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Title: **Redefining the impact assessment of buildings: an uncertainty-based approach to rating codes.**

Silvio Caputo and Mark Gaterell

Abstract: Discrepancies between predicted and in-use building performance are well documented in impact assessments for buildings such as rating codes. This is a consequence of uncertainties that undermine predictions, which include procedural errors as well as users' behaviour and technological change. Debate on impact assessment for buildings predominantly focuses on operational issues and does not question the deterministic model on which assessments are based as a potential, underlying cause of ineffectiveness. This article builds on a non-deterministic urban planning theory and the principles it outlines, which can help manage uncertain factors over time. A rating code model is proposed that merges its typical steps of assessment (i.e. classification, characterisation and valuation) with those principles, applied within the impact assessment of buildings. These are *experimentation* (of other criteria than those typically appraised), *exploration* (the process of identifying the long-term vulnerability of such criteria) and *inquiry* (iterating and critically evaluating the assessment over time).

Keywords: Impact assessment of buildings; Rating codes; Uncertainty; Uncertainty-based planning.

1 **1. Introduction.**

2 Increasingly used worldwide (Cole and Valdebenito, 2013), rating codes are perhaps the most popular
3 assessment to measure the impact of buildings on the environment, which in Europe – as for 2012 -
4 account for 40% of total energy use and 36% of total CO₂ emission (Zhao and Magoulès, 2012).

5 Rating codes were designed to predict the ‘whole building’ performance (Fowler and Rauch, 2006) by
6 using clusters of indicators representing several areas of sustainability in relationship to building
7 design and use (Chandratilake and Dias, 2013), measuring such indicators and aggregating them to
8 express a final rating. The introduction of the European Energy Performance of Buildings Directive
9 (2002) has further contributed to promote the use of these impact assessment tools within the building
10 industry, and national and local governments (Schweber and Hasan Haroglu, 2014).

11

12 Being mainly voluntary, rating codes are used by developers, building owners and practitioners to
13 demonstrate the high quality of their buildings. The ratings used in many of these tools have also
14 become benchmarks in policies and planning frameworks, thus utilised in the decision-making
15 process leading to planning consent (Retzlaff, 2009). However, rating codes are not without problems.
16 Their stated aim – at least in the UK – is to facilitate a holistic approach to sustainability (BREEAM,
17 2014). Cole (1998) links their aim to sustainable development, hence encompassing social,
18 environmental and economic dimensions. But rating codes struggle with the difficulty of integrating
19 multiple aspects of sustainability within their assessment’s structure, in particular social sustainability
20 (see Mateus and Bragança, 2011; Lutzkendorf and Lorenz, 2006). Furthermore, effectiveness of rating
21 codes is questioned (see Cole, 2005), also in the light of the increasing evidence that buildings in use
22 do not perform as initially rated (Carbon Trust, 2012; Menezes et al., 2012; Perez-Lombardi et al,
23 2009), because of many uncertain factors that are not considered in the assessment process such as
24 users’ behaviour (Fabi et al, 2012), which some authors claim to be the main cause of discrepancies
25 between predictions and real performance (Galvin and Sunikka-Blank, 2012; Zachary et al., 2010;
26 Haas and Biermayr, 2000).

27

28 Since their introduction in 1990 rating codes have been in constant evolution, attempting to improve
29 their predictive accuracy. BREEAM – a UK rating code – issued different versions (1998, 2006, 2011
30 and 2014) which have progressively improved the assessment system by, for example, specialising the
31 appraisal depending on the building type (e.g. supermarkets, education, industrial buildings, etc.).
32 Although significant, these improvements do not address uncertain factors mainly because, this paper
33 argues, it would require a structural shift from the current rating code’s quantitative approach, which
34 is deterministic and leads stakeholders involved in the process of design and construction to accept
35 predictions as real, to one that is sensitive to project-specific characteristics and open to multiple
36 outcomes. This article proposes an outline model of rating code which learns from principles

37 elaborated in an urban planning theory that, by recognising uncertainty as a defining feature of the
38 present urban context, identifies principles that can help manage it (Hillier, 2011).

39

40 The paper is structured as follows: in the next section, rating codes are briefly introduced and
41 shortcomings that have been identified in relevant literature highlighted. Subsequently, different
42 typologies of uncertainty are reviewed in order to identify one that is typically not considered in
43 impact assessments for buildings. Principles of the urban planning theory mentioned above are
44 subsequently discussed in order to transpose them to the rating code field and generate a new rating
45 code model to manage uncertainty. The article also identifies lack of debate as a reason why rating
46 codes still preserve their deterministic approach.

47

48 **2. Impact assessment for buildings: advantages and shortcomings of rating codes.**

49 There are two main systems used to assess the environmental impact of buildings, life cycle analysis
50 and criteria-based tools (Cheng et al. 2017; Assefa et al., 2007). The former, initially designed to
51 assess the life cycle of products or processes (Bribián et al., 2009), measures the impact of the entire
52 building's lifecycle within some boundaries set at the beginning of the analysis (e.g. from the
53 extraction and processing of materials to the decommissioning of the building). The latter is a
54 quantitative assessment, measuring the performance of criteria (i.e. indicators) for resource use, social
55 (e.g. health and wellbeing) and ecological impact. Criteria are scored, and scores weighted and
56 aggregated in order to generate a final rating for the whole building performance. BREEAM, the first
57 rating code launched in 1990 by the UK-based Building Research Establishment, is a criteria-based
58 tool assessing issues such as energy, water efficiency, waste management, and land use and ecology.
59 BREEAM was successful, and other rating codes followed (e.g. LEED in the USA, CASBEE in Japan
60 and DGNB in Germany), with 40 rating systems established worldwide by 2008 (Pushkar and Shaviv,
61 2016). All rating codes are based on the same assessment system but with different weighting and
62 selection of criteria. Such differences are sufficient to generate differences in final results when
63 different rating codes are used to assess a building (Wallhagen and Glaumann 2011; Wallhagen et al.,
64 2013; Cheng et al., 2017), thus showing that – despite sharing the same system of assessment - a
65 common methodology and theoretical approach for criteria-based assessments is missing (Wallhagen
66 et al., 2013). Nevertheless, as mentioned above, the use of these impact assessments for buildings is
67 increasingly popular and is now embedded in many planning procedures and policies (Retzlaff, 2009)
68 or used by financial and insurance companies utilising them as ‘a basis for risk and mortgage
69 appraisals and real estate valuations’ (Cole, 2005).

70

71 Cole (1998) defined rating codes as tools enabling ‘informed decisions based on the outcome of the
72 assessment that is most critical’. This definition portrays rating codes as tools designed to provide
73 evidence-base for decision-making. Much of the literature on this topic focuses on effectiveness in

74 terms of precision and reliability of results (Krizmane, 2016; Yu et al., 2015; Alyamia and Rezguib,,
75 2012; Menezes et al, 2012; Kajikawa, 2011; Mateus and Luís Bragança, 2011; Reijnders and van
76 Roekel, 1999) or comparability across the different rating codes (Becchio et al., 2014; Cheng et al,
77 2017; Adegbile, 2013; Chew and Das, 2008; Crawley and Aho, 1999) in order to increase their
78 effectiveness within the decision-making process. But only few studies (mentioned in the following
79 sections) discuss fundamental shortcomings, which affect the capability of the impact assessment tool
80 to meet its broader aim and point at the danger of relying on ratings that are merely predictive when
81 taking decisions. What follows is a brief overview of such shortcomings.

82

83 *Scope and complexity* - Within a criteria-based system of assessment, sustainable performance is
84 defined by the selection of criteria, which, in rating codes, typically privileges environmental, rather
85 than social, factors (Conte and Monno, 2012; Fenner and Ryce, 2008). But the complexity of
86 sustainability can hardly be captured within a set of categories/criteria (Lützkendorf and Lorenz,
87 2006; Berardi, 2012). Moreover, there are several interpretations of social sustainability (Dempsey et
88 al., 2009), which is understood in different ways. Generally, rating codes refer to it as a function of
89 health and wellbeing (e.g. ventilation, view out) (Haroglu, 2013), whereas it is suggested that it
90 should include factors such as education and awareness of sustainability (Mateus and Braganca, 2011)
91 or even factors related to social cohesion and participation in the design process (Amasuomo et al.,
92 2017). Such a broader understanding of social sustainability has implications not only in terms of the
93 assessment model (e.g. how can awareness of sustainability be measured?) but also in terms of the
94 role of the actors, who may need to be involved, for example, in a post occupancy phase of the
95 building life, as a means to assess the impact of the educational component of the building design and
96 process. Other authors point at the excessively general nature of categories/criteria that sometimes fail
97 to reflect contextual conditions, e.g. water scarcity, which may necessitate local or even building-
98 specific modifications to the weighting system as a consequence of site-specific vulnerabilities and
99 criticalities (Chandratilake and Dias, 2013; Alyami and Rezgui, 2012). Furthermore, by excluding or
100 including certain criteria, technologies or design strategy, rating codes can generate imbalances in the
101 appraisal (Retzlaff, 2009).

102

103 The need to include more refined criteria for social sustainability and other aspects of buildings'
104 sustainable performance is a symptom of a wider problem related to the scope of the assessment. Such
105 a scope is generally confined to the building and the building site, whereas there are externalities that
106 should be considered in order to generate an *absolute* (Cole, 1998), rather than local, impact
107 assessment. To this end, Conte and Monno (2012) propose a rating code that links criteria typically
108 included in the rating code assessment to a broader impact at an urban scale, with scores assigned to
109 building-related criteria only when these generate positive impact at an urban scale. This proposal,
110 however, exposes the complexity of an absolute assessment: in fact, the difficulty of identifying and

111 including a sufficient number of criteria capturing the multi-dimensional, multi-scale concept of
112 sustainability and building construction or the attempt to measure its absolute impact poses the
113 problem of manageability: increasing complexity may lead to higher effectiveness of the assessment
114 but at the cost of operability (Chandratilake and Dias, 2013). It would also require a shift in the
115 impact assessment culture (Conte and Monno, 2012; Cole, 1998) which at present sees buildings as
116 discrete entities rather than part of a wider urban system.

117

118 *Assessment and educational tool* – Literature on rating codes is quite limited and rarely questions the
119 use of the impact assessment's results within the decision-making process (Haapio and Vittaniemi,
120 2008). However, a few studies can be found on the capability of rating codes not only to assess but to
121 promote and raise awareness about sustainability (Haroglu, 2013). These tools are voluntary and
122 therefore used only for a small share of the newly built. Nevertheless, the impact they generate in the
123 process of assessment amplifies their effectiveness since it raises awareness amongst the actors
124 involved in the design and construction process, including practitioners, building industry and
125 decision-makers at large (Cole, 2005). Scientific analysis alone cannot elucidate the impact of human
126 interventions on sustainability (Krizmane, 2016; Cole, 2005). It is therefore the role and utilisation of
127 the assessment tool within the wider process of design, implementation and use that can generate real
128 effectiveness. To this end, the potential of rating codes to direct design choices towards sustainable
129 building design and construction could turn it into a powerful design tool. But rating codes were not
130 originally created as a design tool (Cole, 1998). In order to do so, the rating code should provide
131 guidelines at an initial design stage and more accurate criteria as the design and construction progress
132 (Thuvander et al. 2013), or a more flexible selection of sustainability criteria which does not constrict
133 design options (Cole, 1998). Effectiveness in raising awareness is also problematic for other actors
134 such as occupants. Cheng et al. (2017) maintain that the involvement of the building users within the
135 design process, in order to identify their needs and goals, is necessary. Without, it will be difficult to
136 judge which one of the energy saving concepts and measures perform well and which ones do not
137 work at all. Moreover, it could be added, the identification and engagement of representative samples
138 of occupants can be problematic. These reflections imply not only that the post occupancy phase, in
139 which measurement of the real resource use can be gathered and analysed, must become an essential
140 requirement of the assessment but also that the assessment must be conceived as a flexible tool in
141 which criteria that have proved ineffective can be exchanged for others.

142

143 *Gap* - Perhaps the main shortcoming debated is the difference between predicted building
144 performance and real operational life, which often do not match for a number of reasons both
145 technological and behavioural (Carbon Trust, 2012; Menezes et al., 2012; Perez-Lombardi et al,
146 2009). Performance gaps were not evidenced only in the UK but also in studies conducted in China
147 (Zhao and Zhou, 2017) and in LEED certified buildings worldwide (Newsham et al., 2009). The

148 majority of these studies focus on energy consumption, comparing real usage with prediction. There is
149 a paucity of studies on other criteria such as ecology, which is probably more difficult to measure.
150 Nevertheless, an energy performance gap points not only at operational assessment shortcomings but
151 also at failure to raise awareness in occupants, which is one of the aspirations of the tool. The high
152 degree of uncertainty associated with predictions formulated further confirms that ratings generated
153 from assessments are merely hypothetical (or aspirational) performance targets (Fenner and Ryce,
154 2008).

155

156 It is worth stressing that the majority of a limited literature on rating codes focuses on procedural
157 issues. This may have limited the role that debate in literature has played in the evolution of this
158 impact assessment. As a term of comparison, we note that literature on another model of assessment,
159 Environmental Impact Assessment (EIA), has played an important role in its evolution. EIAs were
160 introduced in the 1970s to assess the impact of human interventions, following the US National
161 Environmental Policy Act (NEPA) and in response to environmental concerns that were later on
162 captured in the definition of sustainable development (Cashmore, 2004). EIAs were subsequently
163 introduced in the UK in the 1980s and since then, they have been evolving in response to three
164 modifications of the European Directive 85/337/EEC, and they are likely to change in response to the
165 latest 2014 Directive (Jha-Thakur and Fischer, 2017). One of the main issues highlighted soon after its
166 introduction in the UK is the risk for this assessment to be used as scientific evidence on which
167 choices can be made by decision-makers (Cashmore, 2004), which was subsequently debated in other
168 studies (Cashmore et al, 2010; Morgan, 2012; Lobos and Partidario, 2014). The role of the assessment
169 within the process of decision-making and the factors at play within it (i.e. political, economic, etc.)
170 are such that this process is neither linear nor rational (Pope et al., 2013; Weston, 2000). Within such
171 debate, the review of theories on decision making (Weston, 2000; Fischer et al., 2010) led, amongst
172 other things, to understand the assessment as one that must be adapted to the context. Fischer et al
173 (2010), for example, suggest that an appropriate selection of context-sensitive indicators (i.e.
174 understood and valued by the stakeholders who will take a decision) can lead to higher effectiveness
175 of the assessment in terms of impact on the planning decisions taken.

176

177 Another much debated issue is uncertainty, which is directly addressed in the latest EU Directive,
178 requiring that a list of uncertainties involved in a project be included in EIA reports (Fischer et al.,
179 2016). Uncertainty as an element impeding the effectiveness of the assessment is debated from many
180 standpoints, including a conceptual perspective focusing on the aims of the assessment and how their
181 correct definition impacts effectiveness (Cashmore et al, 2010), the precautionary measures that
182 should be formulated in connection with uncertainties (Weston, 2000) and more. Jalava et al. (2013)
183 argue that EIAs are meant to reduce risks and uncertainties of human interventions but at the same
184 time they may not express all the uncertainties that remain unresolved with sufficient clarity. In a

185 review of follow-up (ex-post) assessments of transport infrastructure projects in England and Norway,
186 Nicolaisen and Driscoll (2016) too note a lack of communication of the uncertainties related to the
187 reliability of internal and external factors of projects. In fact, a follow-up to an assessment is not only
188 instrumental to measuring its effectiveness but also a way to learn from previous failures (Jones and
189 Fischer, 2016), thus possibly mitigating uncertainties in subsequent projects and assessments.

190

191 As mentioned above, the richness and depth of the issues debated in this abundant stream of literature
192 stimulate change by pointing to new directions, whereas, in comparison, literature on rating codes is
193 not so active. In fact, the overview presented in this section shows that the impact assessment model
194 of rating codes, in particular its deterministic, path-dependent nature, limits their potential to be
195 effective at several levels (assessing real impact, educating, and linking the assessment of the building
196 to the wider scope of sustainable development). The predictive character of ratings is acknowledged
197 within the BREEAM manual (2014) and – although only optional - post-occupancy evaluation is
198 offered as part of the assessment. Although important, such an option does not address the fact that
199 predictions are in reality the evidence-base on which planning consent and design choices are made.
200 We propose an uncertainty-based approach to address such limits and, in the following section, we
201 give a brief overview of the concept of uncertainty and the way this has been defined in different
202 fields of impact assessment.

203

204 **3. Typologies of uncertainty and uncertainty management in an urban planning theory.**

205 Uncertainty has been defined not only as the mere absence of information but also its incompleteness.
206 New information can resolve uncertainty or generate further uncertainty at a deeper level (Walker et
207 al, 2003). Uncertainties in predicting the environmental impact of planned interventions can refer to
208 inaccuracy of baseline information, changes operated within the project assessed and incorrect
209 understanding of causal effects (Tullos, 2009; Perdicoulis and Glasson, 2006). They can also refer to
210 collection of data (Booth and Choudhary, 2013; Garcia Sanchez et al., 2014) and users' behaviour,
211 which are inherent to any environmental assessment process (Weston, 2000; Leung et al., 2015). A
212 useful categorisation of uncertainties is provided by Rotmans and van Asselt (2001). They point out
213 that there are two recurrent typologies of uncertainty which in turn characterise several common
214 types. These are *lack of knowledge* and *variability*. The former includes inexactness and
215 immeasurability, the latter includes human behaviour, technological surprise and societal randomness.
216 A brief review of uncertainty according to different discipline-specific perspectives shows similar
217 understandings of uncertainty as defined by these two typologies (see Table 1).

218

219 TABLE 1

220

221 Uncertainty associated with *lack of knowledge* is generally modelled though ever-more sophisticated
222 mathematical and statistical methods such as Bayesian, fuzzy-rule based methods and model
223 divergence corrections (see Ascough et al., 2008). *Variability* is arguably more difficult to quantify
224 and is perhaps better captured through tools for qualitative assessments such as scenario analysis.
225 Duiker and Greig, (2007) point out that scenario analysis is particularly useful for EIAs, especially for
226 the development of risk management strategies. Scenario analysis is a systemic investigation which
227 can be used to broaden the scope of analysis to include factors exogenous to the system considered
228 both in space and time, which may have significant impact on performance. A case in point is given
229 by a study documenting an assessment on a local ecological system that, by looking at the effect of
230 climate change on the migration of species exogenous to the system, surmises the impact of such a
231 migration on the local fauna (Duinker and Greig, 2007). Such a migration is hypothetical but plausible
232 and, when considered as a concrete threat, can generate different strategies than those with a
233 conventional appraisal procedure.

234

235 Examples of applications of scenario analysis to the impact assessment of buildings can also be found.
236 For example, Hunt et al. (2012) merge a rating code (the Code for Sustainable Homes) with a scenario
237 based exploration of domestic water efficient technologies. This leads to the identification of the
238 technology that is likely to be more efficient under different scenarios of water consumption. Caputo
239 et al. (2012) assess the long-term conformity to several levels of energy efficiency within the Code for
240 Sustainable Homes of a development in Birmingham, using scenario analysis. In all these
241 experimental studies, quantitative and qualitative assessments are not generated deterministically.
242 Instead, *variability* is taken into account using several methods of scenario analysis (e.g. horizon
243 scanning, scenarios and visioning) in order to identify a number of possible outcomes. Inevitably, the
244 process is holistic and also discursive, in that it does not only offer quantifications but also reasoning,
245 which is in turn instrumental to the identification of causes behind uncertainty and ways to address
246 them. For rating code models, moving away from determinism would therefore entail embracing a
247 very different approach that recognises the impossibility of reaching precise results and the advantage
248 of working flexibly with multiple options.

249

250 Scenario analysis, however, is only a tool that can be helpful if used within a structured approach in
251 which results from the analysis can be meaningfully utilised. It is difficult to imagine how this
252 technique can be integrated into the path-dependent model of rating codes. In fact, a conceptualisation
253 provided by Wallahagen (2013) depicts such a model as follows:

- 254 • Structure (hierarchical structure, components, complexity);
- 255 • Content (labels, scoring, categories, parameters);

256 • Aggregation (method, weighting) and Scope (functional equivalent, spatial boundaries,
257 temporal boundaries, impacts).

258 Another conceptualisation that is less prescriptive and attempts to capture the underlying principles of
259 the impact assessment model is provided by Fenner and Ryce (2008):

- 260 • *classification* (i.e the identification of inputs and categories),
- 261 • *characterisation* (i.e. definition of the contribution of each input to the assessment); and
- 262 • *valuation* (i.e. scores and rankings).

263

264 We use this conceptualisation as a stepping stone allowing to include *variability* in the assessment. To
265 this end, we turn to a theory developed in urban planning which directly addresses *variability* in order
266 to learn and apply the learning to rating codes.

267

268 *A non-deterministic approach to urban planning to manage uncertainty.*

269 In reaction to an approach to planning relying excessively on trends and forecasts to determine
270 patterns of urban development, Myers and Kitsuse (2000) call for qualitative approaches integrating
271 data analysis, which can help make sense of past events and the present, and construct a line of
272 continuity to better anticipate future challenges. Prescriptive targets such as housing units and
273 commercial floor space risk to be meaningless and unattained in a world with high uncertainty (see
274 Balducci, 2011). Hillier (2011) proposes a theoretical approach to deal with ‘virtualities unseen in the
275 present’ (Balducci, 2011). She introduces the concept of different ‘trajectories or visions of the longer
276 term future’ as opposed to a future envisioned in continuity with the present, or as a path-dependent
277 repetition of the past. She argues for a ‘cartographic method’ to develop planning, in which
278 potentialities are traced and maps of the interplay of critical factors and phenomena are drawn up.
279 Myers and Kitsuse (2000) reach the same conclusion when they say that scenarios have the power to
280 demystify the future by ‘reducing complexity while bringing multiple perspectives into
281 consideration’. *Variability* as a form of uncertainty can be addressed by charting future possible
282 events with the aim of generating a *possibility space* (see Duinker and Greig, 2007), within which
283 options for urban development can be examined and their performance evaluated under a number of
284 variables.

285

286 Hillier is aware of the difficulties of applying theoretical insights into practice (2005; 2011). Hillier is
287 not alone; other scholars have developed work and provided insights on the difficulties of moving
288 from strictly normative ways to envisage and implement urban development to new approaches
289 focusing on process (i.e. a dynamic understanding of phenomena) (see Fainstein, 2005; Galloway and
290 Mahayni, 1977). Nevertheless, Hillier attempts the formulation of three guiding principles that

291 recognise the dynamic rather than static nature of urban transformation, which can have an impact on
292 the way planning is understood in practice:

- 293 • the investigation of ‘virtualities’ unseen in the present;
- 294 • the experimentation with what may yet happen; and
- 295 • the temporary inquiry into what at a given time and place we might yet think or do.

296

297 What follows is a brief elaboration of these principles and an attempt to transpose them to the rating
298 code field.

299

300 The first principle can be associated with a permanent exercise of horizon scanning ensuring that,
301 when planning, what is possible is identified and not ignored. This exercise, for example, can give a
302 voice to those urban stakeholders (e.g. local communities, associations and small enterprises) who are
303 part of (and informally involved in) any urban transformational process, and with their actions elicit
304 surfacing needs and wants or influence the success or failure of top-down plans. The principle can
305 thus be seen as a call to planning intended as an exploratory practice, attentive to how bottom-up
306 processes can steer transformation in cities in ways that are not intentionally and centrally planned.
307 Harnessing these processes becomes a way to turn uncertainties into opportunities and can lead to a
308 planning strategy highly adaptive to emergent phenomena and therefore endowing resilience. With
309 regards to rating codes, it is this exploratory dimension that can be useful to transform them into
310 effective design tools. This dimension requires systemic inquiry into the possible vulnerabilities of
311 design options. For example, buildings designed with open spaces and to perform efficiently through
312 natural ventilation may be, shortly after their delivery, renovated with cellular spaces, thus
313 compromising their passive cooling strategy (Montazami et al, 2015). Passive design principles are
314 currently strongly promoted, although it is unsure whether they will perform effectively against a
315 medium-to-long term scenario of higher mean temperatures (Sameni et al, 2015). Exploration, in
316 other words, can also help identify technical solutions and connected criteria that are appropriate for
317 particular contexts, which is another shortcoming of rating codes highlighted above.

318

319 The second principle suggests experimentation as an approach to ascertain benefits and advantages of
320 emerging trends in urban transformation. Herein, the eventualities are not only perceived as adverse
321 events to be managed but also as occasions to test new arrangements and take advantage of their
322 positive aspects. In planning, this entails a shift of attitude to governance allowing emergent
323 phenomena to influence the planning agenda and be tested for their effectiveness in addressing
324 societal issues. Eventualities are place-specific and experimentations are thus responses to
325 specificities of local conditions. This can be linked to another characteristic of rating codes, which
326 offer a generalised, universal set of requirements for compliance, thus leaving no space for options

327 that are not included within the rating frameworks or for any other alternative that departs from an
328 understanding of sustainable building performance and its scope as defined within such frameworks.

329

330 The last principle promotes a permanent attitude to inquiry and reflection on the state of things at any
331 time. It suggests critical and self-critical analysis as an approach to verify the effectiveness of
332 directions undertaken and also preparedness to change when analysis points to the need for different
333 directions. It is a principle that brings together the first two, recognising that exploration and
334 experimentation necessitate critical reflection to evaluate effectiveness of all options. This requires
335 openness to change and flexibility in decision-making for urban development. By extension, it can be
336 an invitation to understand rating codes differently, not only as a quantitative and/or qualitative
337 evaluation of buildings' performance but also as instruments enabling inquiry, therefore dialectical
338 exchange between stakeholders, leading to awareness of substantive objectives for sustainable
339 performance and solutions that are robust over time.

340

341 **4. An outline of an uncertainty-based approach to rating codes for buildings.**

342 In the sections above, shortcomings of the rating codes have been outlined together with principles of
343 a non-deterministic planning theory, suitable to deal with *variability*. Factors of uncertainty for rating
344 codes such as limited scope of the assessment, educational impact and gap between predicted and in-
345 use performance, which limit their effectiveness can be revisited using the concepts of exploration,
346 investigation and inquiry. We bring together these insights and propose a new model of rating codes,
347 starting from the conceptualisation of Fenner and Ryce (2008) introduced above. A diagram of a new
348 rating code merging the two is represented in Figure 1.

349

350 **FIGURE 1**

351

352 In the diagram, the stages of *classification and characterisation*, which are currently fixed
353 components in all rating codes, are complemented with an *experimentation* stage, in which new
354 technologies or strategies that are not captured in the existing *classification and characterisation*
355 stages can be identified and proposed. For example, a study shows how, in some of the most common
356 rating codes (e.g. LEED, BREEAM and GBRT), passive design features are penalised if compared to
357 conventional energy saving strategies (Chen et al., 2015). In an amended rating code model it would
358 be possible to propose and include passive solar design criteria under the *energy* category, thus
359 superseding some of the existing criteria for energy efficiency. Different weighting and scores can be
360 proposed to encourage higher efficiency in water usage, renewable energy generation or ecology, in
361 response to particular contextual conditions and stresses. Other categories could be introduced,
362 focusing on, for example, users' behaviour, household waste and food production, whenever relevant
363 to the particular site, ambition of the development proposed and social profile of the users. To this

364 end, a site and building specific investigation must be developed, which can lead to the identification
365 of alternative strategies to sustainable performance that are more likely to be successful in the long
366 term, within a particular socio-economic and environmental context. Furthermore, the identification
367 of optimal strategies that need to be captured with appropriate criteria within the rating system
368 requires dialogue with planning departments, thus encouraging dialectic debate and active
369 participation in shaping the assessment.

370

371 In the *exploration* stage, a scenario analysis can be developed, in which the lifetime of the proposed
372 building is specified and vulnerable factors that may undermine buildings' performance are identified.
373 For example, as mentioned above, ventilation strategies can be impacted by changes in layout over the
374 lifetime of buildings (Montazami et al., 2015). The perceived economic value of office buildings can
375 be strictly related to its flexibility of spaces and systems upgrading (Vimpari and Junnila, 2016).
376 Similar to the aforementioned need for EIA to make internal and external factors of uncertainty
377 explicit within the EIA assessment, rating codes too can increase their effectiveness by eliciting
378 uncertainties and use this process to generate solutions mitigating future risks. A way to implement
379 this in practice implies the use of scenario-based techniques that can lead to broaden the scope of
380 assessment and elicit relationships between actors, policies and diverse factors (e.g. 'what ifs'
381 inquiring consequences of changes of use, layout, external conditions, number and profile of users,
382 etc.), which cannot be captured in checklists for sustainable performance (Hacking and Guthrie,
383 2008). At its most basic, this type of quantitative evaluation could take the format of a risk analysis
384 such as those required for large development or infrastructural projects. Other frameworks for this
385 stage of the assessment that can be used are however available and in use. For example, BREEAM
386 Renovation, organises the lifecycle of buildings in sub-cycles such as structural, systems and
387 components, each one with a particular life cycle (e.g. 60 years for the structural cycle). A similar
388 framework could be used to identify points of vulnerability across each cycle and demonstrate that
389 such points have been addressed within the project.

390

391 In the final stage, *valuation* must be formulated that can capture both the performance forecasted, and
392 vulnerabilities possibly undermining such performance and connected causes. For example,
393 quantifications can be expressed with performance ranges, rather than discrete figures, and qualitative
394 evaluations explaining the reasons for each particular performance within the range. Valuation should
395 not be limited to the building as modelled during the design stage but extended to the in-use
396 performance. Hillier envisions planning as a practice in which 'outcomes are volatile; where problems
397 are not 'solved' once and for all but are rather constantly recast, reformulated in new perspectives'
398 (Hillier, 2005:278). This is a dynamic vision of urban planning that suggests, by extension, an
399 assessment iterated over time, following a reflective phase in which solutions are revisited and lessons
400 are learned. Stakeholders involved in the design, construction and use of a building are therefore

401 participating in a long-term design and monitoring process of the building, learning from this process
402 and applying lessons to periodically improve performance. Conceptually, this principle seems distant
403 from the linearity of the rating code model of classification-characterisation-valuation. Here again, the
404 parallel with the EIAs debate mentioned above regarding the advantages of a follow-up assessment,
405 can offer a useful term of comparison. Extending the timescale of the assessment can be functional
406 both to establishing the level of exactitude of predictions and using this knowledge to improve future
407 assessments, and to modifying, whenever technically and economically viable, anything that does not
408 function as predicted. To this end, Soft Landings (www.bsria.co.uk/services/design/soft-landings)
409 offers a framework which could be valid also for a new type of uncertainty-based assessment. A
410 protocol rather than a conventional appraisal, Soft Landings expands the temporal limits of the
411 assessment to the post-occupancy phase, at the same time modifying relationships and obligations of
412 the actors involved in the building process (i.e. clients, designers and constructors collaborating
413 beyond completion to ensure the correct use of the building). This, in turn, requires the redefinition of
414 stakeholders' remits and responsibilities (within the design, construction and management process),
415 which can no longer be limited to the delivery of buildings but also include their maintenance.

416

417 A further reflection is necessary about the issue of effectiveness. In reviewing literature on
418 effectiveness and EIAs, Chanchitpricha and Bond (2013) identify four categories contributing to its
419 conceptualisation: procedural (i.e. complying with standards and principles), substantive (i.e. attaining
420 intended objectives), transactive (i.e. cost and time effective) and normative. In particular, normative
421 effectiveness (that is: the potential of assessments to influence positively attitudes towards sustainable
422 development of stakeholders involved in any development process), suggests a role for impact
423 assessments that transcends the mere provision of scientific evidence and somehow stimulate a
424 process of change. Transferring this to rating codes entails that these tools can be used to (and
425 designed in a way that) help embed sustainability in urban policies. However, such a normative
426 change risks to be static because of the rating codes' path dependent model, which reduce sustainable
427 performance to a number of possible options universally applied and considers performance as
428 predicted rather than in use. A normative change that is more dynamic can only be achieved through
429 progressive learning and models of assessment are needed that can facilitate this process. The
430 uncertainty-based model of assessment for buildings proposed here is an initial attempt to emphasise
431 the potential for dynamic normative change.

432

433 **5. Conclusions.**

434 As a contribution of this paper to the debate on rating codes for buildings, a new model based on
435 uncertainty has been outlined in the section above. The new rating code model requires a shift of
436 focus from an effectiveness understood as reliability and robustness of the assessment results to one
437 that is based on an identification of a *possibility space*, in which buildings can be examined during

438 their lifetime, vulnerabilities impacting predicted performance values identified and fluctuations of
439 such values determined, thus making uncertainties explicit. The resulting model is an evolution of the
440 three-stage model that typically characterises rating codes (i.e. *categorisation*, *classification* and
441 *valuation*), which are reformulated in accordance to the principles of *experimentation* (of other
442 options of sustainable performance that transcend those typically appraised in rating codes) and
443 *exploration* (the process of identifying the long-term vulnerability of such options), thus enabling to
444 address *variability* (i.e. uncertainty related to randomness of nature, human behaviour and
445 technological surprises). *Inquiry* is also used to ensure that the resulting assessment is iterated over
446 time, with strategies initially formulated adjusted if needed. *Variability* is addressed in three ways:
447 firstly by identifying approaches that are in line with site-specific conditions (with site boundaries that
448 can vary from local to city-wide depending on the ambition and nature of the project); secondly, by
449 ensuring that such approaches are implemented effectively over the life-cycle of the building; and
450 thirdly, by providing a form of scoring that encourages this exploration. This, in turn, can improve
451 effectiveness of the building's impact assessment by addressing issues of scope, educational impact
452 and performance gap that are indicated in literature as ineffectively dealt with in the current rating
453 code model.

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Table 1. Categories of uncertainties (right hand side column) identified in literature

Authors	Categories of uncertainty
<i>Walker et al, 2003</i>	<ul style="list-style-type: none"> • Level of uncertainty (statistical; scenario and ignorance, total ignorance) • Nature of uncertainty (epistemic and variability)
<i>Rotmans and van Asselt, 2001</i>	<ul style="list-style-type: none"> • Variability (randomness of nature, human behaviour and technological surprises) • Lack of knowledge (lack of measurements, conflicting evidence and ignorance)
<i>Leung et al, 2015</i>	<ul style="list-style-type: none"> • Incomplete information, and the prediction and management of those outcomes • Communication (decision-making under uncertain conditions) • Avoidance (behaviour).
<i>Hopfe and Hensen, 2011</i>	<ul style="list-style-type: none"> • Physical (materials properties), • Design (geometry), • Scenario uncertainties (internal gains and climate change).
<i>Mirakyan and DeGuio, 2015</i>	<ul style="list-style-type: none"> • Linguistic (vagueness and ambiguity) • Knowledge (context; model and technical) • Variability (natural; human; institutional and technological) • Decision (objectives; criteria and strategies) • Procedural (available time, resources and imperfect communication)
<i>Regan et al, 2002</i>	<ul style="list-style-type: none"> • Epistemic (imperfect measurement devices, insufficient data, extrapolations and interpolations, and variability over time or space.) • Linguistic (scientific vocabulary or theoretical indeterminacies.)
<i>Ragas et al., 2009</i>	<ul style="list-style-type: none"> • problem definition uncertainty • true uncertainty (lack of knowledge) • variability (phenomenon of the real world)

Figure 1. The three stages of the rating code model (Fenner and Ryce, 2008) are represented in black. Intermediate stages – mediated from the uncertainty-based planning principles – are added in order to form an uncertainty-based model of assessment.