https://doi.org/10.1016/j.jobe.2020.101588

A comparative review of building component rating systems

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Abstract: Buildings are composed of large number of interdependent components. Rating of the building components serves as a benchmark for comparison during condition assessment of the building. The aim of this study is to carry out comparative analysis of existing building component rating models. This study compares 9 different building component rating systems followed by their critical analysis and comparison of similarities, differences and limitations. Similarities between different rating system reviewed are that the condition of a building is assessed by dividing entire building into smaller components into a hierarchy, the severity of building defects is assessed using a rating scale and weighting coefficients are used to determine the relative importance of each component for assessment in the final aggregated rating. Major differences between different building component rating systems were the objectives and scope of the assessment, different methodology, tools and aggregation techniques used to arrive at final assessment of whole building. The processes to evaluate the rating of building components were highly subjective as most of the rating systems were based on visual observation and interpretation of the inspection personnel. Existing inspection practices and rating methodology can be improved to reduce the time, cost and subjectivity in assessment of building components.

Keywords: building component; rating system; benchmarking; condition assessment

Introduction

Buildings are designed and constructed primarily to provide a safe and healthy environment for its users and occupants (Douglas 1996). However, the condition of building and its components changes over time due to wear and tear during its operational use (Yau et al. 2008). Physical deterioration of building reduces the ability of building to perform it's intended function (Grussing et al. 2009). Since buildings with similar age may or may not be in same state, condition assessment can serve as a benchmark for comparison between different buildings and also for the same building at different period of time (Vanier 2001). According to Ho et al. (2000) benchmarking is the establishment of "metrics" by which the measurements can be made while use of metrics also enables the study of performance of individual elements and provides means of evaluation of improvement. According to (Ahluwalia 2008) condition assessment of a building is performed fundamentally to assist the ranking of all the components of building. Salim and Zahari (2011) describes rating as a set of scale of categorization designed to elicit information about quantitative or qualitative attribute. The rating of building components can serve as an indicator of their performance and it can be a critical tool for evaluation of building condition. Dejaco et al. (2017) explains rating system as key performance indicators which can help stakeholders to make better choices in operation, maintenance and repair of the building facilities. According to Ruiz et al. (2019) periodic inspection of buildings is useful to quantify the severity of deterioration of building components and rating scale is useful to assess the grade of severity of the deterioration in order to prioritise interventions and decision making in maintenance during service life of the building. With focus of this study on building component condition, nine different rating models were selected for this comparative study that have proposed methods for evaluating condition of building components using a scoring or rating system. The selected 9 ratings are different than green building ratings or sustainability ratings that are used to evaluate and recognise buildings which meet certain criteria or standards in design, construction or operation and generally deals with reducing negative impacts on our climate or natural environment (Reeder 2010; Vierra 2019).

Research Objectives

The aim of this paper is to do comparative analysis of different rating models for assessing buildings and their components. This study is an attempt to distinguish similarities and differences between the different types of building component rating models. This study will also examine the limitations of the selected rating models. The study presented here would contribute to existing body of knowledge by providing an insight into different rating models for assessment of physical building components.

Background

In this study literature search was carried out in major scientific research databases such as Scopus, Web of Science, Science Direct, ASCE Online Library, ICE Online Library, Google Scholar as well as repositories of universities. Scopus and Web of Science are most important and reliable databases of scientific publications across multiple disciplines (Aghaei Chadegani et al. 2013; Guz and Rushchitsky 2009) while Google Scholar provides more varied and wider coverage across disciplines than Scopus and Web of Science (Harzing and Alakangas 2016).
Following keywords interchangeably as well as in different combination with each other were used for literature search: building ratings; component rating; building condition assessment; building performance evaluation; building quality assessment; facility condition; building index; facility condition index. For this study peer reviewed academic research papers from different journals; conference proceedings; journal articles; technical reports; thesis & dissertation; codes and standards were considered for review of literature. The literature was further narrowed down to past 25 years from year 1994-2019 within subject field of building

engineering; maintenance & management; facilities & asset management using different databases of scientific research databases mentioned earlier.

Identification and selection of relevant papers for this study is discussed in research methodology. It was noted during literature search that numerous studies have been conducted for environmental rating of the building while very few are available for rating of physical building components exclusively.

After reviewing literature about building component ratings the authors have not found a comprehensive comparative review of building component rating models. To fill this gap this paper presents a comparative review of different building component rating models focusing on their similarities and difference with recommendations for future research in development of new rating models. Building stakeholders will need a rating tool for assessment and decision making for repair and maintenance to meet the challenge of sustainability of existing buildings and also to maintain the health and safety of existing buildings. Existing building component rating systems still are subjective, time consuming and costly (Ahluwalia and Hegazy 2006; Hegazy et al. 2010; Silva and de Brito 2019; Straub 2002) hence there is a need for development of a new more objective, quick, economical, technology based and easy to understand building component rating system.

Research Methodology

The methodology adopted for this study can be broadly described in following steps as shown in Figure 1. To review building component rating models following five step process was followed: Literature search, Literature selection, Analysis, Discussion & Conclusion. The aim of this study is to do comparative analysis of existing building component rating models. It was imperative to describe the rating models and their methods of assessment first before their comparison. Thus, an overview of selected nine building component rating models is presented in this paper first followed by description of the selected rating model and their process of assessment in brief. Following the overview of selected rating models, a comparative analysis is presented based on building hierarchy, rating scale, rating criteria and main purpose of rating. After noting comparison of similarities and differences between the selected rating models critical analysis is presented under discussion. The limitation and deficiencies of the selected rating models are examined and discussed in this paper. Finally, the literature review is concluded with suggestions of future scope of research.

[Figure 1 near here]

Literature Selection

Many articles not related to topic of research were shown in search results which were filtered out to consider the relevant papers related to building component rating only. In literature search it was also noted that environmental ratings of buildings predominate in number of search results while ratings of physical building components seem to be rather very few in comparison. A graph is plotted for number of publications containing “building rating” in their title of past 25 years from year 1994-2019 in order to display evolution of research in the topic of building component rating. Google Scholar search results are varied, fairly reliable and comprehensive (Martin-Martin et al. 2017) hence it’s search results of number of publications are plotted against the year as shown in Figure 2. Following trends were noticed during literature search as shown in the graph:

- The trend of building ratings continues to be persistent across the years with increasing number of publications every year.
- Physical building component rating is overlooked area of research despite growing trend in other building rating categories in published literature in last 25 years.

It was also noted during literature search that topics of research like green building, energy rating and related to environmental condition of the building are published predominantly under published literatures title ‘building ratings’ compared to literatures related to physical building component ratings.

In order to limit the broad scope of other type of ratings to only building component ratings two major selection criteria was adopted. First criteria of selection of literature was that the research must be exclusively for buildings only and second criteria of selection was rating of physical components of buildings must be using a scoring system or rating scale. With the above, mentioned selection criteria nine different rating models were identified and selected for this study that have proposed methods for evaluating condition of buildings using a scoring or rating system.

[Figure 2 near here]

Bibliometric Analysis of Literature Search

In order to gain understanding of building component rating related research, the contribution of researchers from different institutions, universities and countries is quantitatively assessed and analysed. Figure 3 shows most frequently cited academic journals between 1994-2019. ‘Facilities’ and ‘Journal of Performance of Constructed Facilities’ produced most of the publications related to building component rating during the studied period. ‘Facilities’ published 12 papers as most number of papers compared to other journals indicating it’s most significant contribution in research of building component rating. Other academic journals such as ‘Journal of Performance of Constructed Facilities’ published 6 papers while ‘Building and Environment’, ’Structural Survey’ and ‘Structure and Infrastructure Engineering’ published 5 papers each respectively. ‘Procedia Engineering’ published 4 papers, ‘Journal of Facilities Management’ published 3 papers while other journals such as ‘Journal of Building

Engineering, 'International journal of Housing Science and Its Applications' and 'Journal of Urban Planning and Development' published 2 papers each. These statistics shown in figure 3 with small number of papers published over the years reflects relatively fewer efforts by researchers in development of new building component rating systems for building.

[Figure 3 near here]

Table 1 shows institutions/universities contributing at least two papers related to building component rating during the year 1994-upto June 2019. The University of Waterloo in Canada contributed most number of building component related publications (11 papers), followed by The University of Hong Kong (9 papers), Texas A&M University in US (5 papers). Four papers each were contributed by Politecnico di Milano in Italy, National Center for Education Statistics (NCES) in US, Construction Engineering Research Laboratory in US, Universiti Teknologi and University of Malaya in Malaysia. Three papers were contributed from Concordia University in Canada while two papers each were contributed from Hong Kong Polytechnic University, City University of Hong Kong, University of North Carolina in US, Delft University of Technology in Netherland, National Laboratory for Civil Engineering in Portugal and Construction Research Centre, National Research Council of Canada.

[Table 1 near here]

The majority of research origin of building component rating related publications is shown in table 2 during the year 1994-upto June 2019. It is evident from Table 2; United States is the largest contributor to building component rating related publications involving up to 10 institutions/universities contributing 23 publications during the studied period. United States, Canada, Hong Kong, Malaysia and United Kingdom contributed 71 out of 96 publications almost equal to 74% or two thirds of the total publications during studied period of 1994-2019. Other countries like Italy and Netherland contributed four papers; Germany and Denmark contributed three papers; Portugal, South Africa, Egypt and Spain contributed two papers each during the studied period. The lag in research related to building component rating in developed and as well as developing countries could be due to large number of components in the building of and their complex interrelationship.

[Table 2 near here]

Literature search results citations were further analysed using VOSviewer, which is a software tool for constructing and visualizing bibliometric networks based on citations and text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature (VanEck and Waltman 2016, 2010). In VOSviewer a distance based approach is used to plot bibliometric network map of nodes in such a way that the distance between two nodes approximately indicates the relatedness of the nodes (VanEck and Waltman 2014). If the distance between two nodes is smaller than there are highly related to each other. Keywords are important contents of research papers usually indicating the area of study of the research published. A network of co-occurrence of keywords is plotted with VOS viewer using filtered citation search results as shown in Figure 4. It can be noted from Figure 4a that 'asset management' was most frequently mentioned keyword. Other recurrently mentioned prominent keywords includes building, maintenance, inspection, condition assessment, lifecycle, facility management, decision making, performance indicators, defects.

[Figure 4a near here]

Another analysis was carried out using VOSviewer for mapping of countries of origin of research publications as shown in Figure 4b. It can be noted from Figure 4b research scholars publishing from institutions in United States are leading in research related to building component rating systems. Other substantial contributions based on most citations are from Canada, Hong Kong, Malaysia Italy, Portugal, Israel, Spain and United Kingdom. However, it is worth noting except Malaysia which is emerging developing country all other countries/regions mentioned in figure 4b are developed countries/regions. Mostly developed countries/regions are actively publishing research related to building component rating. Howevere, there is still lag in research related to building component rating many countries.

[Figure 4b near here]

Building Component Rating Models

Several building component rating systems have been developed with different purpose with different methodology. Based on selection criteria of this study following selected literature of nine building component rating models are briefly described below.

National Health Facilities Audit

Abbott et al. (2007) proposed a five-point colour coded rating system for hospital building rating in South Africa for evaluation of maintenance budget. The five-point colour coded rating scale is shown in Figure 5. Each colour represents a condition with rating from 1-5 with rating 5 represented by blue colour as very good condition and rating 1 represented by red colour as very bad condition while intermediate ratings 4,3,2 represented by cyan, green and yellow colour as good, fair and bad condition respectively. In their model, condition assessment is conducted at element or component level and corresponding maintenance action relevant to the condition ratings are calculated along with the maintenance, rehabilitation and replacement costs in a tabular form. The elements of each building are aggregated to ascertain the budget at building level and further aggregated at facility level. Using their color-coded condition rating changes in subsequent assessments can be easily identified. According to Abbott et al. colour coded ratings makes assessment reports more user-friendly and easy to interpret by non-technical users to use the information. Abbott et.al, highlights the importance of regular and consistent condition assessment to ensure sustainability and also the need to optimise the application of assessment data due to high cost involved in physical site visits while conducting condition assessment.

[Figure 5 near here]

Defect Index

Pedro et al. (2008) explains the method for assessing the condition of buildings in Portugal which is evaluated by dividing the entire building into elements and building defects detected in an element are assessed on a scale based on pre-defined criteria. In this condition assessment model the level of defect in the different elements is logged in a checklist and then aggregated with a formula to produce a numerical score. This checklist is divided into eight divisions: identification of the building by its location, address, characterization of the building by number of units, floor, type use, defects in functional elements, defect index, description of severe and critical defects, evaluation, observations, evaluator's details, and maintenance coefficient (Pedro et al. 2008). The functional elements consist of sub elements and are distributed into three groups: whole building, the shared parts between more than one units, and the unit. The rating scale is five point based on level of defect ranging from 5 points for minor defect while 1 point for critical defect and 4,3,2 points for slight, medium and severe defects respectively (Pedro et al. 2008).

The score of each element is calculated as product of the number of points linked to the defect level and the weighting coefficient varying from 1 (minor importance) to 6 (major importance). The defect index is calculated as sum of total scores for applicable functional elements divided by sum of total weights of applicable functional elements (Pedro et al. 2008).

Defect Index is further categorized in to five types of conditions ranging from very bad, bad, medium, good and excellent condition. Defect Index (DI) falling between 4.5 to 5 is considered to be excellent while DI between 1 to 1.5 is considered to be very bad condition. The condition determined by the evaluator is converted into a maintenance coefficient taking account of possible maintenance and repairs carried out by landlords and tenants. The primary purpose of condition assessment model described by Pedro et al. 2008 is for deciding maximum value of the rent in Portugal however it can also be used for maintenance purpose but it would require more detailed inspection and correspondingly higher cost. The assessment procedure is highly subjective and depends on the competence of the evaluator.

Integrated Condition Assessment Model

Eweda et al. (2010) proposed integrated condition assessment model that considers both the physical and the environmental aspects for rating of educational buildings in Canada. The primary objective of his model was to assist owners and facility managers in condition assessment process for asset management. Eweda, used "space" in the building as the principal element of evaluation. Analytical Network Process (ANP) and Analytical Hierarchy Process (AHP) techniques were used on data collected from experts to assign relative weights in this model. The Multi Attribute Utility Theory (MAUT) was used to calculate the physical and environmental conditions of each space, and the K-mean clustering technique to calculate the integrated condition of each one. The main components in this study were: Spaces inside the building and their ranking, Physical & Environmental Assessment of Space & Integrated condition for the spaces and the entire building. This study uses condition index which ranges from 0-100 and corresponding alphabetical ratings from A-F. Condition index from 90-100 is rated A which represents excellent condition with no defects while condition index from 0-19 is rated F which represents complete failure. Intermediate conditions are rated as very good, good, fair and poor for condition indices ranging from 75-89,60-74,40-59,20-39 respectively.

Eweda (2012) further used Building Information Model (BIM) as a tool for storing, exchanging, and transferring assessment data inputs as well as serving in the assessment process. In his model initially relative weight of each space type per unit area is calculated then relative weight of each single space in the building is calculated using the relative weights per unit area of the space type it belongs to and the space surface area. Then family decomposed weight was calculated as a product of three values namely relative weight of each space, relative weight of each category inside the space and relative weight of each family inside each category (Eweda et al. 2015). Utility value is used in this model for the subjective assessment of components. The physical condition assessment of the space was assessed as a simple product of utility value of category inside the space and its weight (Eweda et al. 2015). The physical evaluation criteria developed by Eweda requires a large amount of data to calculate relative weights for spaces and physical elements using AHP. This model can be enhanced using more objective data for calculation of relative weights.

Dutch Standard for Condition Assessment of Buildings

Straub (2009), explains the use of condition assessment of buildings using Dutch standard NEN 2767, Netherland. In this assessment model the condition of objects can be expressed in a score ranking from 1 to 6. This condition score is based on three parameters namely the severity, extent and intensity of the defect. The assessment is based on the detection of defects in functional elements, and on the definition of their importance, extent and intensity (Straub 2009). Dutch standard consists of standardized list of building parts and defects which cover 80 to 90 per cent of the common building components in housing and real estate. The building inspector in the field has to determine the defects from standardized list of defects and rate according to the scale and intensity of each defect (Kuijper and Bezemer 2017). The Dutch condition assessment process is shown in Figure 6. The defect assessment occurs first followed by classification of importance of defects, then identifying intensity and extent of defect. The extent and intensity of a defect combined with importance of defect leads to final condition rating with defect score as intermediary.

[Figure 6 near here]

The Dutch standard classifies the importance/severity of defect of building components into minor, serious and critical as shown below (Kuijper and Bezemer 2017; Straub 2009):

- Minor: There is no influence on the functioning of a building or part of the building due to minor defects e.g. defects in finishes of coating, scribbles on the wall.
- Serious: A serious defect gradually damages the performance of building components and lead to degradation of the building or part of the building usually without hampering the direct functioning of the component or the building for example material surface damage, aging of components.
- Critical: A critical defect is classified as functional defects and those defects that threatens the building structure, e.g. safety, stability and distortion. Functional defects are those which are associated with the failure of the component.

The Dutch standard classifies intensity of defects which influences the condition of building components into three classes namely Intensity 1, 2 and 3 as low, medium and high intensities respectively. Intensity class 1 which is low intensity defects are hardly visible while class 2 defects are progressive and class 3 are high intensity defects which cannot progress further (Straub 2009). The Extent of defect is classified into five classes which signifies the net proportion of a defect with respect to total size of the building or part being considered. The extent of defects classes ranges from 1 to 5 with different percentages ranging less than 2 % for extent class 1 defects which may occur incidentally to greater than 70% for extent class 5 defects which occurs generally. Dutch assessment uses six-point scale rating from 1-6 with condition rating 1 representing excellent condition while 6 represents very bad condition.

The Dutch condition assessment is used to determine the condition of each building, plan maintenance, prioritize funds, monitor building component degradation and compare the condition of different buildings.

Building Health and Hygiene Index (BHHI) & Building Safety and Conditions Index (BSCI)

Yau et al. 2009, developed a building classification model called as Building Quality Index (BQI) in Hong Kong. This model is composed of two different modules for assessments and serves as a benchmarking tool which rates the buildings with reference to the performance of the buildings with provision to add other modules if required as shown in Figure 7.

[Figure 7 near here]

According to (Yau et al. 2009) the two modules developed are Building Health and Hygiene Index (BHHI) which gives the overall health performance of the building and Building Safety and Conditions Index (BSCI) which gives the overall safety performance of the building. BHHI measures the performance of buildings in safeguarding occupants against physical and mental health risks while BSCI measures the performance of building in safeguarding occupants and the public against the risk of physical injury and death, like fire and falling objects (Ho et al. 2005a; b; c, 2008; Ho and Yau 2004).

According to (Ho et al. 2005a) BHHI & BSCI are divided into sub-indices in the hierarchy and combining BHHI & BSCI with other modules will form Building Quality Index (BQI). The cumulative product of ratings (F) and relative weightings (w) determined from inputs by experts using Analytic Hierarchy Process (AHP) will produce the corresponding index values (e.g. BHHI & BSCI) (Yau et al. 2009). Ho et al. 2008 specifically mentions that BHHI and BSCI have different objectives (i.e., health and safety), so their scores should not be compared however weighted arithmetic mean was adopted to combine individual ratings. Wing et al. 2012, using the principles and framework of BHHI and BSCI proposed a consolidated and simplified Dilapidation Index (DI). According to Wing et al. 2012, DI act as a tool for benchmarking buildings with reference to their current level of dilapidation and future susceptibility to dilapidation. The computation of Dilapidation Index (DI) is similar to BHHI & BSCI. DI operates like a penalty point system, each building factor receives a rating ranging from 0 (for the best scenario) to 100 (for the worst scenario). After rating aggregation, each building's DI also ranges from 0 to 100.

Housing Health and Safety Rating System (HHSRS)

Housing Health and Safety Rating System (HHSRS) evaluates the potential risks to health and safety from the deficiencies identified in dwellings and this rating system is also backed by law in United Kingdom (HHSRS 2005, 2006a). Vilhena et al. 2011 describes HHSRS as the evaluation of both the possibility of an occurrence that could cause harm and the probable severity of the consequences of such an occurrence. This Rating System uses a formula to generate a numerical Hazard Score and is not affected by type and age of building or method of construction as it is about the assessment of hazards and the potential consequences of those hazards and judgment is made as to whether that risk from hazard is acceptable or not (HHSRS 2006a). This rating system requires for each hazard, two judgements from local authority officers about assessment of the possibility over the next twelve months, of an occurrence that could cause harm to a member of the vulnerable age group even if people of those age groups may not actually be living in the property at the time of assessment and the range of potential consequences from such an occurrence. (HHSRS 2006a; b).
Following three different sets of numbers are used to generate a Hazard Score by HHSRS scoring programs (HHSRS 2006a).

1) Each four class of harm has a weighting representing the degree of incapacity to the victim resulting from the occurrence

2) Ratio expressed as possibility of an occurrence involving a member of a vulnerable group
3) A percentage for each four classes of harm expressed for spread of possible harms resulting from an occurrence

The Hazard Score is expressed as numerical score calculated as the aggregation of the products of the weightings for each Class of Harm, multiplied by the likelihood of an occurrence, and multiplied by the set of percentages showing the spread of Harm (HHSRS 2006a).
Further Hazard scores are grouped in ten different Hazard Bands (Band A-J) with Band J being the safest and A being the most dangerous. Hazard Score ranges 5000 or more for Band A, 2000 to 4999 for Band B and 1000 to 1999 for Band C. While for Band D the hazard score ranges from 500 to 999 and range keeps reducing for subsequent bands from E to J with hazard score for Band J being 9 or less. Higher hazard scoring falling within hazard bands A-C are serious ones termed as Category 1 and local authority has duty to take action outlined in the section on enforcement in HHSRS Guidance while hazards falling within bands D-J are termed to carry lower risk and are called Category 2 (Adcock and Wilson 2016; HHSRS 2005, 2006b).
HHSRS despite having pre-set tables with different range of scale tends to be more complicated in terms of calculation to arrive at hazard score. However, a rating system backed by law has huge potential to be accepted widely among stakeholders and public if they are straightforward and simple to adopt.

Facility Condition Index (FCI)

In United States, for maintenance of school facilities U.S Department of Education, National Centre of Education Statistics (NCES) developed condition scales for assessment of building components (Amani et al. 2012; NCES 2003). According to Ahluwalia (2008) the primary purpose of NCES condition assessment is to decide the level of preventive maintenance required for school building's components and systems. NCES condition rating scale is divided into eight condition categories. This rating scale describes the state of condition of component assessed ranging from 1-8, with rating 1 equivalent to new or in excellent condition while rating 8 means emergency intervention required as the component may cause injury or loss of life (Amani et al. 2011).

NCES uses Facility Condition Index (FCI) as a tool to compare the condition of school facilities and decide whether it is more economical to fully modernize an existing school or to replace it. FCI is calculated as a ratio of the total cost to correct the identified deficiencies to current replacement value. It is noted that if FCI is more than 1, it may be more cost effective to replace it rather than modernize it (National Forum on Education Statistics. 2012; NCES 2003)

Building Index

Dejaco et al. 2014, proposed two types of rating as Key Performance Indicators (KPI) namely Technical Index and Document Index for building condition assessment in Italy. In his proposition Technical index is to assess the building condition in terms of aging and abnormalities of its components while Documents index is to describe the availability of building documents taking into account legal requirements.

In this model of assessment Technical Index is composed of three sub-indexes with first two comparing the actual service life of each component with its reference called service life indexes (D^+, D^-) and third index evaluating anomalies found on each building component called degradation index (A). Each document score is evaluated as a product of its importance, weight and presence which is 1 if the document is available and 0 if not. Aggregating each document score Document Index is calculated as weighted ratio between the number of available documents and the number of documents that should be available for the specific building (Cecconi et al. 2014; Dejaco et al. 2014)

According to Dejaco et al. (2017), a single KPI is more easily understood which leads him to a combined Building Index calculated as a simple average of both the Technical Index and Document Index but to avoid misunderstanding both indexes are always presented together. Building Index is presented as pie doughnut chart representing both technical index and document index. Technical and Document indices are represented graphically in the form of radar chart in percentage. Documents availability of existing buildings affects the field inspection during condition assessment process irrespective of techniques used or methodologies adopted. Document availability index can be helpful in compliance with local building regulations as well as for more detailed inspection. However, Dejaco used average of document index and technical index to arrive at building index which can be misunderstood and may lead to misleading overall rating of the building.

Integrated Building Indicator System (IBIS)

Salim and Zahari, (2011) proposed Integrated Building Indicator System (IBIS), a rating system to assess existing building condition and determine cost of remedial action for building defects before repairing or rehabilitation of office buildings in Malaysia. IBIS model considered following factors into account type of building, function of building, gross floor area, number of defects, cost of remedial action of each defect and total cost of remedial work of building. The formula used in IBIS is a product of ratio between cost of overall defects and gross floor area in sq. m. with a constant which gives the rating. In IBIS model, the five building condition rating are based on cost of each defect ranging from rating 1-5 with rating 5 being the lowest cost of each defect while rating 1 being the highest cost of each defect. The highest rating 5 will consist of minor defects in the building while lowest rating will consist of serious defects with the highest cost of remedial work.

Comparison of Building Component Rating Models

It is imperative to understand that inspection and condition assessment of building occurs at component level (Uzarski et al. 2007) and further each component ratings are aggregated and rolled up to arrive at building ratings. For comparison common assessment criteria is chosen to compare between the selected nine rating models. The rating models are compared with respect to building hierarchies they use in their model to organize and group the building components; the rating scale; rating criteria; purpose of rating; inspection methods and tools used in the rating model.

Building Hierarchy

Buildings are composed of large number of interdependent components and systems (Amani 2014). Building hierarchy is intended to rationally organize and group various building components into different categories for classification (Mayo and Karanja 2018). For example, a building is composed of different systems such as Structure, Mechanical, Electrical or Plumbing these systems can be further divided into multiple components such as wall, beams, columns, lift, escalators, water pipes. These components when grouped together into categories can be presented in the form of hierarchy to keep track of them while rating the components during condition assessment. For objective assessment of building Straub (2009) asserts the necessity for a well-defined and hierarchical classification of building components.

Ho et al. (2005b), developed building hierarchy by dividing the building into two main branches Design and Management. According to Ho et al. (2005b), Design aspect of the building represents the physical hardware of the building which is fixed and difficult to change while Management aspect is analogous to software which is dynamic and controllable. 'Design' is divided in to three categories namely Architecture, Building Services and External Environment and 'Management' is divided into two categories Operation & Management and

Building Management. (Ho et al. 2005a) developed two different indices one for building health and another for building safety both using the same categories in their hierarchy except the components of the categories changes according to the type of condition assessment.

The building hierarchy used by Eweda et al. (2015) is divided into four main categories Architectural, Mechanical, Electrical & Structural. These categories are further sub divided into components such as walls, floors, windows, doors for Architectural category; HVAC, plumbing for Mechanical category; Lighting, wiring, communication network for electrical category and beams, columns, slabs, foundation stairs, ramps for Structural category.

Portuguese method of building condition assessment divides building into 37 functional elements and these elements are organized into three groups as whole building, shared parts and individual unit Pedro et al. (2008). In this method each functional element consists of a set of sub-elements with a specific function (e.g. columns, supporting walls, beams, floors and structural parts of balconies).

Dutch condition assessment method uses first four codes of the Dutch SfB classification (NL SfB) as their hierarchical classification which covers 80 to 90 per cent of the common building components in housing and real estate (Straub 2009). These four categories are Ground structure, Structure Primary elements carcass, Secondary elements and Finishes. Ground structure may include floor bed, retaining walls, foundations; Primary Structure includes building frames, internal and external walls, stairs, roofs; Secondary elements includes internal & external wall openings, handrails, balustrades; Finishes include internal & external wall finishes, ceiling finishes (Tu Delft 2019).

[Table 3 near here]

The building hierarchy of different rating models is summarized as shown in Table 3. Portuguese method of condition assessment divided whole building in to 3 groups and 37 elements (Pedro et al. 2008) while Dutch method used 4 categories and 23 elements Straub

(2009). Eweda et al. (2015) divided building in to 4 categories and 17 components while Ho et al. (2005b) divided building into 2 branches, 5 categories and 17 components.

The building hierarchies divided whole building into smaller component units to easily locate and manage them in the building assessment process. Previous studies have shown that developing building hierarchy is an imperative part of the process in evaluation of rating of building components. Different types of buildings may be composed of different types of components however many basic building components of categories like structural, electrical, mechanical remain common among most of the buildings. It is possible during examining the same defects in the building components with same rating methods but with different hierarchy can lead to variable condition rating results. Building hierarchy can have great implications in aggregating component rating to evaluate overall building ratings. To achieve an objective assessment building inspection personnel will require a well-defined hierarchical classification of building components.

From the review of literature, it can be concluded that there is no common standard hierarchy of building components being used. Ideally a building hierarchy should be consistent and logical to track components easily in a large building. Appropriate mechanism for rating building components should complement a comprehensive building hierarchy for efficient and reliable rating system.

Rating Scale

A rating scale compares the condition of different building components, these rating scales can be represented alphabetically or in the form of a numerical score. Different rating systems selected for this study has adopted different rating scales which are tabulated as shown in Table 4.

[Table 4 near here]

Abbott et al. (2007) proposed for hospital buildings numerical rating scale from 1-5 with rating 5 represents very good condition and rating 1 represents very bad condition while intermediate ratings 4,3,2 represents good, fair and poor condition. Pedro et al. (2008) describes Portugal residential building condition rating scale ranging from 1-5 where 5 represents minor defect and 1 represents critical defects while intermediate ratings 4,3,2 represents slight, medium and severe defects respectively. Straub (2009) explains the ranking of condition of residential building components ranging from 1-6 with 6 considered as very bad condition and 1 considered as excellent condition while 5,4,3,2 are considered bad, poor, fair, and good respectively. Eweda (2012) proposed rating scale in terms of percentage ranging from 0-100% and corresponding alphabetical ratings from A-F for educational building. Ratings from range 90-100% is rated A which represents excellent condition with no defects while 0-19% is rated F which represents complete failure. Intermediate conditions are rated as very good, good, fair and poor for conditions ranging from 75-89% (B),60-74% (C),40-59%(D),20-39% (E) respectively. HHSRS rating scale uses alphabetical as well as numerical rating called as Hazard scores are grouped in ten different Hazard Bands (Band A-J) with Band J being the safest and A being the most dangerous. Hazard Score ranges 5000 or more for Band A, 2000 to 4999 for Band B and 1000 to 1999 for Band C. While for Band D the hazard score ranges from 500 to 999 and range keeps reducing for subsequent bands from E to J with E=200-499, F=100-199, G=50-99, H=20-49, I=10-19 and Band J being 9 or less. (Adcock and Wilson 2016; HHSRS 2005, 2006b). NCES (2003) condition rating scale ranges from 1-8 for educational building. The rating 1 is equivalent to excellent condition and rating 8 means emergency intervention required as the component may cause injury or loss of life while 2,3,4,5,6,7 represents good, adequate, fair, poor, non-operable condition and urgent intervention required respectively. Ho et al. (2008) proposed rating scale for residential buildings ranging from 0-1. With 1=Satisfactory, 0.75=Above average,0.5=Acceptable, 0.25=Deficient, 0=Poor. Salim and

Zahari (2011) proposed condition rating ranging from 1-5 with rating 5 represents major repair and replacement of building component, 4 represents medium repair and replacement, 3 represents general maintenance, 2 represents minor repair and 1 represents good condition of building component.

Rating Criteria and Purpose

The models selected in this study uses different rating criteria and were developed for different purpose with different objectives and scope. Table 5 given below summarizes selected rating models of this study with their rating assessment criteria and purpose for which they were developed.

[Table 5 near here]

The assessment criteria used by Abbott et al. (2007) for rating of hospital buildings in South Africa is mainly based on maintenance, rehabilitation and replacement cost similar to United States used for educational buildings (NCES 2003). Gravity of building defects are main criteria used for assessment in Portugal for condition assessment of residential buildings (Pedro et al. 2008). Similar to Portuguese condition assessment in addition to intensity of building defects the extent of the defects are also considered in assessment of residential buildings in Netherlands (Straub 2009). The likelihood of the hazards causing harm to health and safety of occupants is main criteria of assessment for dwellings in United Kingdom (Adcock and Wilson 2016). Similar to United Kingdom in addition to Hazard another additional criteria Hygiene, which can cause harm to safety and health of occupants is also considered for assessment of residential buildings in Hong Kong (Ho et al. 2008). Ageing of building components & availability of documents was the main criteria of assessment in Italy (Dejaco et al. 2017). Type & age of building, defects and cost of remedial work of each defect were the main criteria of assessment in IBIS model (Salim and Zahari 2011).

The building component ratings are being used for different purposes such as deciding rent and taxes (Pedro et al. 2008); for decision making in repair and maintenance purpose (Abbott et al. 2007; NCES 2003; Salim and Zahari 2011; Straub 2009); for health and safety checks of buildings and asset management (Adcock and Wilson 2016; Dejaco et al. 2017; Eweda 2012; Ho et al. 2008). It can be concluded that rating of building components has wide variety of usage for assessment and determining state of health and safety of building to prioritising and decision making in repair and maintenance.

Inspection Method and Tools Used

The one common attribute of rating models selected for this study is their inspection methods for assessment of building components. Table 5 compares selected rating models of this study based on their inspection methods, origin and tools used for assessment.

All the rating models selected for this study inspect and assess the condition of building component by visual observation. As noted by Ahluwalia (2008) there exists variety of techniques and technologies for inspection of building but visual inspection suits more due to diversity of different components in a building. Since a large number of components of the building needs to be physically inspected by inspection personnel from moving one location to another to reduce time and cost of whole building inspection, visual observation seems to be best suited inspection method. Rating systems developed by Ho et al. (2008),Salim and Zahari (2011), Eweda (2012), & Dejaco et al. (2017) are outcomes of academic research while models described by Abbott et al. (2007) & NCES (2003) are initiatives by institutions. Condition assessment ratings described by Straub (2009) is in the form of standard code of practice. HHSRS & Portuguese ratings system are regulations backed by law (Adcock and Wilson 2016; Pedro et al. 2008). Irrespective of origin of geographical location of rating systems in different countries by different institutions be it academic research or standard codes of practice visual observation is the choice for inspection of building components. However, existing inspection methods based on only visual observation can lead to highly subjective results dependant on experience, training and perception of the inspection personnel (Hegazy et al. 2010; Silva and de Brito 2019; Straub 2002).

To improve the rating process different types of tools were developed to aid the rating assessment process. One of the main tools used is checklist forms to guide inspection personnel and record information (Abbott et al. 2007; Ho et al. 2008; Salim and Zahari 2011; Straub 2009). Checklist serves as a standardised guide for inspection personnel to help them record information during inspection. In addition to checklist form, a website also supports documentation and progress of the assessment process of buildings in Portugal (Pedro et al. 2008). Rating models which include complex calculations for aggregation of rating from component level to whole building uses computer programs to aid in assessment process (Adcock and Wilson 2016; Dejaco et al. 2017; Eweda 2012; NCES 2003).

Different tools provide aid in rating assessment to manage information and aggregation of rating for whole building. With developments in the area of computerised checklists and software being used in building component rating process, the results of building rating can be further utilised more efficiently. Using computer programs for rating of building components can also serve as good database for more organised checklist for large number of components in the building. However, correct documentation of files will still be needed for future reference and comparison with previous rating of components for monitoring the condition of building components.

The comparison of selected nine building component rating models for this study are summarised as below:

- Similarities between different rating system reviewed is that assessment is carried out mainly by visual inspection, the condition of the building is assessed by analysis of the entire building divided into smaller components, the severity of building defects is assessed using rating scale and weighting coefficients are used to determine the importance of each component for assessment in the final rating result.

- Major differences between different rating system reviewed are the objectives and scope of the assessment, methods used to arrive at cumulative final assessment & the tools used to develop the rating system.

Limitations of building component rating models

Every rating system has limitation that should be understood before using them. The comparative study of 9 different building component rating systems reveals that each system had different assessment process with different target buildings for different purpose. The limitation of these rating systems are that they do not assess the structural safety of the building, which will require more in-depth inspection. These rating systems also lack protocols for correction of human inspection errors. By using multi-tier inspection when serious defects are encountered, mistakes can be reduced during inspection and thus reducing errors in overall assessment of the ratings. Buildings are composed of large number of interdependent components, the nine rating systems compared in this study did not consider inter-relationship between different building components. As one building component can affect deterioration of other building component. It is also difficult to pinpoint the building defects inside whole buildings based on ratings alone. Another major limitation of rating systems reviewed in this study is their inspection method. Visually checking condition of building components without any instruments incorporates subjective assessment based on training and experience of inspection personnel. However, this limitation of visual observation method of inspection also allows cheaper and faster condition assessment. The rating systems discussed also lack practicality with respect to direct interpretation of final ratings.

Discussion

Literature reviewed in this study reveals that detailed inspection of buildings is technically complex task and requires lot of resources and personnel. In this study it was noted that the processes to evaluate condition of the building components were highly subjective as it was based on visual observation and completely dependent on interpretation of the inspection personnel. Hence the accuracy of rating of building components is reliant on the inspection personnel's training and experience. Education and training of inspection personnel with more objective based standardized methods and processes is also necessary to assure minimal subjective results in the final building rating.

Inspection of large number of building components is a huge task, sorting them in groups and categories and building hierarchy is required for easier management during condition assessment. Different researchers have tried to group building components and build a hierarchy according to their requirements however there is no consensus on common or standard hierarchy of building. Hierarchy of existing building components can be derived from the intended design purpose of building with provisions of any addition or deletion of components in future according to the change of use of building.

The relative weightage of components used in different rating systems reviewed are derived from surveys of experts which may be subjective and may also affect the final rating. Same building components may have different relative weightage in different buildings according to their functional use. Hence there should be flexibility in assigning relative weightage of building components according to the requirements and importance of components of building.

Efforts have been made by various researchers to develop rating system based on visual inspection and mathematical models to simplify assessment. Also efforts have been made to reduce resources and personnel's by adopting use of computer software programs. Previous studies also highlight the importance of regular and consistent condition assessment which is essential for benchmarking of building performance over a period of time for comparison. However, significant resources, cost and time involved in the process of inspection for rating large number of building components is one of the restrictive factor which governs frequency of building inspection and wider acceptability of building component rating systems.

It is evident from literature review that very few developed countries have adopted building component rating system as statutory requirement which encourages building owners and facility managers to embrace it. The subjectivity of assessment based on visual observation only, time consumption and high cost of building inspection of large number of components could be one of the reasons which still discourages facility managers from adopting building component rating system in places where it is not a statutory requirement. There is a need to develop cost effective and reliable building component rating system using consistent methods and metrics with reduced inspection cost and time consumption for sustainable building management.

Based on this study following recommendations are proposed for development of new building component rating system:

- Consistency- The rating system should be based on consistent building hierarchies and results obtained by rating score should be reproducible by others using same standard procedure.
- Easy to use – The rating process should be easy to use with self-explanatory rating scales for wider acceptability among professionals and building stakeholders.
- Objectivity - It is difficult to avoid subjectivity due to involvement of human factor while rating components of building, however care should be taken to reduce subjectivity as much as possible and make the process more objective by use of

tools such as portable non-destructive instruments to complement visual observation methods of rating.

- Modular- – The rating model should capture state of current status of the building components with current knowledge and limitations but also should have provisions for future improvements or additions if required in future. Hence a modular approach should be adopted with provisions for additions of modules in the rating system for future improvements.
- Transparent – The process for rating and assessment should be transparent and open for future examination so it is easy to detect mistakes if any committed during inspection.

Conclusions

Rating building components requires an understanding of interrelationships between the different components and the cascading effect of one component's deterioration on others and also potential effects that could result from building defects detected during the inspection. Hence it is critical to devise a rating system which is based on process which are more objective and less subjective. In this study different building component rating systems were compared and it was found that some of them are academic research outcomes, some are initiatives by institution while some are backed by country's legislation or standard codes of practice. It was noted from the above literature review that building component ratings are being used not just for performance assessment but also for different purposes such as deciding rent and taxes; for decision making in repair and maintenance purpose; for health and safety checks of buildings. In conclusion various condition rating systems suffers from drawbacks in their assessment process which are mostly subjective, time-consuming and costly. The weighting factors used in most of the rating systems were directly derived from few experts or dependent on surveys which can be improved. Prioritizing the critical building components based on previous assessments can help to optimize the frequency of inspection for re-assessment which in turn could reduce the cost and time. The conclusion can be summarised with following points:

- There is lack of mechanism to prioritize the most vulnerable building components in existing building component rating systems.
- Future research in development of new building component rating system should focus on reducing or eliminating subjectivity from assessment.
- Visual inspection which is one of the most widely accepted methods of building inspection must be complimented with use of Non-Destructive Testing (NDT) instruments in evaluation to provide more reliable information & uniformity in assessment with less subjective results.
- A new, more objective, quick, economical and technology based building component inspection system which is not affected by type or age of building is needed, to translate evaluation output into a reliable, consistent and easy to understand building rating system.

Acknowledgement

The authors would like to acknowledge and express their sincere gratitude to the Hong Kong Polytechnic University, Grant No.ZE92, for supporting this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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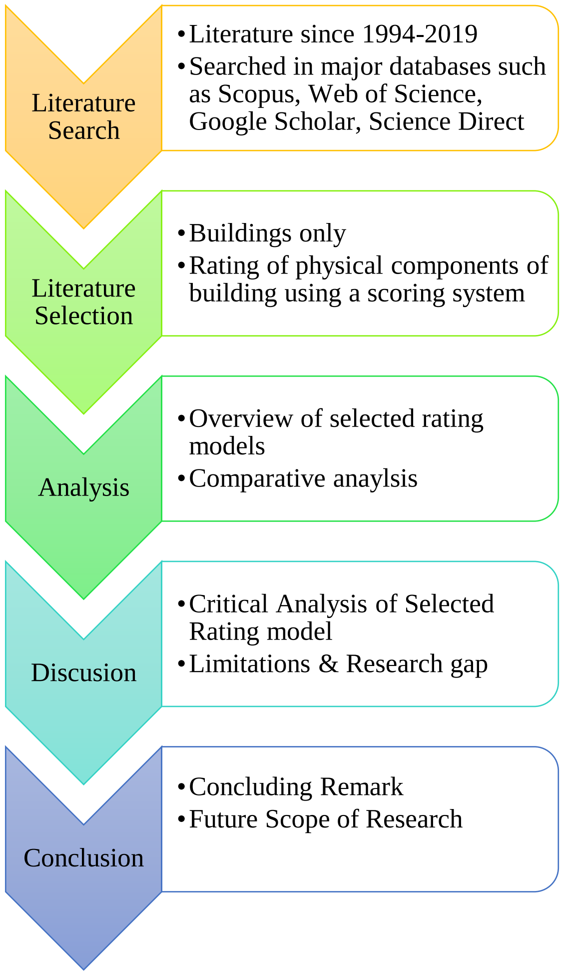

Fig. 1. Flowchart of research methodology

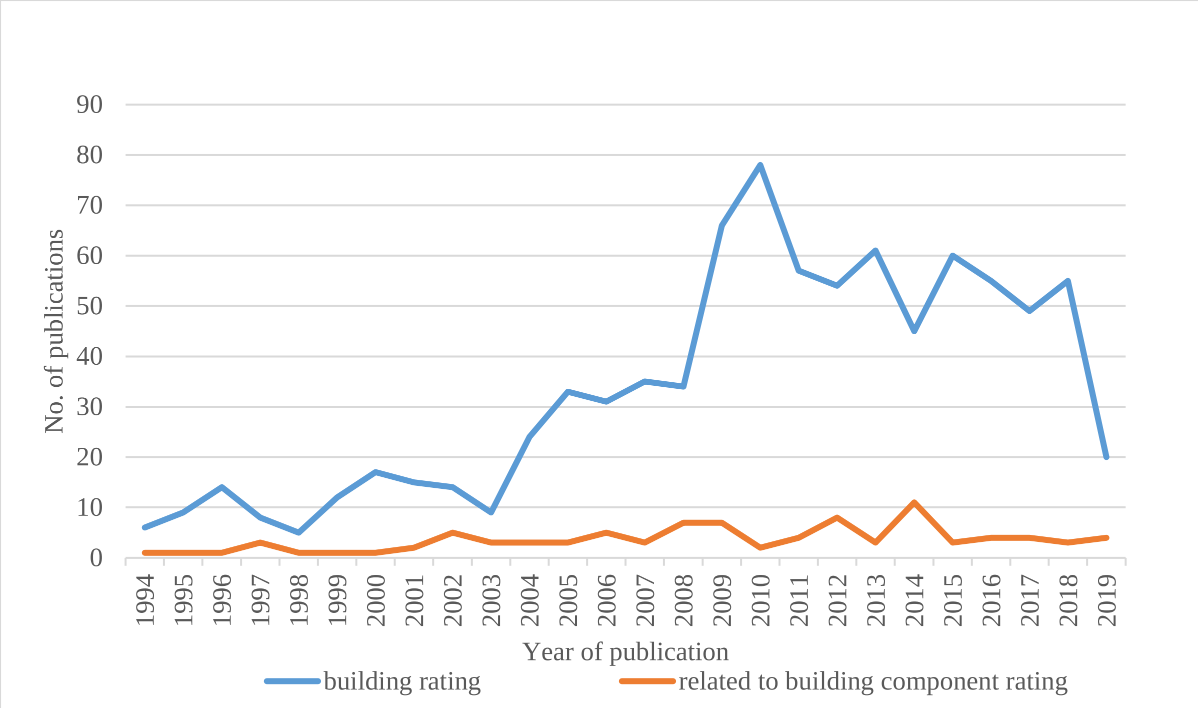

Fig. 2. Research publications from year 1994-up to June 2019

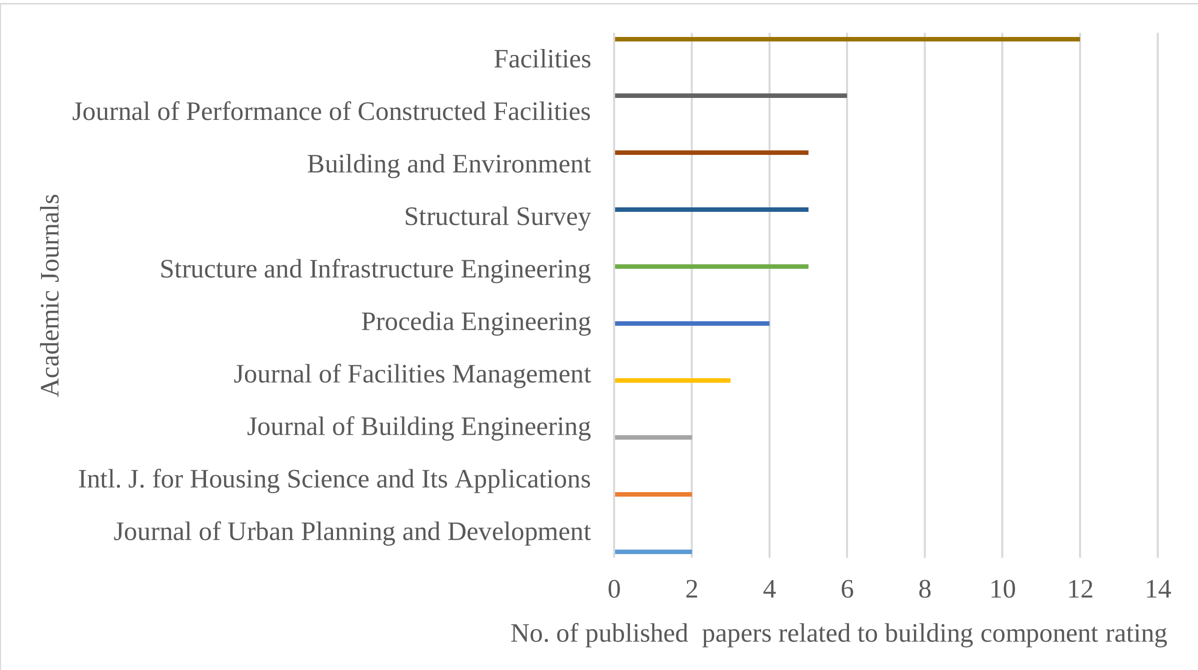

Fig. 3. Most cited academic journals papers related to building component rating from year 1994-up to June 2019

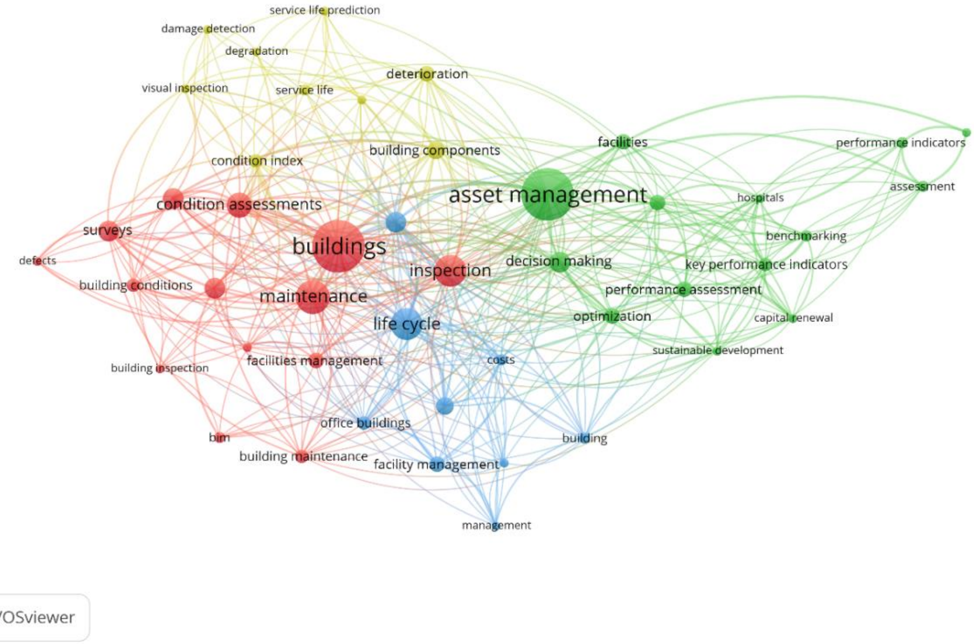

Fig. 4a. Co-occurrence of keywords in research related to building component rating

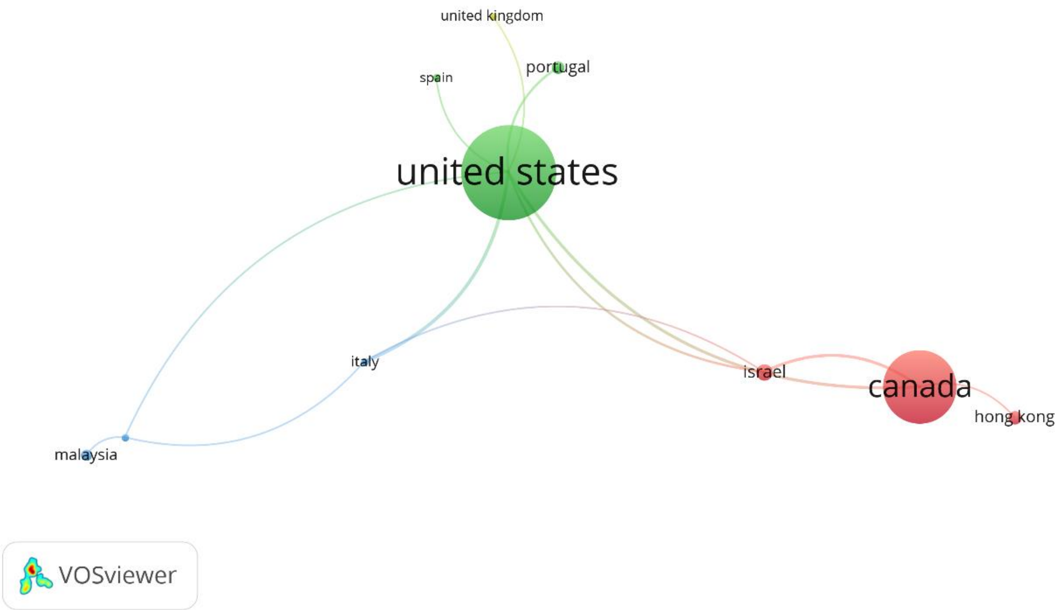

Fig. 4b. Map showing frequently cited countries/regions of origin of building component rating related research publications

Fig. 5. Colour coded Condition Rating proposed by Abbott et al., 2007

Fig. 6. Dutch Condition Assessment Process (Straub 2009)

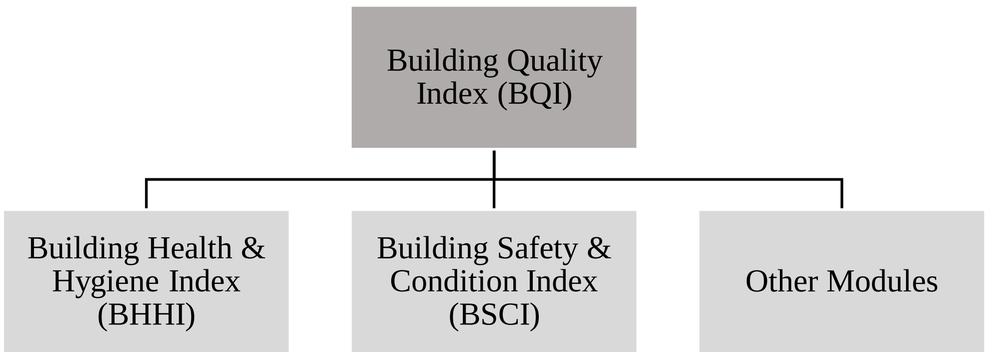

Fig. 7. Composition of Building Quality Index (BQI) proposed by Yau et al. (2009)

Table 1. Research centres contributing most cited papers related to building component rating during 1994-upto June 2019

Institution/ University	Country/Region	No. of publications
University of Waterloo	Canada	11
The University of Hong Kong	Hong Kong, SAR PRC	9
Texas A&M University	United States	5
Politecnico di Milano	Italy	4
National Center for Education Statistics	United States	4
Construction Engineering Research Laboratory	United States	4
Universiti Teknologi	Malaysia	4
University of Malaya	Malaysia	4
Concordia University	Canada	3
The Hong Kong Polytechnic University	Hong Kong, SAR PRC	2
University of North Carolina	United States	2
City University of Hong Kong	Hong Kong, SAR PRC	2
Delft University of Technology	Netherland	2
Construction Research Centre, National Research Council	Canada	2
National Laboratory for Civil Engineering	Portugal	2

Table 2. Research origin of building component rating related publications during 1994-upto June 2019

Country/Region	Institution/ University	No. of publications
United States	10	23
Canada	5	18
Hong Kong, SAR PRC	4	14
Malaysia	4	10
United Kingdom	3	6
Italy	1	4
Netherland	2	4
Germany	3	3
Denmark	3	3
Portugal	2	2
South Africa	2	2
Egypt	2	2
Spain	2	2
France	1	1
Israel	1	1
Iran	1	1
Indonesia	1	1

Table 3. Representation of components in building hierarchies

Reference	Building Type	Hierarchy
(Pedro et al. 2008)	Residential	3 groups and 37 elements
(Straub 2009)	Residential	4 categories and 23 elements
(Eweda et al. 2015)	Educational	4 categories and 17 components
(NCES 2003)	Educational	11 systems and 106 components
(Ho et al. 2005b)	Residential	2 branches, 5 categories and 17 components

Table 4. Different rating scales and description

Reference	Scope of buildings	Rating Scale	Description of Scale
(Abbott et al. 2007)	Hospital Buildings	1-5	Condition: 5=Very Good, 4=Good, 3=Fair, 2=Bad, 1= Very Bad
(Pedro et al. 2008)	Residential	1-5	Defect: 5=Minor, 4=Slight, 3=Medium, 2=Severe, 1=Critical
(Straub 2009)	Residential	1-6	Condition: 6=Very Bad, 5=Bad, 4=Poor, 3=Fair, 2=Good, 1= Excellent
(Eweda 2012)	Educational	0-100%	Condition: A(90-100%)=Excellent, B(75-89)=Very Good, C(60-74)=Good, D(40-59)=Fair, E(20-39)=Poor, F(0-19)=Failure
(Adcock and Wilson 2016)	Dwelling Residential	A-J	Hazard Score: A=5000>,B=2000-4999,C=1000-1999,D=500-999,E=200-499,F=100-199,G=50-99,H=20-49,I=10-19,J=9 or less
(NCES 2003)	Educational	1-8	Condition: 8=Emergency,7=Urgent,6=Non-operable,5=Poor,4=Fair,3=Adequate,2=Good,1= Excellent
(Ho et al. 2008)	Residential	0-1	Grade: 1=Satisfactory, 0.75=Above average,0.5=Acceptable, 0.25=Deficient, 0=Poor
(Salim and Zahari 2011)	Office building	1-5	Scale: 1=Good condition, 2= Minor repair ,3=General maintenance, 4=Medium repair & replacement, 5= Major repair & replacement

Table 5. Comparison of assessment criteria, purpose of rating systems, inspection method, origin of rating and tools used

Reference	Scope of buildings	Assessment Criteria	Principal Purpose of Rating	Inspection Method	Origin of Rating	Tools Used
(Abbott et al. 2007)	Hospital Buildings	Maintenance, Rehabilitation, Replacement cost	For maintenance budget allocation	Visual Observation	Institutional Research (CSIR, Pretoria, South Africa)	Checklist Form
(Pedro et al. 2008)	Residential	Based on gravity of building defects	To decide rent	Visual Observation	Govt. Regulation (Urban Tenancy Regime, Portugal)	Checklist & Website
(Straub 2009)	Residential	Based on intensity and extent of building defects	Maintenance Cost	Visual Observation	Code of Practice (NEN 2767, Netherland)	Checklist Form
(Eweda 2012)	Educational	Based on Space and building defects	Asset Management	Visual Observation	Academic Research (Concordia University, Waterloo, Canada)	BIM & Software
(Adcock and Wilson 2016)	Dwelling Residential	Likelihood of hazards causing harm to health and safety of occupants	Safety Risk Assessment	Visual Observation	Govt. Regulation (HHSRS, United Kingdom)	Computer Software
(NCES 2003)	Educational	Based on replacement cost	Maintenance	Visual Observation	Institutional Research (NCES, United States)	Computer Software
(Ho et al. 2008)	Residential	Based on Hazard and Hygiene which can cause harm to safety and health of occupants	Building Health & Safety	Visual Observation	Academic Research (University of Hong Kong, Hong Kong)	Questionnaire Form
(Dejaco et al. 2017)	Residential	Ageing of building components & availability of documents	Asset Management	Visual Observation	Academic Research (Politecnico di Milano, Italy)	Computer program
(Salim and Zahari 2011)	Office	Type, Age of building, Defects & Cost of remedial work	Repair & Maintenance	Visual Observation	Academic Research (Universiti Teknologi MARA Perak, Malaysia)	Checklist Form

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