Subject Area | Specification | Problem | Difficulty |
|---|-------------|--------------|---------|------------|
| T31 | Carrying, moving and handling objects/Changing and maintaining body position | Reaching/Maintaining a sitting/standing position | Sitting out place/balcony/suppl housing | Refuse bin difficult to reach |
| T32 | Carrying, moving and handling objects/Changing and maintaining body position | Reaching/Maintaining a sitting/standing position | Kitchen/laundry room/utility kitchen | Shelves too deep. Deeper shelves require pullout shelves/turntable units. |
| T33 | Carrying, moving and handling objects/Changing and maintaining body position | Reaching/Maintaining a sitting/standing position | Hygiene area | Grab bar difficult to reach/inaffably positioned (NOT as regards height). |
| T34 | Walking and moving | Moving around using equipment | Paths and roadways/Seating places Entrance door/ramps Lift Sitting out place/balcony/suppl hous Indoor, except hygiene/kitchen | Insufficient manoeuvring space at seating places. |
| T35 | Walking and moving/Purposeful sensory experiences | Walking/Moving around using equipment/Watching | Paths and roadways/Seating places Sitting out place/balcony/suppl housing Entrance door/ramps Lifts Indoor, except hygiene/kitchen | Irregular/uneven surface (irregular surfacing, joins, sloping sections cracks, holes). |
| T36 | Walking and moving/Purposeful sensory experiences | Walking/Moving around using equipment/Watching | Parking | Passenger loading zones far from entrance. |
| T37 | Walking and moving/Purposeful sensory experiences | Walking/Moving around using equipment/Watching | Parking Paths and roadways/Seating places | No stable, even, non-slip surface in car park (loose gravel, sand, clay, etc.). |
| T38 | Walking and moving/Purposeful sensory experiences | Climbing stairs/Moving around using equipment/Watching | Stairs | Projecting nosing/open-riser stairs. |
| T39 | Walking and moving/Purposeful sensory experiences | Moving around using equipment/Watching | Paths and roadways/Seating places Entrance door/ramps | Furniture placed in the path of travel. |
| T40 | Walking and moving/Purposeful sensory experiences | Moving around using equipment/Watching | Entrance door/ramps | Door swing that obstructs use. Refers to door leaves that obstruct when opening and/or closing. |
| T41 | Walking and moving/Purposeful sensory experiences/Applying knowledge | Walking/Moving around using equipment/Watching/Applying knowledge, other specified | Entrance door/ramps Lift | Doors that do not stay in open position/close quickly. |
| T42 | Walking and moving/Purposeful sensory experiences/Applying knowledge | Walking/Climbing stairs/Moving around using equipment/Watching/Applying knowledge, other specified | Paths and roadways/Seating places Stairs | Routes with steps. |
| T43 | Walking and moving/Purposeful sensory experiences/Applying knowledge | Walking/Moving around using equipment/Watching/Focusing attention | Paths and roadways/Seating places | Poor/uneven/dazzling lighting along circulation paths. |
| T44 | Walking and moving/Purposeful sensory experiences/Applying knowledge | Walking/Moving around using equipment/Watching/Focusing attention | Lifts | Wide gap between the lift and the building floor. |
Table 3: Typology of 48 typical person-environment fit constellations, with the ICF as conceptual framework and scoring patterns that quantify range (i.e. functional limitations/use of mobility devices involved) and severity of accessibility problems (Continued)

| Type | Description | Environment, Other | Severity |
|------|-------------|--------------------|----------|
| T45  | 30000003000033 | Walking and moving/Applying knowledge | Moving around using equipment/ Applying knowledge, other specified | Parking | No marked parking for people with functional limitations within 10 m of the entrance. |
| T46  | 40001140000012 | Walking and moving/Applying knowledge | Walking/Applying knowledge, other specified | Parking | Parking place far from entrance. |
| T47  | 00000200000034 | Walking and moving/Changing and maintaining body position | Moving around using equipment/ Maintaining a body position, other specified | Indoor, except hygiene/kitchen | Insufficient manoeuvring spaces where turning is necessary. |
| T48  | 00003330000033 | Walking and moving/Moving around using transportation/Changing and maintaining body position/Carrying, moving and handling objects | Walking/Using transport/Moving around using equipment Maintaining a standing position/ Climbing stairs/Pushing/Pulling | Paths and roadways/Seating places Entrance door/ramps Sitting out place/ balcony/suppl housing Lifts Parking | Rough/unstable ground at seating places |

Note: a type is defined by the combination of characteristics of a particular person-environment fit constellation

*For functional limitations related to each position of the scoring pattern, see Table 1. Severity grades from 0 (=no problem) to 4 (=impossibility)

International classification of functioning, disability and health [21]

Environmental barrier items from the Housing Enabler checklist for the housing environment [10]
### Aspects of functioning

**ICF block** | **ICF category** | **Environmental context** | **Accessibility problem range and severity**
---|---|---|---
**Type T17** | Changing and maintaining body position | Paths and roadway / seating places | Stairs | Lifts | Hygiene area | Kitchen/laundry/ utility kitchen | Indoor, except hygiene/kitchen | Scoring pattern: 00001110000010
| Maintaining a sitting position | Low/high seating surfaces / no armrest | | | | | | |
| | Handrails at entrance placed too high/low | Lift stops abruptly | | | | | |
| | Handrails indoors placed too high/low | No handrail in lift | | | | | |
| | Handrails at entrance too short and/or interrupted at landing | | | | | | |
| | Handrails indoors too short and/or interrupted at landing | | | | | | |
| Walking and moving | Climbing stairs | There are stairs, but all necessary dwelling functions are located on the ground floor | | | | | |

**Type T28**

| Carrying, moving and handling objects / Changing and maintaining body position | Paths and roadway / seating places | Stairs | Lifts | Hygiene area | Kitchen/laundry/ utility kitchen | Indoor, except hygiene/kitchen | Scoring pattern: 000000000100031
|---|---|---|---|---|---|---|---|
| Grasping / Manipulating / Maintaining a body position | | | | | | | |
| | Controls on hardware require high force to activate | Controls on hardware require high force to activate | Controls on hardware require high force to activate | | | | |

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Fig. 2 Examples from the typology of individual manifestations of person-environment fit constellation in the housing environment, types T17 and T28. For functional limitations related to each position of the scoring pattern, see Table 1. Severity grades from 0 (=no problem) to 4 (=impossibility). Note: a type is defined by the combination of characteristics of a particular person-environment fit constellation.

in question does not relate to “Walking and moving”, which is included in T3; it might relate to “Communicating, receiving” but is not related to “Blindness” which is included in the scoring pattern of T5. The barrier is neither related to “Use of communication devices”, nor to “Carrying, moving and handling objects” as included in T6, which means that the most appropriate of the existing scoring patterns seems to be that of T2. However, the reliability of this procedure as well as the validity of the scoring patterns identified for new environmental barrier items remain to be tested.

Likewise, the typology allows for scanning of contexts to which environmental barriers of a particular type are concentrated. This is exemplified in Fig. 2, where five out of eight T17 barriers are concentrated to stairs. The same kind of illustrations as exemplified in Fig. 2 can be provided for all 48 types, thus providing a full overview. Accordingly, the typology may serve as an inventory tool of problematic person-environment fit constellations with the potential to aid future instrument development useful for accessibility research.

**Study limitations**

The way we used the ICF calls for a comment. Environmental factors according to the ICF embrace a broad range of aspects that make up the physical, social and attitudinal environment in which people live their lives, from the immediate environment to overarching systems in the society, such as infrastructure and policies [21]. That is, the physical environment in terms of the natural and built environment is not described in sufficient detail. For a comprehensive understanding of how disability is generated by the interaction of environmental factors and the individual however, more detailed knowledge of the environment is needed [27]. By considering the environmental barrier specifications of the HE together with the range and severity of accessibility problems, information on the interaction of the environment and the individual was gained and made the classification process feasible. Even though our approach is not consistent with the procedure for linking items to the ICF as described by others (see e.g. [28]), using the ICF as a guiding conceptual framework contributed to the development of further knowledge on how health-related domains are related to environmental barriers and the subsequent generation of accessibility problems.

The choice of PCA as the statistical tool for the classification of accessibility problem range and severity (quantified as scoring patterns), also needs to be discussed. As an alternative analytic approach we considered Cluster Analysis (CA) [18], which is traditionally recommended for classification purposes (see e.g. [17]). In contrast to PCA, CA implies a definition of similarity in terms of the absolute values of the scores, meaning that two environmental barrier items are similar to the degree of equality of their scores. However, this
implicit concept of similarity may be too restrictive with respect to the overarching analytical aim of the present study. This expectation was confirmed when we initially run CA to test its feasibility for our purpose, trying out several hierarchical clustering algorithms which altogether did not reveal any clear-cut cluster solution. Thus, it seems that the environmental barriers of the HE are not strictly clustered into few groups according to their scores across the 14 functional limitations. In addition, it should also be considered that the limited score range (0 to 4) means that if the scoring patterns of two environmental barriers are highly correlated, the pair-wise differences between the scores cannot be too large, implying also some degree of similarity in terms of absolute values of the scores. If so, CA would not provide at all much additional benefit compared with PCA.

The proposed typology may appear to be too specific as many of the presumed typical constellations only cover one environmental barrier item. However, any typology is bound to be arbitrary to some extent, as there is a need to select a limited number of attributes from a universe of possible choices [20, 29]. The attributes chosen must strike a balance between being too few and therefore too general, versus being too many and thereby too specific. Moreover, it has to be kept in mind that the typology so far is based on an instrument specifically targeting the housing environment. For example, the constellation that in this typology is only manifested by the absence of visual signal when the lift arrives concerns an environmental barrier that obstructs access in relation to loss of hearing. In public environmental arenas, there are probably many more manifestations of environmental barriers obstructing access in relation to loss of hearing that would be covered by this constellation [30]. Thus, this is an example that demonstrates the potential of the typology to be useful for efforts that aim to extend the EM to other environmental arenas.

Yet, the typology proposed represents a first exploratory step and further methodological research is needed before it can be validly used in various environmental arenas. There are also considerable opportunities for improvement of visual guidelines and display of the typology, including to give the types more meaningful labels in order to facilitate its use as inventory of person-environment fit constellations.

Conclusions
The main contribution of this study is the proposed typology of person-environment fit constellations, based on an existing, internationally acknowledged instrument for assessment and analyses of housing accessibility. Besides being an elegant solution for the extension of the EM to other environmental arenas, it provides a novel methodological platform for the identification and quantification of problematic person-environment fit constellations. Its link to the globally accepted ICF classification system is an advantage, as it facilitates communication within the scientific and health care practice communities. The typology has the advantage of reducing the complexity of reality into a simplified and structured scheme, thus rendering similarities as well as differences more easily detectable. The elucidation of the relations between the dimensions of physical functioning, environmental contexts and scoring patterns contributes to the knowledge base necessary to advance in the field of accessibility research. Since it nurtures reflections on the interaction of functional limitations and environmental barriers in different contexts, the typology furnishes a reference point for further research, ultimately aiming for an environment supportive of activity, participation and health for all.

Abbreviations
CA: Cluster analysis; EM: Enabler methodology; ETA: Ecological theory of ageing; HE: Housing enabler; ICF: The International classification of functioning, disability and health; PCA: Principal component analysis; WHO: World Health Organisation.

Competing interests
In terms of financial interests, BS and SI are the copyright holders and owners of the Housing Enabler (HE) instrument and software, provided as commercial products. The other authors have no competing interests.

Authors’ contributions
BS conceived of the study and drafted the manuscript. OS carried out the statistical analysis. BS, GC and SI conducted the classification. All authors reviewed several versions of the manuscript, read and approved the final version.

Authors’ information
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