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Developing non-exercise activity thermogenesis (NEAT) through building design

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Purpose: Physical inactivity has a considerable negative impact on health. Physical activity has reduced partly due to workplace and lifestyle changes, causing people to spend more time in buildings and increasing sedentary behaviour. This problem presents a largely untapped opportunity for designers and managers to improve building users' health by designing buildings that raise users' Non-Exercise Activity Thermogenesis (NEAT) levels. In this research a conceptual model was developed to assess buildings' performance in providing NEAT-promoting opportunities through building design features and management, in relation to building users' propensity for NEAT behaviours.

Design/methodology/approach: The conceptual model was developed by a multi-disciplinary team of researchers and data to populate the model was obtained through a survey of 75 buildings in Jakarta (Indonesia).

Findings: the presented proof-of-concept shows that the model's 'meso-scale' approach to study physical activity and building design can lead to potential improvements of NEAT levels and physical activity in buildings.

Originality: The review of precedent models shows that this subject has been researched at micro-scale (i.e. detailed monitoring of individuals' movement) and macro-scale (i.e. epidemiological studies of populations' health). The presented model is original as it explores a 'meso-scale'(i.e. building scale) that is unique.

Keywords: Active design, building design, design tools; user behaviour

1 Introduction

Physical inactivity is an important factor contributing to obesity and related conditions (Ng and Popkin, 2012, Guthold et al., 2018), which then increase the likelihood of several non-communicable diseases, including some cancers (Bray et al., 2017). An estimated 9% of yearly premature deaths are attributed to physical inactivity (Lee et al., 2012). Prolonged periods of sitting have been associated with adverse health outcomes (Biswas et al., 2015, Patterson et al., 2018), although there is not yet sufficient understanding about exactly how much sitting might be harmful (Stamatakis et al., 2019). Combined, correlates and determinants have the potential to both positively and negatively impact our predisposition to engage in physical activity and develop sedentary behaviour (Bauman et al., 2012). Amongst these is the time people spend indoors – this has increased in the last century (Höppe, 2002), due to several factors including growing proportions of occupations with low physical activity levels (e.g. office jobs) (Kirk and Rhodes, 2011, Straker and Mathiassen, 2009), along with urbanisation and changes in travel behaviours (Vorster, 2002, Wanner et al., 2012).

Raising people's non-exercise activity thermogenesis (NEAT) levels is an effective way to improve their overall health (Westerterp, 2001, Smith et al., 2015). NEAT refers to "*energy expended for everything we do that is not sleeping, eating or sports-like exercise*" (Levine, 2004). Over two decades of evidence have elucidated the key role that NEAT performs in regulating human energy expenditure and fat gain, and how NEAT can be influenced by people's environments (Levine et al., 1999, Levine, 2007, Levine and McCrady-Spitzer, 2018). In contrast, sedentary behaviour is "*any waking behaviour characterised by an energy expenditure ≤1.5 METs (metabolic equivalents) while in a sitting or reclining posture*" (Sedentary Behaviour Research Network, 2012). Simply standing burns more calories than sitting (Saeidifard et al., 2018). A lack of physical activity is the underlying cause for many people’s poor health – and hence, increasing activity is also a readily available route to improve health (Lee et al., 2012).

Given the time people typically spend in buildings, targeting an increase in NEAT represents a plausible approach to increase overall physical activity and reduce sedentary behaviour (Hollands et al., 2013, Straker and Mathiassen, 2009, Smith et al., 2016). This approach also fits with the notion that physical activity is a multidimensional construct and that the health benefits of physical activity can be achieved in many ways (Thompson et al., 2015). Environments prohibitive to structured exercise can successfully incorporate options for replacing sedentary behaviour with standing or light activities. The obesogenecity of an environment has been defined as "*the sum of influences that the surroundings, opportunities, or conditions of life have on promoting obesity in individuals or populations*" (Swinburn et al., 1999). This encompasses a variety of factors, including (but not limited to) travel infrastructure and food environments (Townshend and Lake, 2017). The built environment's role in contributing to an obesogenic environment is acknowledged and heavily researched (Kirk et al., 2010, Brownson et al., 2009). The location of buildings has received considerable attention, with a focus on the time to complete quotidian tasks by active travel captured in concepts such as the “15 minute city” (Moreno et al., 2021). In contrast, the specific role of indoor environments in modifying physical activity behaviour is a relatively neglected area of building design (Hollands et al., 2013). The way people use and move within a building is largely influenced by the building's design and management. Thus, designers and managers have a largely unexplored opportunity to influence building users' physical activity. Within office-based contexts, this can also increase workers' motivation and productivity (Puig-Ribera et al., 2015, Engelen et al., 2016).

Physical activity guidelines are well-established. For example, in the UK and US, it is recommended that adults obtain at least 150 minutes of moderate-intensity activity per week or 75 minutes of vigorous intense activity per week (Department of Health & Social Care, 2019, Piercy et al., 2018). However, information specific to building design for promoting physical activity, and NEAT benchmark figures for building users, are minimal. A small number of voluntary schemes have begun to consider this issue (Trowbridge et al., 2016). A review of health and well-being certification schemes by McArthur and Powell (2020) showed that the most comprehensive schemes for physical activity are WELL, Fitwel and Living Building Challenge (LBC). These schemes take a similar approach, awarding credits for fulfilling specific movement-enhancing design features (some mandatory within LBC) with different focus areas. Fitwel covers the broadest range of design features and makes the most useful reference point by giving credits for including specific design features that encourage physical activity. 57.0 points (39.5% of total) are for interventions encouraging physical activity in all forms, with 17.7 points (12.3% of total) for stairwells and workspaces interventions, explicitly focussing on raising NEAT levels. The range of activity-promoting design features incentivised in these standards (McArthur and Powell, 2020) primarily reflects the design features investigated in research studies (Zhu et al., 2020, Shrestha et al., 2018, Landais et al., 2020) and as advocated in other guidelines such as the New York City's Active Design Guidelines (Active Design Guidelines Team, 2010).

These current approaches are based on incentivising and incorporating activity-enhancing building design features. A key limitation of these approaches are their blindness to building users' characteristics and physical activity needs, given that physical activity programmes are advised to be tailored to individuals’ needs (Thompson et al., 2015). The design-behaviour-health nexus is complex and has many poorly understood relationships (Figure 1). Consequently, there is an argument that buildings should provide physical activity and NEAT opportunities that meet individuals’ needs. For example, a building where most of the users are call centre workers will have very different NEAT needs from nurses in a large hospital. A 'benchmark' NEAT level can thus be established based on the shared characteristics of buildings users' typical movement habits. Whilst a crude approximation, this nonetheless offers improvement upon current approaches which are ‘occupant-agnostic’. As a potential limitation, it is acknowledged that workforces and leases change in commercial workplaces often enough to make frequent reconfiguration unlikely. However, the principle of tailoring a building's NEAT opportunities with the building population's NEAT needs is a potentially valuable design approach, which has not previously been investigated. In this article, a novel conceptual model for approaching NEAT in building design is described and justified; a design tool is developed from the model, and indicative data from a survey of buildings is used to provide early stage proof-of-concept.

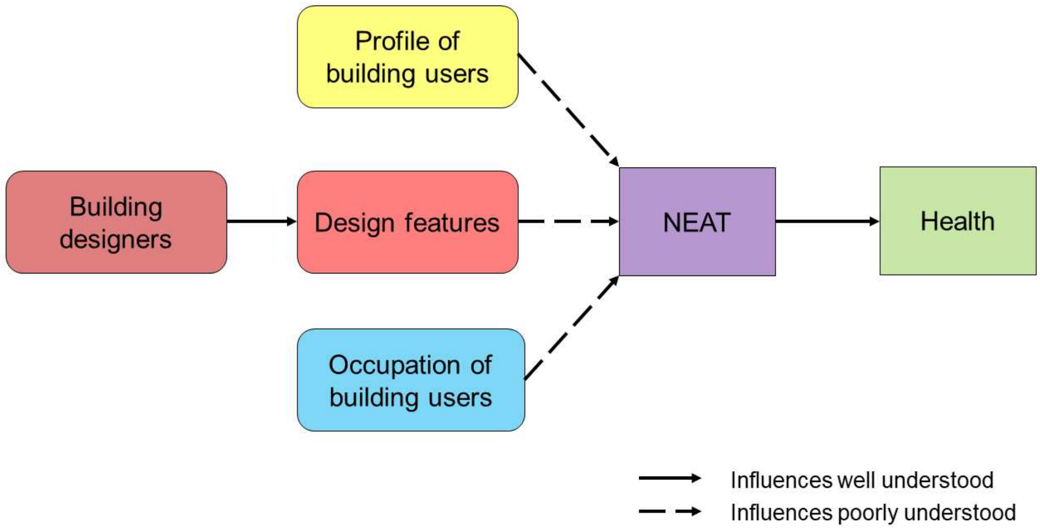

Figure 1: An overview of building-related factors which affect the health of building users.

2 Conceptual model for Building Environment Physical Activity Design (BEPAD) tool

We propose a conceptual model for developing NEAT opportunities through building design, following research developments investigating the capability of building design to enhance users' well-being (Hanc et al., 2019). Well-being was chosen as a guiding concept as it incorporates subjective aspects, such as happiness and sense of fulfilment, which are also linked to physical health (VanderWeele et al., 2020). The underlying principle adopted is that both the building users' level of propensity for NEAT, and the building's opportunities to generate NEAT, are required to give designers and managers the greatest likelihood of enabling physical activity behaviours that are appropriate to the building users' wellbeing needs.

The building users' level of propensity for NEAT is described using two terms:

- Anticipation (A) = a relative measure of how much NEAT might be facilitated by buildings' particular use (e.g. an office).
- Need (N) = a relative measure of how much NEAT is recommended for a specific building's users, based on both their age distribution and their level of sedentary behaviour within the building.

Previous research has determined that people's physical activity behaviour is influenced by multiple factors, including individual factors, social factors, policy, and the built environment itself (Sallis et al., 2006, Sallis et al., 2012). Sallis et al. (2006) ecological model is adopted here to apply to building users' NEAT. Hence, management policies and practices that can facilitate NEAT are assessed, along with the surrounding environment's physical features and the building itself.

The building's opportunities to generate NEAT is described using three terms:

- Environmental potential (E) = measuring how much NEAT arises from the building's location.
- Building potential (B) = a measure of how much NEAT arises from the building's design.
- Management potential (M) = measuring how much NEAT the management is promoting within the building.

Each building is also measured according to the following parameters:

1. Building typology details
2. Users' aggregated level of NEAT
3. Users' aggregated obesogenic risk factors (i.e. NEAT propensity)
4. Building's aggregated NEAT opportunities

These additional measurements are used to determine whether broad relationships exist between NEAT opportunities and propensity. And also, to explore trends relating to the users (e.g. age range) and the building's intrinsic factors (e.g. the number of floors).

This model, limited to physical activities, then informs a 'proof-of-concept' benchmarking design tool, Built Environment Physical Activity Design (BEPAD), developed to enable designers to assess NEAT opportunities and propensity during building design. It also offers an intermediary building scale approach to physical activity that complements the detailed monitoring of individuals' movement and large epidemiological studies of populations' health. The BEPAD tool's output is a score that enables practitioners to assess a building's performance. The BEPAD score for a given building (or design) is determined by its performance relative to other buildings in the survey sample rather than an absolute determination of performance (this is not currently possible). Thus, a scaling factor was used so that the mean interim score (S) over the whole population of buildings sampled to date is 0 (Equation 2). The final BEPAD score is given (on a scale of -5 to +5, omitting 0), based on which 10% grouping a given building falls within.

The initial score (I) is given by Equation 1:

$$I = E + B + M - N - A$$

Equation 1: S = interim score; E = environment score; B = building score; M = management score; N = need score; A = anticipation score

Subsequently, the result is scaled, thus giving an interim score (S) with a mean of zero (Equation 2):

$$S = \alpha(E + B + M) - N - A$$

Equation 2: S = interim score; E = environment score; B = building score; M = management score; N = need score; A = anticipation score; α = scaling factor.

The BEPAD score is configured to reflect a given building's relative performance within a constantly evolving building stock, rather than restricting assessment to a snapshot of performance, stuck in time (Ade and Rehm, 2020) This way, it enables the assessment of existing buildings and helps designers assess and improve buildings' NEAT design at design stage. By estimating the building's likely user population, a designer can evaluate the relative building design NEAT performance against existing buildings, deciding whether it would be advisable to enhance the NEAT potential. For example, a new office or retrofit designed for an employer for whom 50% of their workforce was >65 years of age would suggest a different design approach to NEAT than a workforce of which >50% was <29 years of age. With retirement age increasing in several economies along with the growing trend of 'bridging employment' between full-time work and full retirement (Fisher et al., 2016), the health outcomes of older workers throughout the retirement process is becoming an increasingly researched topic (Shai, 2018, Bertoni et al., 2018). This distinction of age groups within the tool is designed to reflect and inform these emerging trends.

This article develops the conceptual model for this approach to NEAT, presents the BEPAD tool, and provides initial proof-of-concept with indicative data – future collection of data is expected to inform and fine the BEPAD tool, in an iterative loop (Figure 2).

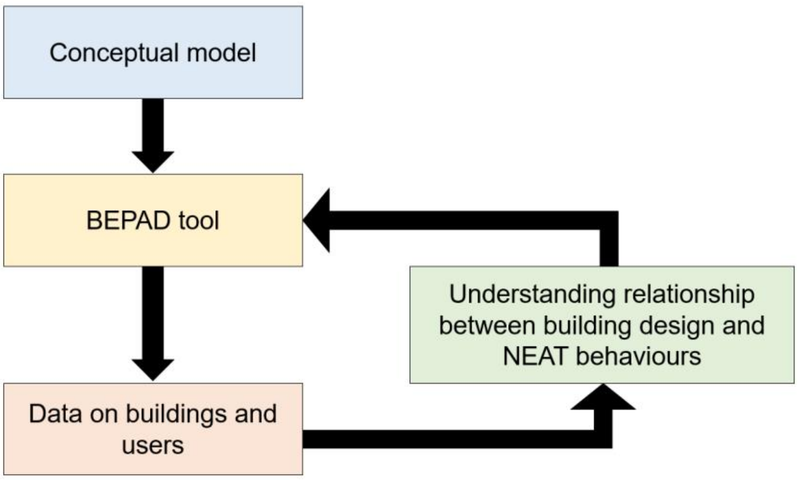

Figure 2: Flowchart of the methodological approach suggested for use of the BEPAD tool.

3 Methods

3.1 Research design

In this section, the scoring methodology is explained, and the complete survey used is provided in the supplementary information. For the two categories of NEAT demand (anticipation and need), scores were determined based on expert panel opinion on obesogenic risk factors. These values can be revised in future to capture new knowledge about obesogenic risk factors.

Anticipation is a simple measure of the intrinsic NEAT provision of a building based on the nature of the building users' activities (Table 1). For example, a factory requiring much physical activity, will inherently provide more NEAT opportunities than a call centre. Respondents were asked to state the building's primary use, from which the physical activity level was inferred. The scoring system was simplified to a single score based on buildings' primary purpose so as to be accessible and user-friendly for respondees. The assessment of multipurpose buildings is more complex and therefore outside the scope of this research. The number of storeys was also asked to respondees. It was anticipated stairs would be more likely to be prominent and accessible than elevators in smaller buildings than taller buildings. Evidence suggests that the relative proximity and visual dominance of elevators and stairs influences building users' physical activity (Zhu et al., 2020, Landais et al., 2020), therefore, building height was inferred an indirect influencing factor in physical activity levels.

Table 1: Anticipation scores for buildings' type and primary function.

Group	Description	Score
A	Low potential. Building designed for the performance of physical activities such as gyms, sports villages or manufacturing that involves physical activity	1
B	Low-moderate potential. Residential buildings (except retirement homes), hospitals or medical centres)	2
C	Moderate potential. The building is designed for educational activities	3
D	High-moderate potential. The building is designed for older adults.	4
E	High potential. The building is designed for sedentary-prone uses, such as office work or sedentary manufacturing	5

Need is a compound measure based on two factors: occupants' age distribution and their level of occupational sedentary behaviour inflicting risks to the development of health-related conditions (Table 2). While 'age' is a poor proxy for lifestyle-related health, well established disease-risk algorithms such as QRisk are heavily influenced by and incorporate 'age' into prediction equations (Hippisley-Cox et al., 2008). The use of 'age' as a factor in the present study was deemed a practical and valid approach to assessing risk at an occupancy level and in the absence of personal clinical data.

The specified age ranges are based on Schofield's equation for estimating humans' basal metabolic rate (Schofield, 1985). Respondents also provided information about the relative differences of populations between buildings by estimating the age range of >50% of the building users and the perceived typical level of sedentary behaviour within the building. Sedentarism perception within the building is a crucial constraint, as the occupants' typical level of sedentary behaviour outside of the building is neither within respondents' knowledge nor within designers' scope of influence. Furthermore, prolonged sedentary behaviour can be harmful independent of overall physical activity levels (Patterson et al., 2018).

Table 2: "Need" scores for buildings, based on the age distribution and level of perceived occupants sedentary behaviour (risk).

Group	Level of perceived sedentary behaviour	Age range (of >50% of users)			
		<19	19 to 29	30 to 65	>65
A	Non-risky group <25% of users do non-sedentary activities in the building	1.00	1.25	1.50	1.75
B	25-50 % of the users do sedentary activities and low exercise whilst in the building	2.00	2.25	2.50	2.75
C	50-75 % of the users do sedentary activities and low exercise whilst in the building	3.00	3.25	3.50	3.75
D	>75 % or more of the users do sedentary activities and do low exercise whilst in the building	4.00	4.25	4.50	4.75

For the three categories of NEAT opportunities (environment, building and management), a 'tick box list' of NEAT-enhancing design features was generated based on recent literature reviews (Zhu et al., 2020, Shrestha et al., 2018, Hollands et al., 2013, Chu et al., 2016, Landais et al., 2020) and the Fitwel certification scheme (Fitwel, 2020), on account of its range and depth of coverage. The number of design features enquired about varied between the categories (

Table 3), and the score for each category is the proportion of design features that a given building has (Equation 3). In this article, "design feature" is used as an inclusive term to refer to the surrounding environment (e.g. walking routes) and physical facilities (e.g. provision of showers) as well as management interventions (e.g. carrying out a commuting survey).

Equation 3: Calculation of opportunity score, for the example of the Environment category. e = number of design features for a given building, n = number of design features enquired about (=5 for the Environment category).

$$E = \frac{\mathrm{e}}{n}$$

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Table 3: Design features considered within each of the three categories: environment, building and management.

Category	Item #	Design features enquired about
Environment	1	Bus, train or tram stop within 800m of the main building entrance
	2	Bus, train or tram stop within 400m of the main building entrance
	3	A direct, easy to follow and well-lit pedestrian route between the transit stop (if within 800m) and the main building entrance.
	4	Safe, high quality walking route for exercise or relaxing, of at least 800m starting within 100m of building
	5	Building located such that daily errands, for example, shopping at lunchtime, can be accomplished on foot.
Building	1	The building has a covered and secure bicycle parking within 50m of the main entrance.
	2	Showers and lockers provided at no charge
	3	Easy to access, high-quality outdoor amenity space within 50m of the main entrance or within building or terrace
	4	Exercise or fitness room within the building (does not apply to gyms, schools or other building where a gym would be expected)*
	5	A main entrance orientated towards pedestrian traffic
	6	The stairwell takes visual prominence over the lift on the entrance floor
	7	The stairwell takes visual prominence over the lift on at least 50% of the floors
	8	From the main entrance, the stairwell must be passed to reach the lift
	9	The architecture uses elements such as balconies and roof terraces to encourage people to walk.
	10	Social points (for example, cafeterias, social/break rooms and meeting rooms breaks in spaces) are of high quality to act as design elements that promote mobility.
	11	Hallways and corridors are connected with exterior green areas to act as elements of design promoting mobility
	12	Inclusion of external space that is not overly weather dependent, for example, covered areas providing shelter from the rain
Management	1	In buildings over five storeys, for non-disabled users, lifts do not stop on every floor
	2	Bi-annual commuting survey completed and results announced to staff.
	3	Car parking, if provided, is not free
	4	The amenity spaces in the building and walking routes, and transit access are well advertised within the building, via permanent display
	5	Points of interest within 2km of walking are well advertised within the building, via permanent display
	6	The stairwell is attractive (for example, contains art or uses high-quality materials and finishes)
	7	Permanent point-of-decision prompts promoting staircase use placed in all lift lobbies areas.

* Note: It is acknowledge that Exercise of Fitness Room can be considered a ambiguous element. However, the justification for its inclusion lies on the potential that these spaces have for accommodating NEAT activities such as low intensity yoga, meditation, physiotherapy and rehabilitation, passive range of motion (ROM) exercises and various “spa” activities.

Survey sample

A survey was carried out to gather values for anticipation (A), need (N), building (B), environment (E) and management (M) from users of 75 buildings of various scales. All respondents had pre-existing knowledge of the building such as estimated floor area, occupancy and users' activities. The surveyed buildings were located in the Greater Jakarta Metropolitan Area, home to >30 million people. Indonesia is a relevant context for this pilot study because of the GREENSHIP certification operated by the Green Building Council Indonesia (GBCI), which does not contain guidance on physical activity design within buildings but give credits for building accessibility features (e.g. bicycle facilities). Greater Jakarta urbanisation trajectory and health trends (Green Building Council Indonesia, 2020) are also relevant. In Indonesia, there are growing rates of diabetes (Soewondo et al., 2013) and a strong association between obesity and living in urban areas (Rachmi et al., 2017). These factors give great urgency to the role of urban design in improving health outcomes.

The surveyed sample was focussed on, but not restricted to, office buildings of a range of heights, from low to high rise. Offices are typically highly sedentary environments (Parry and Straker, 2013) and offer a high potential for improving NEAT levels through building design. The survey was distributed to people known to work within the selected buildings. One respondent per building completed the survey on behalf of all building users. This approach is justifiable because designers are likely to have access to similar information during the design process. To qualify, respondents had to demonstrate pre-existing knowledge of the estimated floor area, occupancy, or activities within the buildings. In total, 75 complete responses were obtained.

3.2 Analytical approach

Descriptive statistics and power calculations were used to analyse the data received. The analysis focussed on three main aspects: distributions within the results, the distribution of the BEPAD scores, and an interrogation of the correlation between building height and the number of design features.

4 Results

4.1 Characteristics of buildings and user populations

The distribution of results within the sample differed between each category for the building itself (no. of floors) and the building user population (need – age; need – risk; anticipation of NEAT propensity) (Figure 3). The sample contained a variety of building heights, with a relatively even split between the height groupings. For the need category, the occupants's age distribution was slightly dominated by the lower end of the working-age range, 19-29. The risk of sedentary behaviour reported varied widely, with a slight minority of the sample having <50% sedentary. For the anticipation category, a majority of buildings had a high or moderate-high intrinsic propensity for NEAT.

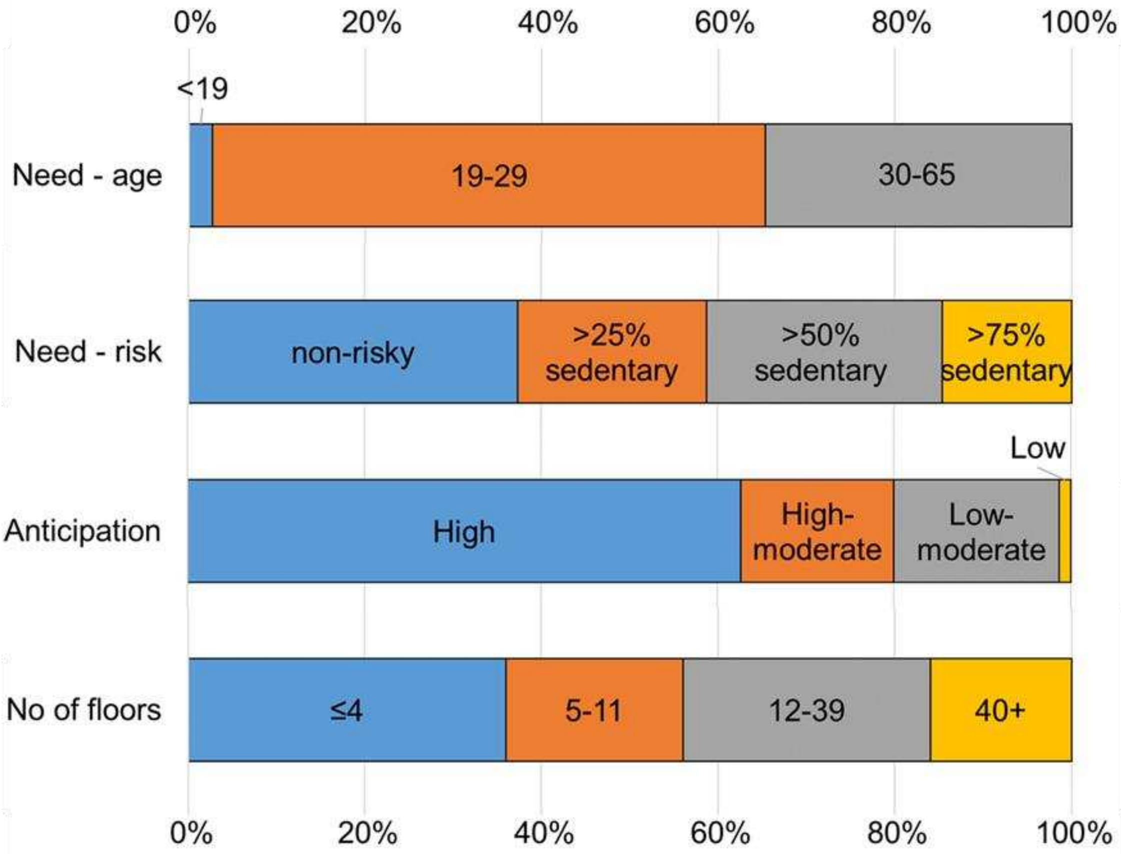

Figure 3: Bar charts showing the distribution of survey results by category for the building (no. of floors) and building user population.

The primary comparison conducted refers to the number of NEAT-facilitiating design features and the perceived level of sedentary behaviour in a given building. The following plots show the distribution in the number of design features - each building's data point is colour and symbol coded to show its risk factor. All three design categories (environment, building and management) showed a spread in the number of design features that the different buildings had. In terms of the relationship between the number of design features and perceived level of sedentary behaviour, there was no apparent correlation either in any of the individual categories of the environment (Figure 4), building (Figure 5) and management (Figure 6), or for the combined total of design features (Figure 7).

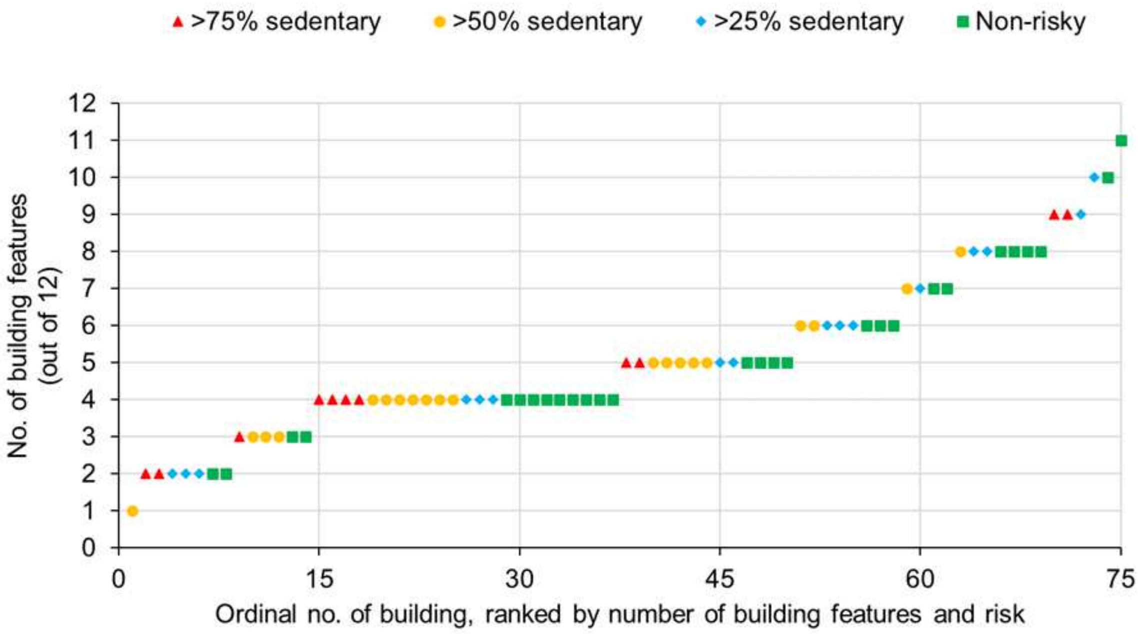

Figure 4: Distribution of the number of building features, colour and symbol-coded by risk of sedentary behaviour.

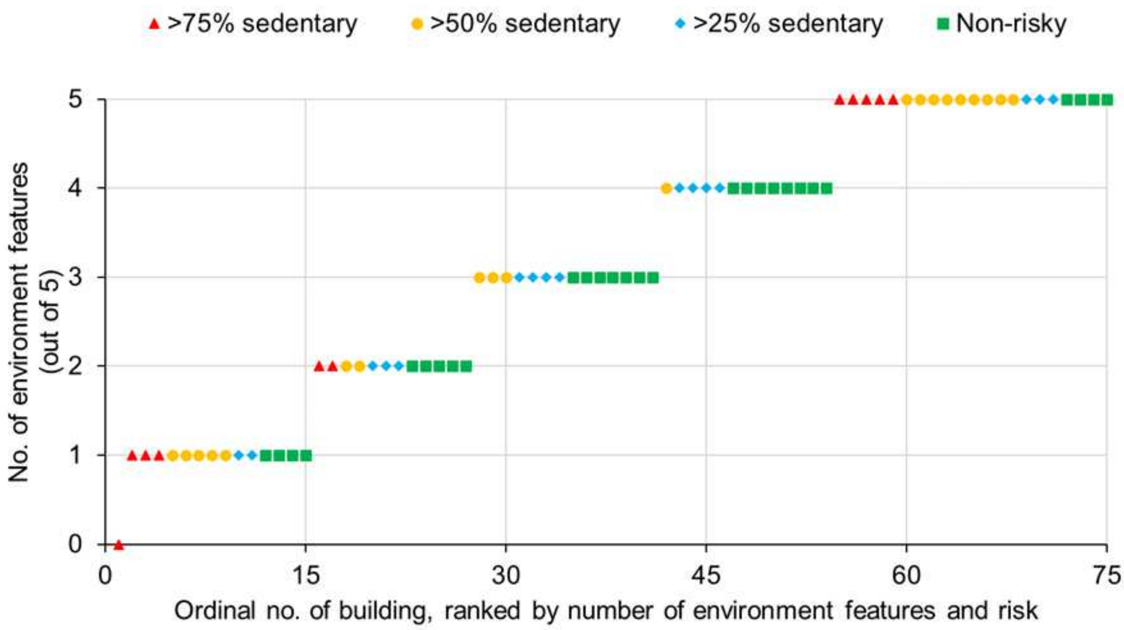

Figure 5: Distribution of the number of environment features, colour and symbol-coded by risk of sedentary behaviour.

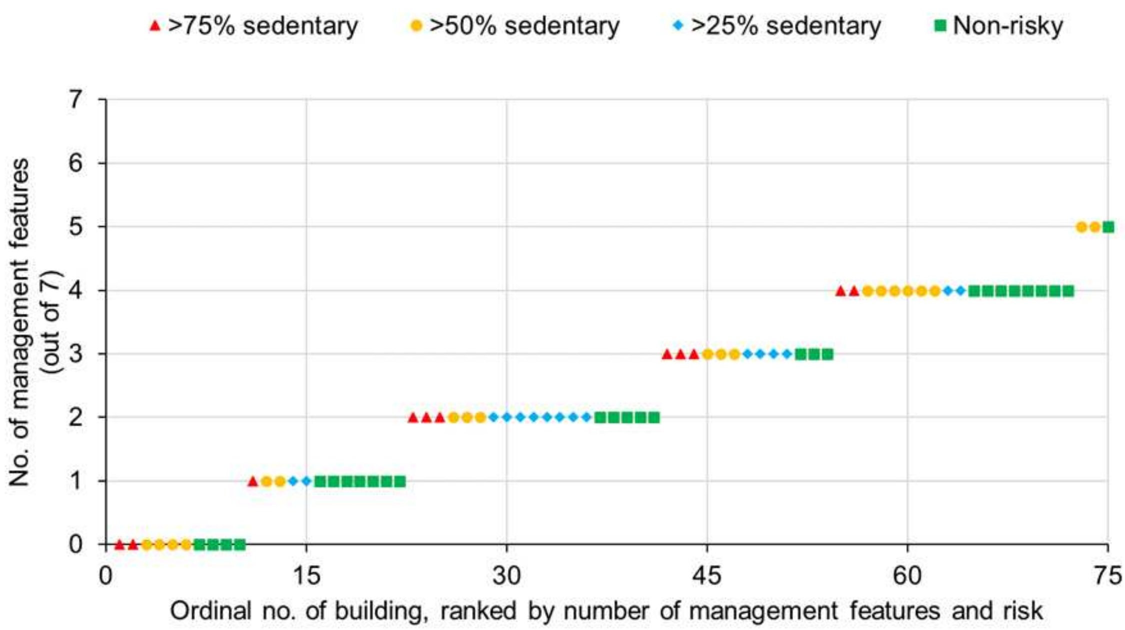

Figure 6: Distribution of the number of management features, colour and symbol-coded by risk of sedentary behaviour.

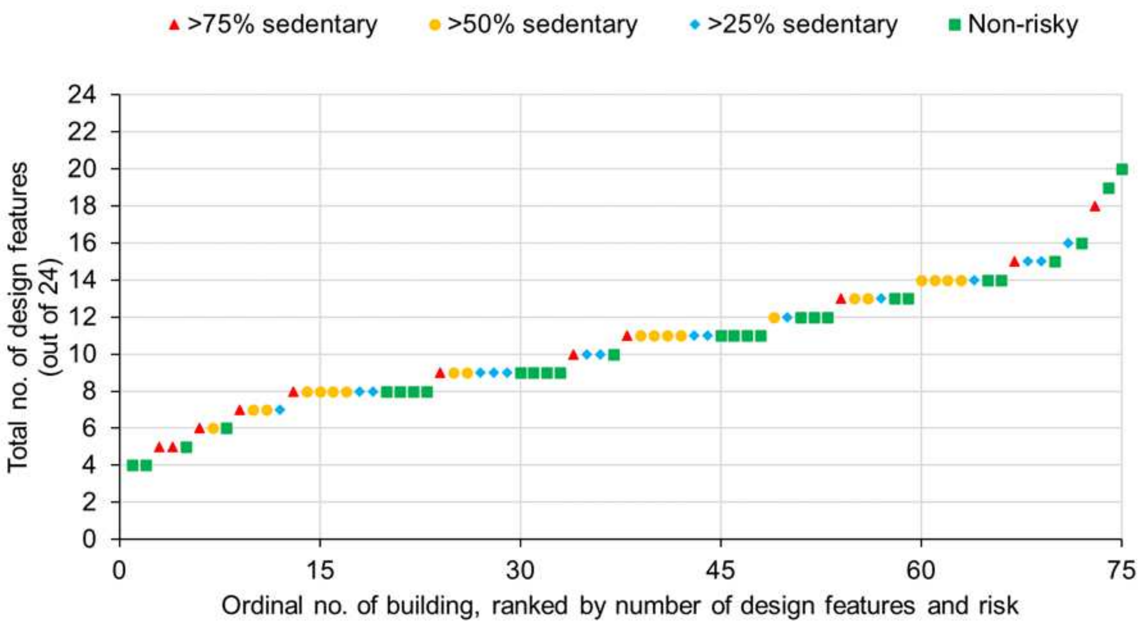

Figure 7: Distribution of the total number of design features, colour and symbol-coded by risk of sedentary behaviour.

4.2 BEPAD scores

A power analysis was completed on the initial scores (I in Equation 1). The mean was -5.24, and the standard deviation 2.02. For the studied sample, the confidence limits were -4.78 and -5.70 for a confidence interval of 95%, and hence the sample size was suitable for the estimation of scaling factor α. Linear regression gave α = 4.77.

Applying α to the initial scores (I) gave the interim scores (S), as described in Equation 2. The final BEPAD score was obtained from the interim scores by dividing the sample group into ten equally-sized groups based on the interim score (Figure 8). The distribution of interim scores had a form suggestive of a normal distribution.

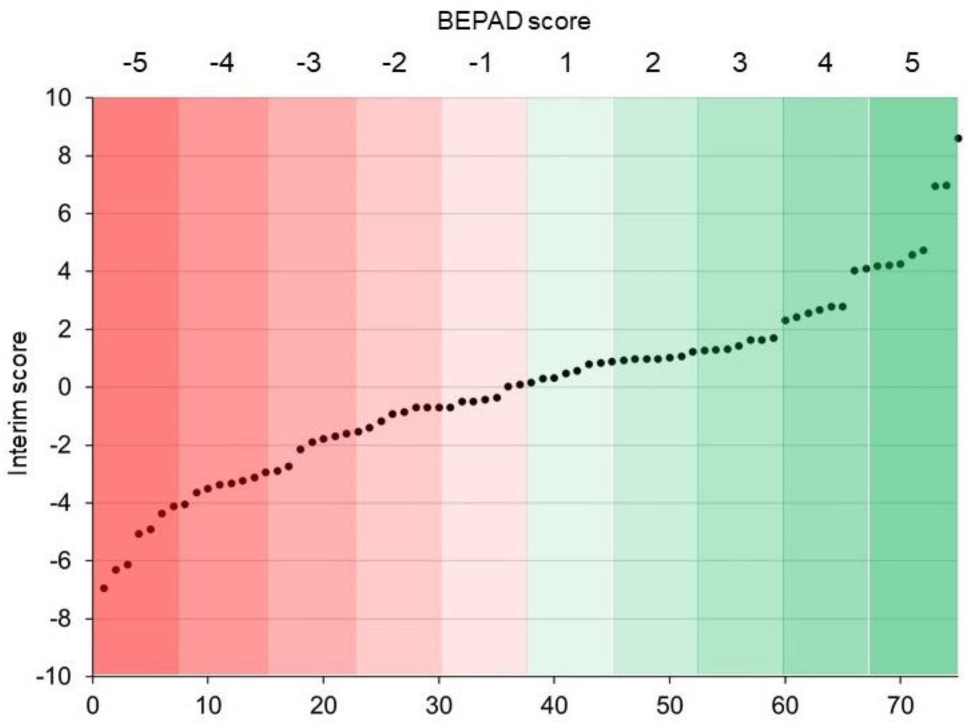

Figure 8: Distribution of interim and BEPAD scores

4.3 Correlation between building height, number of features and interim score

Here, it is argued that BEPAD can potentially contribute to advancing our understanding of the complex relationship between NEAT and building design. As an indicative proof-of-concept, a hypothesis is tested that smaller buildings would be more NEAT-conducive environments (i.e. have a higher number of design features) than taller buildings. When considering the total number of design features (Figure 9) solely, there is no clear trend that taller buildings have a lower total number of features than smaller buildings or vice versa. When considering the interim score (i.e. including both opportunities and propensity) (Figure 10), it is found that the mean scores are higher and positive for smaller buildings (≤11 floors) if compared to taller buildings (≥12 floors), indicating that within this sample the smaller buildings may meet the NEAT needs of building users more effectively than the taller buildings. Given the small size and limited geographic scope of the survey sample, further research on larger samples is required in order to interrogate such relationships with confidence.

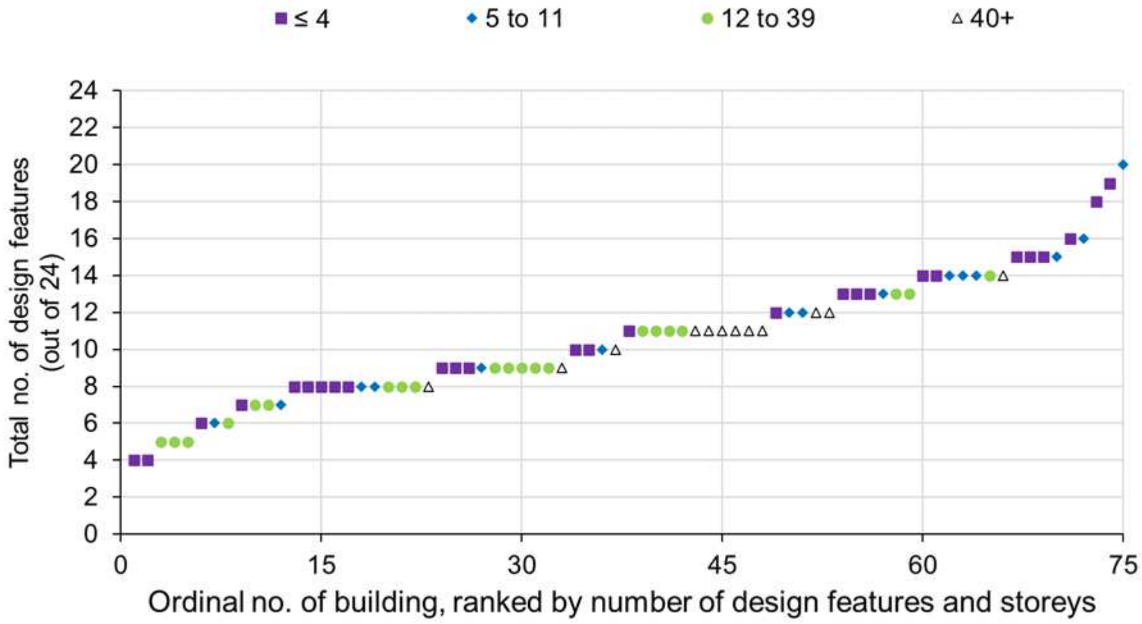

Figure 9: Distribution of the total number of design features, colour and symbol-coded for the different building height categories (storeys).

Figure 10: Distribution of interim score for the different building height categories (storeys).

5 Discussion

5.1 Distribution of risk factors, design features and BEPAD scores

Although no direct comparisons with existing data are possible at this stage (due to this dataset's unique nature), it is possible to assess the validity of this approach by broad comparisons with findings from other approaches. At the most fundamental level, this approach is validated by findings from the epidemiological scale.

Epidemiological studies show higher levels of sedentary behaviour associated with some occupational sectors (Buckley et al., 2015, Kirk and Rhodes, 2011). These macro-scale observations are compatible with the distribution of self-reported levels of sedentary behaviour (Figure 3), where >40% of respondents reported a majority of users were sedentary whilst in the building.

At the building-scale, physical activity cross-sectional studies (i.e. comparing different buildings over the same period) (Ding and Gebel, 2012, Kremers et al., 2012) demonstrate differing levels of effectiveness of activity-enabling design features between buildings (Coleman and Gonzalez, 2001). These broadly agrees with the wide distribution in the range of NEAT-enabling design features in different buildings (Figure 7).

The potential for environmental interventions had been realised to a greater degree (average 3.2 out of 5) than building (5.1 out of 12) and management (2.3 out of 5). This potentialy reflect the consideration of physical activity in planning at neighbourhood level (Salvo et al., 2018).

The range of values of Need and Anticipation given in Figure 3 shows that buildings with a wide range of occupants and use categories were found. The number of design features also varied across risk of sedentary behaviour (Figures 4 to 7) and height of building (Figure 8). This suggests the predictions of α are robust. Further research is required to generate a larger database, capable of verifying accuracy at global, national and regional levels.

5.2 Correlation between building height and number of design features

Correlations between building characteristics, risk factors and NEAT performance can also be explored using the BEPAD tool. From the indicative proof-of-concept was given in Section 4.3, no particular trend between building height and the number of design features was observed in the preliminary analysis. However, smaller buildings typically performed better than taller buildings. Causative links cannot be claimed from the limited sample, but this observation corroborates general findings in the literature. For example, stairs' proximity and visual prominence influences users' physical activity (Zhu et al., 2020). Therefore, taller buildings design emphasising elevator access are expected to have a natural disadvantage compared to smaller buildings in promoting NEAT.

5.3 Value for research and practice

The complex interplay between building design, user risk factors, and NEAT levels **Error! Reference source not found.**remains largely unknown, and novel epistemological approaches for uncovering relationships remain scarce. As discussed above, indicatively BEPAD can provide for both research and practice. As a benchmarking tool, the more data is collected, the more accurately the BEPAD score will reflect reality. It also unlocks an opportunity for citizen science (King et al., 2016) to explore relationships between physical activity or inactivity and the built environment

This pilot study's proof-of-concept tool paves the way for further research to make a comparative analysis with existing approaches and enhance understanding of the link between design features and building users' behavioural habits.

For researchers, this approach offers an alternative way to approach obesogenic environments at building-scale that complements the individual-scale and population-scale existing approaches. There is potential to use this 'opportunities and propensity' approach to NEAT to leverage existing data on building features and possibly validate reported NEAT levels.

For building designers, BEPAD offers a user-friendly approach to designing healthy buildings that are tailored to the building user population and local environment. It is envisaged that emerging certification schemes (e.g. WELL, Fitwel) could adopt this approach to NEAT. When used at early design stages (i.e. RIBA Stage 2), an initial calculation of the BEPAD score could inform stakeholders and trigger discussions with building users, especially when high-risk groups are identified. The initial calculation can then be carried out until stage 4 (technical design). Frequent recalculations of the BEPAD score would enable a quick comparison of different design solutions and consideration of additional management interventions. After building occupation, the BEPAD scores can be monitored annually to capture any further interventions and update the building's performance amongst the global database. It can also be useful for companies seeking to move premises across existing buildings. The emergence of voluntary schemes for physical activity design has a historical precedent, with environmental design. It is envisaged that buildings' design for health impacts will follow a similar trajectory, becoming a key component of building regulations in coming years.

The value of the proposed approach lies in its flexibility, allowing scores to be updated to reflect advances in research; and also its accessibility, being conducive to high volume data collection and relevant to building designers and occupants. In summary, it can guide designers in improving the health of building users by enabling higher levels of NEAT, and complement other approaches to improving buildings' NEAT levels.

5.4 Limitations

The results presented provide only initial indicative benchmarking values, for a small range of building types and purposefully limited to the Jakarta Greater Metropolitan Area. Further research will add more buildings to the dataset, and allow for a more robust validation of this approach. Given the bias of physical activity studies towards metropolitan areas (Feng et al., 2010), it is also desirable to achieve better representation of different contexts.

A survey is advantageous in terms of speed and accessibility, but self-reporting has limitations, including one's interpretation of the terms used. In future iterations, a relatable definition or example could be given to leverage understanding. Another limitation is a lack of detailed data. Given that the survey measurements are made by self-reporting by one building user on behalf of all the building users, this will not be as accurate as direct data collection on individuals. Therefore, there would be great value in future research to validate self-reporting measures of NEAT demand with direct measurement of individuals' distribution of movement using activity-monitoring devices (Sawyer et al 2017).

The proposed tool primarily envisages use for new construction and secondarily for refurbishments (thus emphasising management features). In these scenarios, additional variables could become relevant, such as building age. Due to changes in policies and regulations over time, the building's age is reflected in many design facets. This question was omitted from this version of the survey but could feature in later iterations of BEPAD (along with other questions, such as spatial layout) since it has been designed to improve by increments. Whilst the focus of this study was mainly on building-level and management features, there is the potential to expand the tool to encompass more neighbourhood-level factors.

The assessment of building users' age distribution is an accessible way to assess broad trends in risk factors, and it has already been acknowledged that there will always be exceptions to these broad trends (e.g. extremely active over 65-year-olds). The BEPAD tool cannot give a tailored response to each individual building user, rather, it is intended as a tool to aid and inform the design and is complementary (rather than exclusive) to other modes of engagement with building users at the design stage.

5.5 Reflections

Given the societal challenges that obesity and related non-communicable diseases pose, it is likely additional guidance and regulation will emerge for building and built environment design in the coming years. It is also likely the mainstream certification schemes will further integrate health and well-being aspects. Given that these schemes have been criticised for giving insufficient weight to the social pillar of sustainability (Awadh, 2017), further integration of health-focused design offers a route to address this imbalance.

In the longer term, a trade-off is likely between creating an environment that enables NEAT for people without being at the expense of accessibility for those with limited mobility or other requirements. This trade-off is a growing area of interest in specific environments, such as assisted living facilities (Mahrs Träff et al., 2020). The latter has been regulated for several years (in the UK), so it is more established in the public and designers' minds as being a public good. This assumption fits into a current consensus that tailored policy and environmental approaches are needed to increase physical activity for different population groups, focusing on disadvantaged groups (Heath et al., 2012).

There is also the spectre of unforeseen consequences. Although good NEAT design may be possible, there will likely be feedback effects, partly owing to human free will. This overlaps with aspects of behavioural science in public health, particularly nudging (Marteau et al., 2011, Hollands et al., 2017), and offers complexity but also rich potential for future research in the area of physical activity (Forberger et al., 2019).

6 Conclusions

A novel conceptual approach and accompanying BEPAD tool have been developed to assess NEAT design in buildings. This approach offers a flexible and accessible approach to assess buildings' opportunities and propensity for NEAT for both research and practice. This pilot study only offers indicative causal relationship between the number of design features and self-reported sedentary behaviour. However, other observations, namely the wide distribution of both the number of design features and levels of sedentary behaviour of building users, are in broad agreement with other approaches' findings. The BEPAD tool has the capacity for its scores and questions to be updated as more research and understanding on this topic emerges. It is intended that the building level approach presented here can accelerate the development and adoption of NEAT design principles by building designers or organisations moving premises and thus potentially make a contribution to improve the health outcomes of building users.

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No potential conflict of interest is reported by the authors.

Data availability statement

All data created during this research are openly available from the University of Bath data archive at https://researchdata.bath.ac.uk/id/eprint/790

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