Getting innovations adopted in the housing sector

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Abstract

Purpose – The purpose of this study is threefold. First, to provide a taxonomy of innovations in the housing sector. Second, to create a coherent framework that includes the mechanisms that stimulate and hinder the adoption of innovation in the housing sector. Third, to develop propositions for future innovation adoption research.

Design/methodology/approach – A search in Clarivate Analytics' Web of Science, Elsevier' Scopus and the ARCOM database, followed by 'snowballing' as a backward search technique, revealed 94 scientific studies about innovation adoption in the housing sector. These studies were used to conduct a systematic narrative literature review about innovation adoption in the housing sector.

Findings – This study presents the state of knowledge about the adoption of innovation in the housing sector. Based on the unit of analysis by the studies included in our review, we present a taxonomy of housing innovation and we conclude that, typical for low-tech industries, no radical, discontinuous innovations were reported in the field of housing. Based on the data set of this review, a coherent framework has been developed, which includes four categories of determinants and underlying variables. Subsequently, 21 propositions have been deduced, which reflect the key mechanisms affecting the adoption of innovation in housing.

Originality/value – This paper is the first in which the various innovation adoption mechanisms for housing projects are integrated in a coherent innovation adoption framework. This framework not only provides an explanatory overview about innovation adoption in the housing sector but also provides insight to managers how to increase the chances to get their innovations adopted in the housing sector.

Keywords Innovation, Adoption, Housing, Review, Framework

Paper type Literature review

Introduction

Housing projects continue to be plagued by cost and time overruns, low productivity and inefficiency, housing quality issues and a high environmental impact. Innovative solutions, developed within the housing sector or supplied by other industries, are considered necessary to overcome these deficiencies. The awareness of the necessity of innovation in the housing sector has grown in the past few decades, which is reflected in the increasing number of scientific and professional publications about this topic. Despite the availability of innovations, the overall innovation performance of the housing sector falls short, primarily because of the poor adoption and lack of a widespread diffusion of innovations.

Rogers (2003) conceptualized innovation adoption as a communication process in which adoption reflects a pattern of information flow about an innovation. Following Rogers'

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conceptualization of innovation adoption, we define innovation adoption in the housing sector as follows: a communication, learning and decision making process about the application of an economic valuable and non-trivial improvement in a product, process or system relevant to the construction of housing, which is novel to one or several stakeholders involved in the housing project.

With respect to the adoption and further diffusion of innovations, it is widely recognized that the housing sector differs from other sectors because of its loosely coupled, fragmentary production network (Gann and Salter, 2000; Dubois and Gadde, 2002; Taylor and Levitt, 2007). In this respect, several researchers indicated construction, including housing, as an archetypal network industry because of the collaboration of multiple stakeholders to construct buildings (Miozzo and Dewick, 2004). This network reflects numerous interfaces, both technological and organizational, which are complex to coordinate, although these interfaces need to be managed within multi-actor projects. The complex structure of the housing sector, which is based on temporary networks of many stakeholders who are forced to collaborate with each other, is considered a key barrier to both the development and adoption of innovation (Dubois and Gadde, 2002; Gann and Salter, 2000; Bygballe and Ingemansson, 2014; Hoppe, 2012; Berardi, 2013). This argues for the importance of innovation adoption research in the housing sector.

A number of arguments speak for the theoretical and practical relevance of producing a systematic narrative review on the adoption of innovation in the housing sector. First, as has been emphasized by Brown and Eisenhardt (1995), reviews are particularly useful when a growing body of literature, such as about innovation adoption in housing, has not been tied together into a coherent framework. As a result it is difficult to grasp what is actually known (Brown and Eisenhardt, 1995; Keupp *et al.*, 2012). Systematic narrative reviews apply explicit and transparent methods to conduct a thorough search and critical appraisal of individual research projects to draw conclusions about what currently is known and not known about a field of research such as innovation adoption (Tranfield *et al.*, 2003; Briner and Denyer, 2012). Second, despite that several scholars have studied innovation adoption in the housing sector, a comprehensive model explaining the adoption of innovation in that particular context is still lacking. The lack of such a model has been cited as an important shortcoming in the literature (Dieperink *et al.*, 2004). Third, the absence of such a model complicates well-informed decision-making by practitioners and policy-makers to sustain innovation in the housing sector and improve construction practices in housing projects (Popay *et al.*, 2006).

The aim of this study is to present a systematic narrative review concerning the adoption of innovation in the housing sector. Therefore, we address the following research question: which determinants affect the adoption of innovation in housing projects? By addressing this research question, this paper contributes to the innovation literature in three ways:

(1) it presents a taxonomy of innovations specific to the housing industry;

(2) it organizes 'the adoption of innovation in housing' literature and synthesizes the mechanisms that stimulate and hinder the adoption of innovation in housing projects into a coherent framework; and

(3) it presents propositions for future research.

This study is organized as follows. In the next section, we discuss the method we followed for this literature review. In Section 3, we categorize the identified innovation adoption literature in the housing sector according to the applied theoretical concepts and classify the different types of innovations using Henderson and Clark's (1990) conceptual framework of

innovation. This section is followed (Section 4) by a synthesis of the identified adoption mechanisms into a coherent conceptual framework of innovation adoption in the housing sector. Moreover, we deduced 11 determinants with a positive effect and 10 determinants with a negative effect on the adoption of innovation in the housing sector. Finally, in Section 5, we discuss the contributions and limitations of this review and make recommendations for future research.

Methodology

The systematic narrative review method was selected for the purpose of developing a conceptual framework to tie together research concerning the adoption of innovation in housing projects, and then to identify future research directions (Briner and Denyer, 2012; Tranfield *et al.*, 2003). The systematic narrative review approach, unlike meta-analysis and bibliometric reviews, is particularly suitable to this purpose for three reasons.

(1) Systematic narrative reviews are attractive when the body of knowledge becomes increasingly fragmented and transdisciplinary, as well as when it becomes complex – in particular to practitioners – to manage the diversity of knowledge for a specific academic inquiry (Tranfield *et al.*, 2003).

(2) Narratives are at the heart of constructing new explanatory theoretical models and discovering new research directions based on summarizing, explaining and critical reflecting on the findings of multiple studies (Popay *et al.*, 2006).

(3) Systematic narrative reviews are most suitable when multiple storylines exist, reflecting multiple scientific traditions within a research field and which tend to differ from each other with respect to: conceptualization of the topic; language and metaphors used; formulation of research questions; research methods applied as well as qualification used (for example to assess 'quality' or 'success'). This complicates statistical syntheses techniques (Greenhalgh *et al.*, 2004; Greenhalgh *et al.*, 2005).

A key strength of a systematic narrative review is the relative fine-grained content analysis constructing explanatory theoretical models, unlike bibliometric reviews (Schraven *et al.*, 2015; White and McCain, 1998) and meta-analysis (Shadish, 1996; Popay *et al.*, 2006). In contrast, narrative reviews are prone to reviewers' bias relative to bibliometric reviews or meta-analysis.

The authors adhered to the principles and conduct of systematic review – organization, transparency and replicability to minimize the effect of reviewers' bias. This systematic narrative review follows the suggestions by Tranfield *et al.* (2003), Briner and Denyer (2012) and the 'diffusion of innovation' review by Greenhalgh *et al.* (2004) who conducted a systematic review regarding the diffusion of innovations in health service organisations. Therefore, our review followed the five stages of a systematic review: planning; searching; screening; and extracting and conducting a narrative synthesis (Tranfield *et al.*, 2003; Briner and Denyer, 2012).

Planning

The main question guiding our review is: 'which determinants affect the adoption of innovation in the context of housing projects?'.

Searching

We first applied a search query based on the key words 'adoption' and 'housing' and used these keywords to search for relevant, empirical and peer-reviewed scientific journal articles in Clarivate Analytics' Web of Science database. We selected the Web of Science database to conduct our review because it contains the top, high quality innovation journals. This ensures that we construct our conceptual model based on sound theoretical cornerstones derived from scientific studies published in these journals. As a robustness check, we consulted the Scopus database by applying the same keywords. Because several construction-related journals are not included in the Web of Science or Scopus databases, we decided to complement the search process by searching for relevant scientific articles in the ARCOM database. The ARCOM database hosts several influential scientific journals linked to the construction sector. Searching this database ensures that context specific research articles are included in the review.

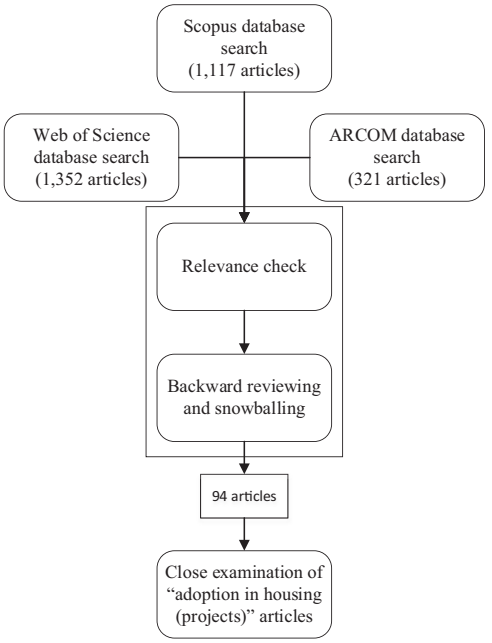
Subsequently, the search queries 'adoption' and 'housing' resulted in 1,352 studies from the Web of Science database and 1,117 studies from the Scopus database, published in the timeframe between January 2008 and July 2019. Based on the search query 'adoption' another 336 articles were found in the ARCOM database. References from all selected studies were also cross-checked to identify additional relevant articles (Figure 1).

Screening

Studies were assessed based on explicit inclusion and exclusion criteria (Appendix S1 Systematic Review Protocol) to ensure that each article in this study is relevant to the adoption-innovation domain in housing projects. Therefore, the abstract, keywords and introduction section were manually evaluated by the authors. We also took into account that synonyms are applied to describe adoption such as 'uptake' and '(user) acceptance'. Furthermore, some researchers used 'diffusion', 'dissemination', 'commercialization', 'implementation' or 'usage' to refer to adoption. These studies were also included in this review. Studies that match one of the following criteria were excluded because they do not primarily focus on innovation adoption in the housing sector:

- Studies that focus on 'implementation' and 'usage' instead of adoption;
- Studies that take social technical regimes shifts, technology transfer and market or industry transitions as focal point of analysis instead of the adoption and/or diffusion of innovation itself. Notwithstanding, studies that include the influence of determinants related to adoption are included in the review;
- Studies that aim to explain the commercialization and marketing of innovation;
- Studies in which focal point of analysis is aimed at consumer adoption without taking into consideration the context of the housing industry (e.g., articles that address the adoption of PV by homeowners from an endogenous perspective without taking into account contextual determinants of the housing industry); and
- Feasibility studies that assess the potential merits or progress of diffusion of specific innovations.

A snowballing approach was used to complement the papers identified, because searching the Web of Science, Scopus and ARCOM databases is unlikely to identify all relevant articles (Briner and Denyer, 2012). In particular, backward and forward reviewing (Webster and Watson, 2002; Levy and Ellis, 2006) was used to identify the papers necessary to derive a richer and more complete understanding. In contrast to the suggestions of Briner and Denyer (2012) we decided not to include grey literature, industry reports and conference



Notes: * The search queries "Adoption [AND] housing" resulted in 1,352 articles from the WoS database and 1,117 articles from the Scopus database respectively, published between 2008-June 2019. Based on the search query "adoption" another 321 articles were found in the ARCOM database

Figure 1.
Conceptual model of the systematic review

proceedings for several reasons. First, industry reports and scientific studies often duplicate each other's results, e.g. compare for example the reports 'The Diffusion of Innovation in the Residential Building Industry' (Koebel *et al.*, 2004) and 'Characteristics of Innovative Production Home Builders' (Koebel and Cavell, 2006) with the research articles published by Koebel (2008); Koebel *et al.* (2015).

Second, industry reports and conference proceedings tend to focus on the state-of-the-art and the potential of innovation rather than extensively identifying adoption mechanisms. Moreover, potential benefits of an innovation are often presented as adoption determinants without further evidence or clear explanation, e.g. reports published about Modern Methods of Construction (Corner *et al.*, 2005; NHBC, 2016).

Third, we also learned that only a few conference proceedings met our quality standards, i.e. these studies did not clearly specify the research question, lack a sound theoretical framework or suffer from methodological issues. Also, in several cases we could not check if the conference articles were evaluated by a double blind peer review process. Thus, scientific articles about innovation adoption in housing and published in double blind reviewed scientific journals were reviewed by the authors.

Because this review addresses the adoption of innovation in the housing sector, we further focused our closer examination on all the studies that passed the screening process. However, before extracting and synthesizing data, we conducted a quality check. To complete our quality check of the sample (Tranfield *et al.*, 2003; Briner and Denyer, 2012), we assessed the research findings relative to the gap in literature and/or research question addressed in the articles. We considered all papers of sufficient quality to be included in the review, although from a methodological point of view it was not always clear how data was collected, processed and/or analysed. Table III presents an overview of the research methodologies applied while studying innovation adoption in housing.

Extracting and synthesizing

We constructed a Data Extraction Form to guide the narrative synthesis. Following Popay *et al.* (2006), a narrative synthesis can be applied when exploring complex and discursive bodies of knowledge. Therefore, we used a narrative synthesis as a way to develop propositions and build them into a conceptual framework that provides nuanced insights about innovation adoption in housing projects. The conceptual framework and propositions bring together findings from a collection of studies to achieve a greater level of understanding, attain a level of theory development and subsequently reveal new opportunities for future research.

A taxonomy of the adoption of innovation in housing literature

The 94 identified studies about innovation adoption in the housing sector were published in 51 different scientific journals ranging from business economics (management, business and economics), environmental science to planning studies (construction). From the 94 articles included in our sample, 62 (66 per cent) were published in a scientific journal with a Scientific Impact Factor (June 2018) (Table I). Table II enlists the articles that have been cited at least more than 20 times. Table III provides an overview of the research methods applied to assess the adoption of innovation in housing.

Next, we assessed the theoretical lenses that researchers applied to study the adoption of innovation in the housing sector (Table IV). Typically, 40 articles applied socio-economic theories and 22 articles built upon Rogers' Diffusion of Innovations theory. Moreover, 14 articles built on organizational behavioural theories and 10 articles could be linked to cognitive behavioural decision science respectively. Surprisingly, we could not link 31 articles to any specific adoption theory. Several of these 31 articles built on previous research findings and were not clearly grounded in theory. Finally, we identified six articles (Mlecnik, 2016; Toole, 1998; Riala and Ilola, 2014; Engström and Hedgren, 2012; Liu *et al.*, 2018; Ramli *et al.*, 2019) that built on several theoretical concepts.

Finally, we assessed the type of innovations that are considered for adoption in the housing sector. The innovations that were studied in these articles can be characterized as technological or administrative innovations (Daft, 1978; Kimberly and Evanisko, 1981; Damanpour, 1987). Within the category technological innovation, researchers took into account the adoption of sustainable technology, new construction materials and methods and industrial building. Surprisingly, only three articles focused on the adoption of ICT as a primary unit of analysis (Kereri and Adamtey, 2019; Liu *et al.*, 2018; van Egmond-de Wilde de Ligny and Mohammadi, 2011). Furthermore, building on the framework of Henderson and Clark (1990), we distinguished between incremental, modular, systemic and radical innovations (Table V). The few studies addressing the adoption of administrative innovations focused on the adoption of an alternative housing delivery system (Shafiei *et al.*,

Journal	2017 Impact factor	No. of articles
Applied Energy	7.900	3
Architectural Engineering and Design Management	n/a	1
Building and Environment	4.539	1
Building Research and Information	3.468	7
Built Environment Project and Asset Management	n/a	1
Business Strategy and the Environment	5.355	1
Cityscape: A Journal of Policy Development and Research	n/a	1
Construction Economics and Building	n/a	1
Construction Innovation	n/a	4
Construction Management and Economics	n/a	4
Energy and Buildings	4.457	1
Energy Efficiency	1.634	3
Energy Policy	4.039	13
Engineering, Construction and Architectural Management	n/a	2
Environment, Development and Sustainability	1.379	1
Forestry Chronicle	0.488	1
Futures	2.256	1
Habitat International	3.000	3
Housing Studies	1.639	2
International Journal of Building Pathology and Adaptation	n/a	1
International Journal of Built Environment and Sustainability	n/a	1
International Journal of Construction Education and Research	n/a	1
International Journal of Engineering and Technology	n/a	1
International Journal of Environmental Research and Public Health	2.145	1
International Journal of GEOMATE	n/a	1
International Journal of Low-Carbon Technologies	0.837	1
International Journal of Organizational Innovation	n/a	1
International Journal of Sustainable Built Environment	n/a	1
Journal of Architectural Engineering	n/a	1
Journal of Cleaner Production	5.651	3
Journal of Construction Engineering and Management	2.201	3
Journal of Engineering Design and Technology	n/a	1
Journal of Engineering, Project and Production Management	n/a	1
Journal of Geography and Regional Planning	n/a	1
Journal of Green Building	n/a	3
Journal of Housing and the Built Environment	1.329	2
Journal of Housing Economics	0.811	1
Journal of Management in Engineering	2.282	1
Journal of Sustainable Real Estate	n/a	1
Journal of the American Planning Association	2.041	1
Malaysian Construction Research Journal	n/a	1
Open House International	0.081	1
Scandinavian Journal of Forest Research	1.600	1
Structural Survey	n/a	1
Sustainability	2.075	4
Sustainable Cities and Society	3.073	2
Technological Forecasting and Social Change	3.129	1
Technology Analyses and Strategic Management	1.49	1
The Bell Journal of Economics	n/a	1
Total Quality Management	1.526	1
Urban Water Journal	2.744	1
		94

Table I.
Overview of scientific journals linked to the field of innovation adoption in housing

Table II.
Articles included in this review sample ($n = 94$) have been cited at least 20 times according to the Web of Science database

#	Reference	Citations WoS	Journal published, including Journal Impact Factor (2017)
1	Nair et al. (2010a)	118	Energy Policy (4.039)
2	Beerepoot and Beerepoot (2007)	72	Energy Policy (4.039)
3	Pan *et al.* (2008)	55	Building Research and Information (3.468)
4	Toole (1998)	54	Journal of Construction Eng. and Man. (2.201)
5	Berardi (2013)	52	Energy Policy (4.039)
6	Gan *et al.* (2015)	52	Habitat International (3.000)
7	Mlecnik *et al.*. (2010)	49	Energy Policy (4.039)
8	Oster and Quigley (1977)	49	The Bell Journal of Economics (–)
9	Achtnicht and Madlener (2014)	45	Energy Policy (4.039)
10	Nair *et al.* (2010b)	41	Applied Energy (7.000)
11	Crabtree and Hes (2009)	40	Housing Studies (1.639)
12	Zhang *et al.* (2014)	39	Habitat International (3.000)
13	Pinkse and Dommisse (2009)	38	Business Strat. and the Environment (5.355)
14	Ozorhon *et al.* (2013)	36	Journal of Management and Eng. (2.282)
15	Hoppe (2012)	32	Energy Policy (4.039)
16	Fawcett (2014)	30	Building Research and Information (3.468)
17	Dewick and Miozzo (2002)	29	Futures (2.256)
18	Haines and Mitchell (2014)	26	Building Research and Information (3.468)
19	Owen *et al.* (2014)	25	Energy Policy (4.039)
20	Tambach *et al.* (2010)	24	Energy Policy (4.039)
21	Blackley and Shepard (1996)	23	Journal of Housing Economics (0.811)
22	Koebel *et al.* (2015)	23	Energy and Buildings (4.457)
23	Lees and Sexton (2014)	20	Building Research and Information (3.468)

Note: Out of the 94 articles included in our review, 21 articles are not included in the WoS database and thus lack a WoS citations count

Table III.
Research methodologies applied in articles included in the review sample ($n = 94$)

Research methodology	No. of times applied ($n = 94$)
Conceptual/literature review	6
Qualitative methodologies including (multiple) case studies; interviews; focus groups; job shadowing/observations	35
Qualitative methodologies involving surveys	34
Mixed research methods	10
Methodologies applying secondary sources/data sets	9

2010; Yusof and Mohd Shafiei, 2011) and sustainable (design) management (e.g. LEED) (Bowers *et al.*, 2014; Mlecnik *et al.*, 2010).

We were unable to identify a single radical innovation. This raises the question why this is the case. Housing and the construction industry in general have been classified as a traditional or low-tech industry and characterized by weak internal innovation capabilities and by strong dependencies on the external provision of machines, equipment and software (Pavitt, 1984; Heidenreich, 2009; Reichstein *et al.*, 2008). In line with the sectorial typology of Pavitt (1984) and Utterback and Abernathy (1975), low-tech industries are characterized by mature and standardized processes that limit the possibilities of further product and process

Theoretical concept (TC)	#	Reference
Socio-economic theories about innovation adoption (40 articles)		
Sociotechnical transition theory	4	Brown *et al.* (2014), Mlecnik (2016), Tambach *et al.* (2010), van Egmond-de Wilde de Ligny and Mohammadi (2011)
Diffusion of innovations theory	22	Akinboade (2012), Blackley and Shepard (1996), Egmond *et al.* (2006), Ganguly *et al.* (2010), Koebel (2008), Koebel *et al.* (2015), Lees and Sexton (2014), McCoy *et al.* (2012), McCoy *et al.* (2015), Mlecnik (2010), Mlecnik (2016) Mlecnik *et al.* (2010), Nair *et al.* (2010a, 2010b, 2012), Njuguna (1997), Ozorhon *et al.* (2013), Ramli *et al.* (2019), Riala and Ilola (2014), Sanderford *et al.* (2015, 2018), Toole (1998)
(Imperfect, asymmetric) information availability	2	Duah and Syal (2016), Syal *et al.* (2013)
(Unarticulated) tacit knowledge	1	Wolfe and Hendriks (2011)
Social learning theory	1	Berry *et al.* (2014)
"Education for sustainability"	2	Bossink (2018), Graham and Warren-Myers (2019)
"Needs of the customer"	1	Adinyira *et al.* (2018)
Change agents, opinion leaders, persona-based research, agency theory	3	Haines and Mitchell (2014), Muyingo (2015), Owen *et al.* (2014)
Theory of planned behaviour/ Technology acceptance model	4	Berardi (2013), Liu *et al.* (2018), Ramli *et al.* (2019), Steinhardt and Manley (2016b)
Organizational behavioural theory (14 articles)		
Evolutionary economics	1	Lees and Sexton (2014)
Institutional theory; isomorphism, innovation-regulation paradox; (national) systems of innovation	7	Beerepoot and Beerepoot (2007), Dewick and Miozzo (2002), Femenías *et al.* (2018), Liu *et al.* (2018), Lindgren and Emmitt (2017), Steinhardt *et al.* (2019), Warren-Myers and Heywood (2018)
Organisational information-processing theory	2	Engström and Hedgren (2012), Levander *et al.* (2011)
Behavioural change	1	Egmond *et al.* (2005)
Readiness towards change	2	Yusof and Mohd Shafiei (2011), Yusof *et al.* (2010)
Dynamic capabilities framework	1	Pinkse and Dommisse (2009)
Cognitive behavioural decision science (10 articles)		
Cognitive decision theory, decision-making bias	6	Christie *et al.* (2011), Crabtree and Hes (2009), Hedgren and Stehn (2014), Engström and Hedgren (2012), Riala and Ilola (2014), Toole (1998)
Motivation-Opportunity-Ability framework, willingness-to-pay	2	Baumhof *et al.* (2018), Tan *et al.* (2017)

(*continued*)

Table IV. Overview of theoretical concepts applied (references in italic build upon several theoretical concepts)

Theoretical concept (TC)	#	Reference
Concepts and models related to environment-related behaviour	2	Boser and El-Gafy (2011), Hauge *et al.* (2013)
Not specifically linked to any adoption theory (31 articles)		
Articles which could not linked to any specific theoretical framework in the field of innovation adoption	31	Abdel-Wahab *et al.* (2011), Achtnicht and Madlener (2014), Ali *et al.* (2018), Azam Haron *et al.* (2015), Bowers *et al.* (2014), Boyd *et al.* (2012), Daget and Zhang (2018), Fawcett (2014), Gan *et al.* (2015), Hoicka and Parker (2018), Hoppe (2012), Im *et al.* (2017), Kereri and Adamtey (2019), McCabe *et al.* (2018), Mueller and Berker (2013), Nahmens and Reichel (2013), Ojoko *et al.* (2018), Olsthoorn *et al.* (2019), Oster and Quigley (1977), Pan and Cooper (2011), Pan *et al.* (2007, 2008), Parsons *et al.* (2010), Roders and Straub (2015), Swan *et al.* (2017, 2013a, 2013b), Xiahou *et al.* (2018), Yang and Yang (2015), Akmam Syed Zakaria *et al.* (2018), Zhang *et al.* (2014)

Table IV.

innovations. As a result, cost optimization strategies dominate in contrast to innovation emanating from R&D investments, which are often found economically not profitable (Greenhalgh and Rogers, 2006; Heidenreich, 2009). Nevertheless, innovations do occur in low-tech industries. Supported by recent research about innovation in low-tech industries (Heidenreich, 2009; Hirsch-Kreinsen, 2008; Reichstein *et al.*, 2005; Reichstein *et al.*, 2008), innovation can take place without formal R&D and could be the result of incremental product improvements, customer-oriented developments or process optimisation strategies. To summarize, the incremental and architectural innovations identified in this review have in common that they build upon given technologies that are continuously improved. All the modular innovations identified in this review were – not surprisingly – developed and introduced by suppliers from outside the housing sector. These modular innovations in particular include industrially produced building components (wall sections and floor slabs) and the adoption of new energy technologies.

Mechanisms affecting the adoption of innovation in housing

In this section, we discuss the determinants affecting the adoption of innovation in the context of housing projects. Therefore, we first explore what constitutes a specific adoption determinant and subsequently we present a proposition about how it affects adoption. Rogers (2003, 1962) theory on innovation adoption, the Technology-Organization-Environment framework developed by Tornatzky *et al.* (1990) and Brown's (1981) Framework on adopter behaviour were applied as a starting point to synthesize the adoption determinants derived from the 94 studies included in this review. The developed conceptual framework (Figure 2) encompasses the drivers and inhibitors affecting the (intention to) adopt an innovation in the context of housing projects. This conceptual framework comprises four categories of determinants that are linked to three theoretical cornerstones

	Core concept	
	Reinforced	Overturned
Linkage between core concepts and components		
Unchanged	*Incremental Innovation* *(Green) building materials* *Such as: insulation materials; (energy efficient) doors & windows; composites* [04][08][14][15][20][22][31][40][41][48][55][56][57][61][62][70][71][85] *Building equipment* *Such as: scaffolding, formwork, machinery* [69]	*Modular Innovation* *Renewable energy technologies* Such as: PV systems; solar hot water systems; various HVAC systems (with heat recovery); heat pumps [01][04][08][09][11][14][20][37][38][41][42][46][53][62][64][68][73][79][80][81][87] *Water efficiency technologies* [04][09][20][62][67][88] *Modular -factory-built- wall and floor panels* *Such as: timber frame panels; (insulating) precast concrete; volumetric units* [04][09][11][12][37][41][47][54][63][69][85]
Changed	*Architectural (systemic) innovation* *Sustainable building concepts*[c] *Such as: high performance buildings (for example Passive House; LEED; Energy Label; Energy Star; CASBEE); energy efficient retrofitting (Passive House); low-waste building technologies* [02][06][07][10][13][17][18][19][23][24][25][28][30][33][34][49][50][51][52][60][74][75][82][83][84][90] *Industrial building* [05][06][12][16][21][26][27][35][43][45][59][65][66][76][77][78][89][93][94]	*Radical innovation* *Not identified*

Note: [a]*[03][32][58][72][83][91][92] include management innovations (building design techniques; strategies for climate adaptation measures; housing delivery system) which do not fit into the model* [b]*Limited attention have been devoted to research the adoption of ICT innovation in the context of housing, including Radio Frequency Identification Devices (RFID) [39][44] and domotics [86]. These innovations do not fit within the framework.* [c]*Most articles refer to 'sustainable construction' without further specification of the innovations involved. For example, articles [23][24][25][82] address deep retrofitting toward energy efficient housing and articles [74][75][87] focus on sustainable 'high performance buildings' which only can be achieved by applying systemic innovations (for example applying passive house principles). From a complementarity perspective these innovations include both technological and management innovations (Tatum, 1987);* References can be found in Appendix

Table V.
A taxonomy of innovation types in the housing sector (based on the framework of Henderson and Clark, 1990)[a,b]

found in innovation adoption research, i.e. socio-economic theory, organizational behavioural theory and cognitive behavioural decision science (van Oorschot *et al.*, 2018).

In the following sections, we will address the four categories of adoption determinants, i.e. product's characteristics and innovation attributes; adopter characteristics; industry characteristics; and influence of the environment.

Product's characteristics and innovation attributes

Rogers (2003) found that the adoption of innovation can be explained by five perceived characteristics of innovation: relative advantage; compatibility; complexity; trialability and observability. Researchers assessed the influence of these perceived characteristics on the adoption of innovation in the housing sector. They found that innovations should possess some form of relative advantage over alternatives (Table VI) (McCoy *et al.*, 2012; Mlecnik *et al.*, 2010; Xiahou *et al.*, 2018). In particular when homeowners are involved in the adoption decision-making process, the relative advantage should encompass immediate benefits such as comfort improvement or the replacement of particular building components because of their poor physical condition (Achtnicht and Madlener, 2014; Baumhof *et al.*, 2018; Nair *et al.*, 2010b; Roders and Straub, 2015; Swan *et al.*, 2013b). However, the immaturity of an

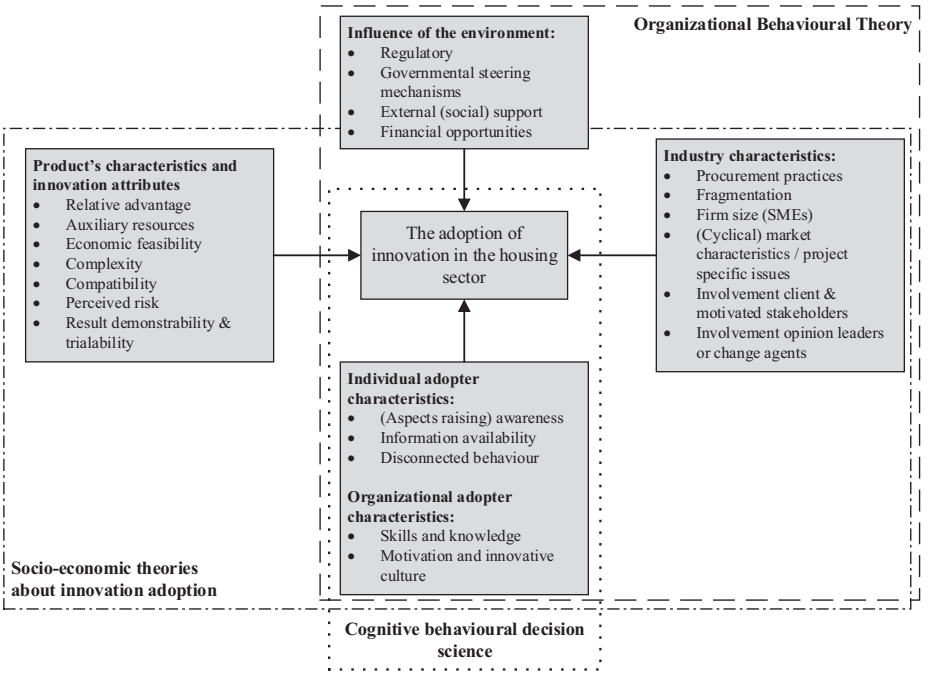


Figure 2.
A conceptual framework of innovation adoption in the housing sector

Table VI.
Determinants of relative advantage in the context of housing

Determinants of relative advantage	
Economic benefits and cost reduction	Improved comfort
Completion time reduction	Addressing labour shortage
Improved health and safety	(Project) management improvement
Higher quality	Productivity improvement
Architectural value	Supply chain integration
End-user empowerment	Reduced environmental impact

innovation (Gan *et al.*, 2015; Zhang *et al.*, 2014) can have a detrimental effect on the perceived relative advantage and the decision to adopt the innovation.

Furthermore, evidence has been found for the influence of complexity (Nahmens and Reichel, 2013) and compatibility (Gan *et al.*, 2015) on the adoption of innovation in the housing sector. Technological complexity and difficulties in using a new technology have a negative effect on adoption. The impact of the adversity of complexity increases when the application of the innovation highly depends on the availability of skilled personnel (Gan *et al.*, 2015; Nahmens and Reichel, 2013; Zhang *et al.*, 2014) and the level of change to familiar construction processes (McCoy *et al.*, 2012; Nahmens and Reichel, 2013). Also homeowners or tenants could perceive an innovation as complex. Research have identified stepwise adoption as a key strategy to overcome the complexity inertia. Concerning energy efficiency in housing, it was found that a staged approach in contrast to an one-off integrated deep-renovation approach stimulates adoption of energy efficiency measures (Fawcett, 2014;

Hoicka and Parker, 2018; Mlecnik, 2010). Moreover, closely related to the concept of compatibility, if the innovation requires to learn something new or change the way work is done (i.e. lack of interoperability and fit in existing supplier relations), it diminishes the propensity to adopt the innovation (Gan *et al.*, 2015; Mlecnik *et al.*, 2010). In addition, evidence has been found that innovations could benefit from result demonstrability and trialability (Mueller and Berker, 2013; Xiahou *et al.*, 2018; McCoy *et al.*, 2012; Mlecnik *et al.*, 2010). In contrast, perceived risk concerning the impact of negative consequences for applying the innovation hinders the adoption of innovation (McCoy *et al.*, 2012; Mlecnik *et al.*, 2010). To summarize, this leads to the following five propositions:

P1. Relative advantage. The relative advantage of an innovation over alternatives has a positive effect on adoption. In the same way, the immaturity of the innovation has a negative effect on adoption and moderates the effect of relative advantage.

P2. Complexity. Complexity, emanating from a lack of skilled personal and the level of change to familiar construction practices, has a negative effect on adoption. Moreover, the complexity of the construction process in which the innovation needs to be incorporated – involving many stakeholders and interactions at multiple levels – has a negative effect on adoption.

P3. Compatibility. Lack of compatibility with existing construction processes (concerning the way work is done, the lack of interoperability and fit in existing supplier relations) has a negative effect on adoption of innovation.

P4. Result demonstrability and trial-ability. Result demonstrability and trial-ability have a positive effect on innovation adoption.

P5. Perceived risk. Perceived risk concerning the impact of negative consequences for applying the innovation has a negative effect on innovation adoption.

In addition to Rogers' perceived characteristics of an innovation, we identified two additional innovation determinants that are addressed in literature on innovation adoption in the housing sector. First, several researchers addressed the impact of auxiliary resources on innovation adoption. A wide range of resources have been identified that spur the uptake of innovation or when absent could hinder adoption, including assessment tools, standards and certification, governmental support, professional expertise and guidance, knowledge level availability and learning cycles, exemplary projects and understanding of (latent) client needs (Gan *et al.*, 2015; Zhang *et al.*, 2014; Mlecnik, 2010; Mueller and Berker, 2013). Second, several variables have been found to influence adoption taking into account the economic feasibility of the innovation: investment costs, the payback period, time constraints to assess economic feasibility, energy costs and financial incentives (Gan *et al.*, 2015; Zhang *et al.*, 2014). The perceived (poor) economic feasibility is considered one of the key determinants of innovation adoption in housing. To summarize, this leads to the following two propositions:

P6. Auxiliary resources. Auxiliary resources, consisting of assessment tools, standards and certification, governmental support, professional expertise and guidance, knowledge level, exemplary projects and understanding of (latent) client needs, support the adoption of innovation. In contrast, the absence of these resources hinders the adoption of innovation.

P7. Economic feasibility. Economic feasibility issues concerning high investment cost, a relative long payback period and time constraint to assess the economic feasibility

have a negative effect on adoption of innovation. In contrast, (governmental) financial incentives have a positive effect on the adoption of innovation.

Adopter characteristics

Individual adoption characteristics. After the introduction of a classification of innovation adopters ranging from innovators to laggards (Rogers, 2003), studies have examined the intrinsic personal characteristics of individuals facing a decision to adopt a particular innovation. However, adopter characteristics (such as income, age, gender and education) only gained modest attention in the housing sector (Nair *et al.*, 2010a, 2010b, 2012). In this respect, resistance (to change), aversion, (lack of) willingness and reluctance, which are frequently mentioned in other sectors, gained only minor attention in housing so far and are poorly understood in the context of housing (Ozorhon *et al.*, 2013; Njuguna, 1997; Baumhof *et al.*, 2018; Tan *et al.*, 2017). Nevertheless, a particular personal characteristic addressed by several researchers is the lack of awareness of the availability of new solutions and its economic benefits (Bowers *et al.*, 2014; Azam Haron *et al.*, 2015; Gan *et al.*, 2015). Education and access to specific information create awareness and thus education and training could stimulate adoption (Oster and Quigley, 1977). However, typical for a low-cost and supply-driven industry culture, a lack of market demand and a lack of market orientation diminishes awareness, have a negative effect on adoption (Bowers *et al.*, 2014; Gan *et al.*, 2015; Nahmens and Reichel, 2013).

Besides that education and access to specific information create awareness about possible innovations, it also provides the knowledge base and skills to decide to whether to adopt these innovations. In this respect, previous experiences positively stimulate the adoption of innovation (Bowers *et al.*, 2014; Sasatani *et al.*, 2015). As has been emphasized in general adoption theory, information is key to the adoption and diffusion of innovation (Rogers, 2003; Oster and Quigley, 1977; Toole, 1998). However, in housing, it has been found that imperfect and asymmetric information have a negative effect on adoption (Duah and Syal, 2016; Syal *et al.*, 2013). This not only links to the decision whether to adopt an innovation but also to the information required to apply and/or operate the innovation; thus, continued adoption highly depends on adequate information hand-over and 'social learning' to use innovations such as sustainable energy technologies (Brown *et al.*, 2014; Swan *et al.*, 2017, 2013a, 2013b, McCabe *et al.*, 2018; Berry *et al.*, 2014). To summarize, this leads to the following two propositions:

P8. (Aspects raising) awareness. The lack of awareness (knowledge dissemination) of an innovation has a negative effect on adoption.

P9. Information availability. Imperfect and asymmetric information availability have a negative effect on the adoption of innovation. Moreover, poor information processing capabilities have a negative effect on innovation adoption.

Adoption research builds on the assumption that adoption follows from a rational decision-making process (Rogers, 2003). Christie *et al.* (2011) addressed the nature of decision-making by individual decision making in housing projects, i.e. homeowners. These researchers introduced the concept of 'apparent disconnect': sustainable related considerations are taken into account and positively valued and still sustainable innovations are rejected. Thus, although innovations rationally are considered valuable, bias against these innovations inhibits its adoption. Christie *et al.* built on the concepts of bounded rationality (Simon, 1957; Simon, 1991), loss aversion (Kahneman *et al.*, 1991) and regret avoidance (Samuelson and Zeckhauser, 1988) to explain disconnected behaviour. The majority (79 per cent) of the

homeowners involved in their research project showed 'disconnected behaviour', indicating that they want the technology but are not willing to pay for it.

In addition, research revealed that, in the case of adoption in housing, incumbent frames of reference and the information infrastructure on which it is based are not sufficient to guide decision making about an innovation. An experience-based, mechanistic form of decision-making has proven to create bias against the innovation (Engström and Hedgren, 2012; Hedgren and Stehn, 2014; Levander *et al.*, 2011). This leads to the following proposition:

P10. Disconnected behaviour. Bias of the decision maker against an innovation – emerging from an incumbent frame of reference; risk avoidance behaviour and aversion to change – has a negative effect on its adoption.

Organizational adoption characteristics. Many adoption decisions involve individuals employed by an organization. In this respect, researchers assessed the motivation and innovative culture of firms active in the housing sector. Motivation and the innovation culture refer to the ability and willingness to adopt an innovation (Yusof and Mohd Shafiei, 2011; Yusof *et al.*, 2010), i.e. reflecting the readiness or innovation capability maturity of the organization (Pinkse and Dommisse, 2009).

First, market readiness variables, including:

(a) Market responsiveness – looking for new ideas from the market; and

(b) Market orientation – meeting the needs of clients as main goal, have a positive effect on adoption (Yusof and Mohd Shafiei, 2011; Yusof *et al.*, 2010).

Next, organizational readiness variables reflect the innovative culture of the firm. Expressed by policy guidelines, policy plans and action plans on certain issues, organizational readiness have a positive effect on adoption (Egmond *et al.*, 2005; Swan *et al.*, 2017, 2013b; Roders and Straub, 2015). Moreover, a risk taking culture (Pan *et al.*, 2007; Pinkse and Dommisse, 2009) and self-efficacy (perception of its own capacity) (Egmond *et al.*, 2005) has a positive effect on adoption. In contrast, organizational bias and negativism, which relate to overemphasizing negative characteristics of the innovation, have a negative effect on adoption (Pinkse and Dommisse, 2009; Riala and Ilola, 2014). Also, the split-incentive problem undermines the willingness to adopt, while the costs of adopting the innovation are for the contractor while the buyers benefit from the merits (Pinkse and Dommisse, 2009).

Third, resource readiness, in particular concerning information gathering capabilities and appropriate technical capacity and knowhow, have a positive effect on adoption. Capabilities concerning communication are most relevant considering the difficulties of communicating the merits of the innovation to other stakeholders in the project as well as client and/or end-users (Pinkse and Dommisse, 2009; Yusof and Mohd Shafiei, 2011; Yusof *et al.*, 2010).

Lack of data, tools and/or knowledge to convey the benefits to other stakeholders hinders the adoption of innovation (Crabtree and Hes, 2009). This is further complicated by the nature of the information, which often involves tacit knowledge (Wolfe and Hendriks, 2011; Duah and Syal, 2016; Syal *et al.*, 2013). In this respect, Pinkse and Dommisse (2009) found that communicating the advantages of sustainable technologies to potential home buyers to create market demand remains a major challenge to contractors. It has proven difficult for a contractor to evaluate and next communicate about innovations because of the complex interactions among the various stakeholders. This seems particularly challenging when the

innovation is considered risky and requires to break out the technological lock-in. This leads to the following two propositions:

P11. Skills and knowledge. Previous experiences and education and training, contributing to the necessary skills and knowledge, have a positive effect on innovation adoption.

P12. Motivation and innovation culture. Motivation and innovation culture refer to a firm's innovation readiness level and has a positive effect on innovation adoption.

Industry characteristics

Adoption scholars have reported about the importance to take into account the effect of contextual determinants such as the industry structure and the technological characteristics (Downs and Mohr, 1976; Brown, 1981; Tornatzky *et al.*, 1990; Attewell, 1992). Many innovations are adopted in housing projects, involving multiple project stakeholders. Within housing projects, the following contextual determinants affect the adoption of innovation: involvement of clients and motivated stakeholders, involvement of opinion leaders or change agents, fragmentation, procurement practices and market characteristics.

Several researchers have assessed the influence of stakeholders on adoption. Specifically, the role of clients and occupants with respect to innovation adoption have been assessed (Hauge *et al.*, 2013; Hoppe, 2012). Professional clients such as volume builders or social housing associations are named as potential change agents. They not only supply housing to consumers but also generate demand from the supply chain (Warren-Myers and Heywood, 2018). Although it is agreed that the involvement of professional clients could spur innovation in housing, without the support of occupants the innovation could still be rejected, referred to as the principal-agent inertia. The principal-agent inertia reflects that end-users, people who are mostly affected by whether an innovation will be adopted, are not directly involved in the decision-making process. Thus, adoption depends on a decision of 'agents', representatives of social housing associations, housing co-operations and volume builders, to adopt a particular innovation. Poor end-user engagement and discarding the voice of the customer could result in an adoption decision, which deviates from end-user(s) demand and subsequently hinders the adoption of innovation (Azam Haron *et al.*, 2015; Brown *et al.*, 2014; McCabe *et al.*, 2018; Muyingo, 2015) (Table VII).

Owen *et al.* (2014) and Nair *et al.* (2012) have considered the positive influence of a largely overlooked change agent, namely, energy technology installers and advisors, on the adoption of energy technology in residential retrofit projects. The empirical findings indicate that advisors and installers play a powerful role in influencing both the adoption and use of energy efficiency technologies. This leads to the following proposition:

P13. Client involvement, motivated stakeholders and change agents. The early involvement of clients/end-users and highly motivated (project) stakeholders have

Table VII. Determinants of the principal-agent inertia

Determinants of the principal-agent inertia	
Tenant-installer-landlord relationship inertia: distrust of end-user	Information asymmetry
Unclear understanding user needs: mismatch design and consumer requirements	Horizon incentive problem
	Influence problem
	Hand-over problem

a positive effect on innovation adoption. In the same respect, the early involvement of change agents has a positive effect on innovation adoption.

Many innovations in the housing sector will be adopted at the project level. Not surprisingly, it was found that the instability and fragmentation of temporary aggregations of many stakeholders in construction projects are barriers to adopting innovation, particularly new technologies. Fragmentation within the housing sector hinders adoption because of the complex interactions among the various stakeholders involved. Poor supply chain integration and cooperation affects adoption by:

- insufficient coordination and collaboration within the supply chain which negatively affect adoption (Wolfe and Hendriks, 2011; McCoy *et al.*, 2012);
- late introduction of the innovation, subsequently resulting in the late involvement of key stakeholders, negatively affect adoption (Berardi, 2013; Hoppe, 2012; McCoy *et al.*, 2012); and
- structural barriers emanating from temporary project aggregation and a lack of partnering concept (i.e. loss of control, distrust, incomplete information and insufficient communication) negatively affect adoption (Berardi, 2013; Gan *et al.*, 2015; Hoppe, 2012). Hoppe (2012) and McCabe *et al.* (2018) found that where a breakdown of communication between stakeholders occurred, there was also a breakdown in trust, which is not conductive to innovation.

This leads to the following proposition:

P14. Fragmentation. Poor coordination within the fragmented housing sector – reflecting loose couplings within and across construction firms – hinders the adoption of innovation beyond single projects.

Characteristic to a fragmented industry, the housing sector largely consists of small and medium enterprises (SMEs). It has been found that firm size, measured by construction revenues and/or the number of employees and reflecting the available economic and information resources, affect the propensity to adopt innovations in housing (Yusof and Mohd Shafiei, 2011; Yusof *et al.*, 2010). For example, Ganguly *et al.* (2010) found that large firms are more likely to adopt innovative building materials. Large firms continue the application of established building materials while slowly increasing the usage of the innovative counterpart. In contrast, when SMEs do adopt the same innovative building materials, it replaces the traditional materials at a faster rate. Thus, SMEs differ from large firms with respect to adoption timing and the level of adoption. Overall, previous research found that construction SMEs are less likely to adopt innovation in contrast to large firms (Blackley and Shepard, 1996; Oster and Quigley, 1977). This leads to the following proposition:

P15. Firm size. The small firm size of construction SMEs has a negative effect on innovation adoption.

Traditional project procurement practices, i.e. projects awarded to the lowest bid, are considered a critical barrier to adoption. Traditional procurement appears not conductive to overcoming the disadvantages (lack of trust, low level of cooperation, lack of information and communication) of fragmentation and loose network ties (Gan *et al.*, 2015). Warren-Myers and Heywood (2018) found that integrated procurement practices, such as Design

and Construct, in line with a supporting supply chain, stimulate the adoption of (sustainable) innovation in housing.

Moreover, several determinants related to the construction process of housing projects were found to hinder adoption, including the time of introduction and the delay at which interest emerges; project deadlines and delays and organization of the process (Hauge *et al.*, 2013; Hoppe, 2012; McCoy *et al.*, 2012). An example of traditional construction practices hindering adoption is provided by Berardi (2013) who found that the uptake of energy-saving technologies is slowed down by the late involvement of key stakeholders with the greatest interest (often the occupants). Consequently, most of the choices related to construction are made by stakeholders with low motivation for the adoption of energy-saving technologies and high power to impose their will. Hoppe (2012) also found that over-ambitious project goals and poor experiences in previous projects hinder the adoption of innovations. This leads to the following proposition:

P16. Procurement practices. Traditional procurement and lowest price orientation is not conductive to overcoming the disadvantages of fragmentation and loose network ties and have a negative effect on innovation adoption. Next, the construction process organization (i.e. the time of introduction and the delay at which interest emerges, project deadlines and delays, and organization of the process) has a negative effect on innovation adoption.

Several researchers claim that the cyclical nature of the housing sector caused by regular downturns, and resulting in uncertainties in market outlook, hinders the adoption of innovation (Blackley and Shepard, 1996; Nahmens and Reichel, 2013). Several other economic determinants, related to project(-site) conditions, affect the adoption of innovation in housing. The propensity to adopt innovations varies directly with an increase in the price of the houses being constructed; innovations are more likely being adopted in the high-end market, consisting of larger and higher priced dwellings, in contrast to low-end markets (social housing).

In addition, the nature of the construction project, i.e. new build versus renovation, building typology and conventional versus industrialized construction shape the conditions to apply an innovation (Blackley and Shepard, 1996; Ganguly *et al.*, 2010). These aspects refer to project specific issues, which could affect the adoption of innovation in projects (Table VIII). A notable example is the poor accessibility of a construction site which hinders the application of large volumetric building modules. This leads to the following proposition:

P17. (Cyclical) market conditions project specific issues. Cyclical market conditions (regular downturns) have a negative effect on innovation adoption. In addition,

Table VIII. Project(-site) specific issues affecting innovation adoption in housing

Project(-site) specific issues	
Building type and form	Perceived (thermal) comfort
Ownership	Energy cost
Heritage restrictions	Market segment (price level)
Level of repetition	Site location
Age of the building	Geographic/climate issues
Past investments (no-regret)	

project(-site) specific issues (low-end market segment, housing typology, site conditions) have a negative effect on adoption.

To summarize, fragmentation, lowest bid procurement practices, project specific issues and market uncertainties are considered detrimental to the adoption of innovations in the housing sector. Therefore, several scholars refer to 'contextual difficulties' or 'structural barriers' hindering the adoption of innovation in construction. In contrast to the importance of contextual difficulties we found that many research projects lack an adequate link to the context in which adoption decision-making takes place. This is supported by adoption research conducted in other parts of the construction sector (Larsen, 2011; Mukherjee and Muga, 2010).

Influences of the environment

Adoption behaviour of stakeholders in the housing sector is affected by environmental forces, including regulatory, financial opportunities and social support.

One form of institutional pressure often addressed concerning the adoption of innovation in the housing sector is the effect of building regulations. In particular, the European Energy Performance of Buildings Directive and national sustainable construction agendas have been taken as focal point of analysis (Mlecnik *et al.*, 2010). The main question is how and to what extent policy instruments and regulation effect innovation and innovation adoption. This research fits within a larger debate about regulation, competition and innovation (Dorée *et al.*, 2003), also referred to as the innovation-regulation paradox (Dewick and Miozzo, 2002). Contradicting findings have been presented; some researchers claim that building regulations inhibit adoption where others just found the opposite (Beerepoot and Beerepoot, 2007; Gan *et al.*, 2015; Mlecnik *et al.*, 2010; Oster and Quigley, 1977). However, it is generally accepted that, although the modest influence of building regulations, it will be more likely that an innovation will be adopted when legislation and regulations are in place (Beerepoot and Beerepoot, 2007; Gan *et al.*, 2015). This leads to the following proposition:

P18. Regulatory. Building regulations have a coercive and positive effect on innovation adoption.

Governmental steering mechanisms such as legal support and permit procedures, governmental policy implementation effort, efficient monitoring systems and grants enhance the potential adoption of innovations in housing (Gan *et al.*, 2015; Swan *et al.*, 2013a; Tambach *et al.*, 2010). Typical to innovation in low-tech industries such as housing, innovations tend to be developed upstream by component manufactures and need to be adopted downstream by contractors and the involved project stakeholders (Miozzo and Dewick, 2002; Pries and Janszen, 1995). Therefore, when applied in the wrong way and targeting the wrong stakeholders in the value chain, governmental steering mechanisms do not stimulate innovation and even could hinder the adoption of innovation (Beerepoot and Beerepoot, 2007; Koebel *et al.*, 2015). This leads to the following proposition:

P19. Governmental steering mechanisms. Governmental steering mechanisms (i.e. legal support and permit procedures, governmental policy implementation effort, efficient monitoring systems and grants) have a positive effect on innovation adoption.

However, as emphasized by institutional theory, the effect of government influence should not be exaggerated (Vermeulen *et al.*, 2007). It was found that without the legitimacy provided by construction firms, unions, interest groups and consumers adoption can become problematic (Gan *et al.*, 2015; Oster and Quigley, 1977). For example, Egmond *et al.*

(2005, 2006) found that energy-relevant behaviour of housing associations to a large extent depends on institutional forces, including subjective norm, feedback of peer organizations and feedback from authorities. In this respect, the subjective norm of an organization refers to the strength of the opinions and feedback of other (governmental) organizations about the appropriateness of adopting a particular innovation.

In addition, it has been emphasized that for many innovations the support from financial institutions is required to cover the upfront (investment) costs (Gan *et al.*, 2015; Yusof and Mohd Shafiei, 2011; Yusof *et al.*, 2010). Specifically, innovative and alternate financing options – which normally need to be approved by the authorities – including lease contracts, community financing and subsidies, are considered to stimulate adoption (McCabe *et al.*, 2018).

To summarize, external support, including client demand, subjective norm, feedback of peer organizations, feedback of authorities, regulations and facilitating and encouraging policy instruments (covenants, information, benchmarks and demonstration), have a positive effect on adoption (Yusof and Mohd Shafiei, 2011; Yusof *et al.*, 2010; Pinkse and Dommisse, 2009; Egmond *et al.*, 2005; Egmond *et al.*, 2006). This leads to the following two propositions:

P20. External support. External support, reflecting strength of the opinions and feedback of other (governmental) organizations, has a positive effect on innovation adoption.

P21. Financial opportunities. Support from financial institutions to cover the investment cost has a positive effect on innovation adoption.

Determinants of innovation adoption in the housing sector

The determinants identified in this review link to 21 propositions that affect the adoption of innovation in the housing sector. Some of these propositions have a negative effect on adoption and are considered as barriers for innovation adoption, while propositions with a positive effect stimulate innovation adoption and subsequently diffusion. This indication is based on whether the studies included in our sample have identified the involved determinants as drivers (+) or barriers (−) to innovation adoption. Figure 3 presents an overview of the propositions and their effect on adoption.

Contribution, implications, limitations and research agenda

Major research results

This study has produced the following major research results. First, this paper opened with a taxonomy of innovations. Building upon the framework of Henderson and Clark (1990), we were able to identify three types of innovation, i.e. incremental, modular and systemic innovations. We did not identify in the selected literature any radical, discontinuous innovations. This result agrees with the theory about innovation in low-tech sectors in which firms apply business strategies driven by cost optimization rather than innovation (Greenhalgh and Rogers, 2006; Heidenreich, 2009).

Second, there have been no attempts in the literature to identify and synthesize the different variables affecting the adoption of innovation in the housing sector to date. One of the primary contributions of this paper is that it has synthesized existing literature about innovation adoption in housing projects. The conceptual framework developed in this review comprises four categories of determinants and their underlying variables that affect the adoption of technology innovation in housing projects. The four categories of determinants are as follows: influence of the environment; product's characteristics and innovation attributes; industry characteristics and individual adopter characteristics.

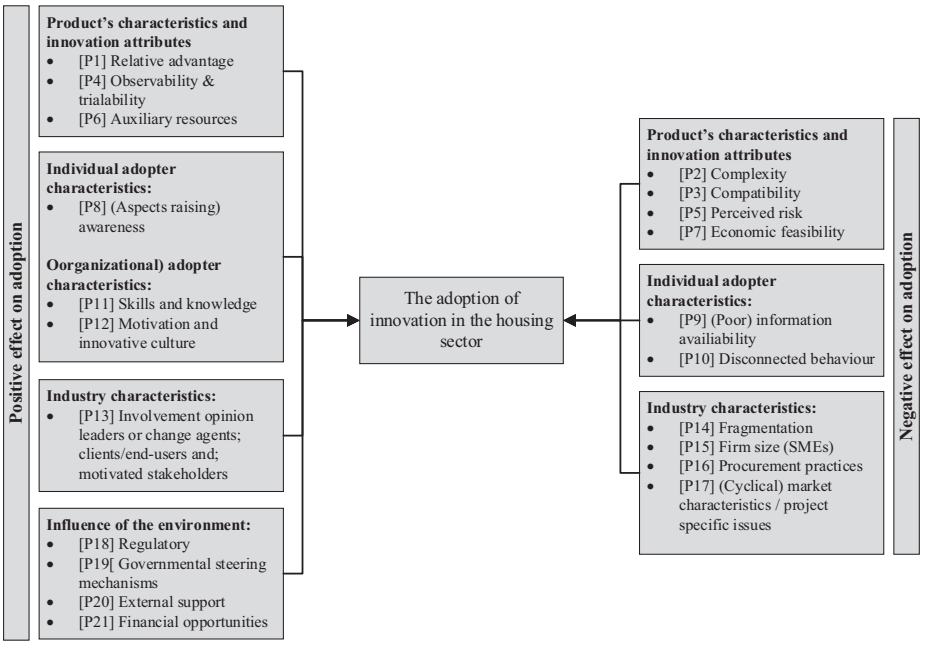


Figure 3.
A coherent framework of positive and negative effects on innovation adoption in the housing sector

Third, based on the literature review, 21 propositions were constructed that describe the key mechanisms by which the potential decision to adopt an innovation in a housing project is affected. As such, the conceptual framework together with the 21 propositions provide an integrated view about what is known concerning the mechanisms affecting innovation adoption in housing projects.

Literature research further revealed that the most influential articles specifically researched the adoption of technological innovations in the field of sustainable housing or in the field of industrial house building. These technological innovations can be linked to the current debate about the high environmental impact, the poor quality and low efficiency of house building.

Policy implications

The conceptual innovation adoption framework that has been developed in this study can serve as a tool to inform policy-makers to develop policies that could stimulate the adoption of particular innovations. For at least three adoption barriers, i.e. perceived risk (*P5*), financial feasibility (*P7*) and knowledge availability (*P9*), the government could play an important role as change agent, policy maker or knowledge broker by providing coercive regulation, financial incentives and knowledge infrastructure. For example, the European Parliament introduced the Energy Performance of Buildings Directive, Directive 2010/31/EU, which stimulated the adoption of energy efficiency technologies. In the past, governments have developed different types of financial incentives to appropriate the adoption and uptake of energy efficiency technologies such as heat pumps and solar panels.

Implications for practitioners

For practitioners, the results of this research indicate which mechanisms affect the adoption of a particular technological innovation in house building. In particular, because the 21

propositions developed in our review are identified as critical prerequisites to adoption. In line with previous conducted reviews in the field of innovation management studies and organizational learning theory, we suggest that innovation managers attempt to test our propositions in practice (Taylor *et al.*, 2010; Slater *et al.*, 2014). Practice-based testing may improve insights about the adoption potential of an innovation when introduced in the market. Having this information can help in guiding the development strategy of innovations. For example, by developing instruments to convey the benefits of a technological innovation to its potential beneficiary (Crabtree and Hes, 2009) or solving compatibility issues with respect to interoperability issues with traditional practices and the mismatch with existing supplier relations (Gan *et al.*, 2015; Mlecnik *et al.*, 2010). Thus, a comprehensive framework should enable managers to take into account the full range of determinants affecting the adoption potential of an innovation. However, managers need to be willing and able to implement this practice-based strategy.

Limitations in the selected innovation adoption literature and of the review method

With respect to the innovation adoption literature that we have selected for this review, some critical observations can be made. First, the 94 studies included in this literature review, can to a significant extant be characterised as explorative. The selected research papers also appeared difficult to be coupled to each other. From the references that were provided in the respective papers, we observed that no citations were made to other relevant papers in many cases. We were further surprised to determine that in our sample of 94 articles, 31 articles could not be linked to adoption theory and that only 22 articles were built on Rogers (2003) seminal work. It is often implicitly noticed in literature that (the adoption of) innovation in the housing sector can be challenging (Winch, 1998; Gann and Salter, 2000; Bossink, 2004; Blayse and Manley, 2004; Gambatese and Hallowell, 2011; Reichstein *et al.*, 2005; Reichstein *et al.*, 2008). However, most articles in our literature selection lack a clear explanation why this is the case or why general adoption theories do not apply to housing.

Moreover, the review method that we applied is not free of its limitations. Although we followed a narrative systematic review protocol as suggested by Tranfield *et al.* (2003) and Briner and Denyer (2012), this review is not entirely free of reviewers' bias such as the negative effect of pre-existing beliefs. Next, many researchers applied synonyms for 'adoption' or refer to adoption applying different terms such as acceptance, usage, implementation or diffusion. This made it in particular challenging to identify relevant articles while relevant articles could be easily missed.

Agenda for future research

This review provides a solid base for the development of a parsimonious, middle-range theory of innovation adoption (Campbell *et al.*, 2003; Wong *et al.*, 2010; Wisdom *et al.*, 2014). The authors identified five lines of inquiry to be explored in the future.

First, because the number of variables included in our conceptual framework is high, we suggest therefore identifying critical variables by uncovering causal logic during case studies (Eisenhardt, 1989).

Second, quantitative research could contribute to our understanding of the effect of the adoption variables by assessing the causal effect of the variables on the adoption of innovation. This line of research is further supported by methodological issues found in several articles in our dataset, i.e. it was not always clear how data was collected, processed and/or analysed by the authors.

The third line of inquiry contributes to the generalizability of the conceptual framework, including the 21 propositions developed in our review. The articles included in this review

predominately researched the adoption of technological innovations in the housing sector. Therefore, it is expected that the framework poorly explains the adoption of other types of innovations such as management and service innovations. Moreover, one could wonder if the conceptual framework is applicable beyond housing, e.g. within other sectors in construction such as infrastructure and commercial and community buildings.

Next, the decision to adopt innovation in housing projects, involves multiple interrelated variables. As a result, future research should take into account the 'system dynamics' of interrelated adoption variables (Tan *et al.*, 2017). Applying conceptual maps could advance research into innovation adoption in housing. These conceptual maps should include three types of interconnectedness: the interrelation between adoption variables; the interrelation between adopter and adoption variables and the interrelation between innovation type and adoption variables (Elazouni *et al.*, 2005; Sexton and Barrett, 2005; Rosales-Carreón and García-Díaz, 2015).

Finally, what can be deduced from literature is that adoption is constituted by multiple adoption decisions at the individual, project, organizational or industry level. This reflects that most innovations are not adopted at the level of a single organization (by a single individual), but at the level of inter-organizational projects. Thus, the diffusion of a technological innovation depends on its subsequent adoption at the organizational and industry level across projects (Winch, 1998; Dubois, 2000; Dubois and Gadde, 2002; Bygballe and Ingemansson, 2014; Xue *et al.*, 2014). To summarize, it is hypothesized that the adoption of a technological innovation depends on multiple adoption decisions, each of which is affected by a different sub-set of innovation adoption variables. This could be subject to future research to better grasp how adoption decisions of innovation in housing projects are taken.

Conclusion

The principal contribution of this review is to offer a new conceptual perspective on the determinants that affect the adoption of innovation in housing projects. This paper contributes to the innovation literature in three ways. First, building upon the framework of Henderson and Clark (1990) and an extensive literature review about innovations being adopted in the housing sector, we were able to categorize the innovations in the housing sector into three types of innovation: incremental, modular and architectural. The most important innovations in housing projects that have been reported so far in literature are related to energy efficient housing and industrial house building. This review also revealed that house building lacks radical, disruptive innovations that are characteristic for traditional low-tech industries (Pavitt, 1984; Utterback and Abernathy, 1975). Low-tech industry practices provide limited possibilities of further product and process innovations; therefore, cost optimization dominates in contrast to innovation strategies (Greenhalgh and Rogers, 2006; Heidenreich, 2009). Second, this study is the first in which the various innovation adoption mechanisms for housing projects are integrated in a coherent innovation adoption framework. Third, it provides and underpins 21 propositions that reflect the state of knowledge about the mechanisms that effect the possible adoption of innovations in the housing sector.

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Appendix

[1]	(Abdel-Wahab *et al.*, 2011)	[33]	(Haines and Mitchell, 2014)	[65]	(Pan *et al.*, 2007)
[2]	(Achtnicht and Madlener, 2014)	[34]	(Hauge *et al.*, 2013)	[66]	(Pan *et al.*, 2008)
[3]	(Adinyira *et al.*, 2018)	[35]	(Hedgren and Stehn, 2014)	[67]	(Parsons *et al.*, 2010)
[4]	(Akinboade, 2012)	[36]	(Hoicka and Parker, 2018)	[68]	(Pinkse and Dommisse, 2009)
[5]	(Ali *et al.*, 2018)	[37]	(Hoppe, 2012)	[69]	(Poon *et al.*, 2003)
[6]	(Azam Haron *et al.*, 2015)	[38]	(Im *et al.*, 2017)	[70]	(Ramli *et al.*, 2019)
[7]	(Baumhof *et al.*, 2018)	[39]	(Kereri and Adamtey, 2019)	[71]	(Riala and Ilola, 2014)
[8]	(Beerepoot and Beerepoot, 2007)	[40]	(Koebel, 2008)	[72]	(Roders and Straub, 2015)
[9]	(Berardi, 2013)	[41]	(Koebel *et al.*, 2015)	[73]	(Sanderford *et al.*, 2015)
[10]	(Berry *et al.*, 2014)	[42]	(Lees and Sexton, 2014)	[74]	(Sanderford *et al.*, 2018)
[11]	(Blackley and Shepard, 1996)	[43]	(Levander *et al.*, 2011)	[75]	(Sasatani *et al.*, 2015)
[12]	(Blismas and Wakefield, 2009)	[44]	(Liu *et al.*, 2018)	[76]	(Steinhardt and Manley, 2016a)
[13]	(Boser and El-Gafy, 2011)	[45]	(Lindgren and Emmitt, 2017)	[77]	(Steinhardt and Manley, 2016b)
[14]	(Bossink, 2018)	[46]	(McCabe *et al.*, 2018)	[78]	(Steinhardt *et al.*, 2019)
[15]	(Bowers *et al.*, 2014)	[47]	(McCoy *et al.*, 2012)	[79]	(Swan *et al.*, 2017)
[16]	(Boyd *et al.*, 2012)	[48]	(McCoy *et al.*, 2015)	[80]	(Swan *et al.*, 2013a)
[17]	(Brown *et al.*, 2014)	[49]	(Mlecnik, 2010)	[81]	(Swan *et al.*, 2013b)
[18]	(Chen *et al.*, 2011)	[50]	(Mlecnik, 2016)	[82]	(Syal *et al.*, 2013)
[19]	(Christie *et al.*, 2011)	[51]	(Mlecnik *et al.*, 2010)	[83]	(Tambach *et al.*, 2010)
[20]	(Crabtree and Hes, 2009)	[52]	(Mueller and Berker, 2013)	[84]	(Tan *et al.*, 2017)
[21]	(Daget and Zhang, 2018)	[53]	(Muyingo, 2015)	[85]	(Toole, 1998)
[22]	(Dewick and Miozzo, 2002)	[54]	(Nahmens and Reichel, 2013)	[86]	(van Egmond-de Wilde de Ligny and Mohammadi, 2011)
[23]	(Duah and Syal, 2016)	[55]	(Nair *et al.*, 2010a)	[87]	(Warren-Myers and Heywood, 2018)
[24]	(Egmond *et al.*, 2005)	[56]	(Nair *et al.*, 2010b)	[88]	(Wolfe and Hendriks, 2011)
[25]	(Egmond *et al.*, 2006)	[57]	(Nair *et al.*, 2012)	[89]	(Xiahou *et al.*, 2018)
[26]	(Elnaas *et al.*, 2014)	[58]	(Njuguna, 1997)	[90]	(Yang and Yang, 2015)
[27]	(Engström and Hedgren, 2012)	[59]	(Ojoko *et al.*, 2018)	[91]	(Yusof and Mohd Shafiei, 2011)
[28]	(Fawcett, 2014)	[60]	(Olsthoorn *et al.*, 2019)	[92]	(Yusof *et al.*, 2010)
[29]	(Femenías *et al.*, 2018)	[61]	(Oster and Quigley, 1977)	[93]	(Akmam Syed Zakaria *et al.*, 2018)
[30]	(Gan *et al.*, 2015)	[62]	(Owen *et al.*, 2014)	[94]	(Zhang *et al.*, 2014)
[31]	(Ganguly *et al.*, 2010)	[63]	(Ozorhon *et al.*, 2013)		
[32]	(Graham and Warren-Myers, 2019)	[64]	(Pan and Cooper, 2011)		

Table AI.

Statement of the Research Problem	Innovation adoption studies are highly segregated and are built upon a number of theoretical concepts to explain innovation adoption in the housing projects. It is not clear from the extant literature, how much we know about the adoption determinants, or how a set of determinants might affect adoption in different settings. Managers lack an overview of determinants which might affect the adoption of innovation they intend to introduce. RQ: Which determinants affect the adoption of innovation introduced in housing projects?
Objectives of the Systematic Review	To synthesize findings on empirical studies of innovation adoption in housing projects; This, with the aim to capture what we know. To contribute to the development of an agenda for future research in the field of innovation adoption in housing projects.
Strategy for Identifying Relevant Studies	Electronic database search of empirical studies of innovation adoption in housing project settings published in peer reviewed scientific journals, complemented by backward and forward reviewing techniques.
Database Selection	Databases selected include: ARCOM and Web of Science.
Search Terms	To be found in title, abstract, or keywords: innovation adoption construction housing (projects)
Inclusion Criteria	Empirical and conceptual studies (qualitative, quantitative and mixed research methodologies) Peer-reviewed journal articles Only full-text articles English language only Studies that apply synonyms to describe adoption: 'uptake', '(user) acceptance', diffusion', 'dissemination', 'commercialization', 'implementation' or 'usage'
Exclusion Criteria	Articles focussing on 'implementation' and 'usage' instead of adoption; Articles in which social technical regimes shifts, technology transfer and market or industry transitions is taken as focal point of analysis instead of the adoption and/or diffusion of innovation itself. Notwithstanding, papers which include the influence of determinants related to adoption are included in the review; Articles with the aim to explain the commercialization and marketing of innovation; Articles in which the focal point of analysis is aimed at consumer adoption without taking into consideration the context of the housing industry (for example articles which address the adoption of PV by homeowners from an endogenous perspective without taking into account contextual determinants of the housing industry); Feasibility studies in which the potential merits or progress of diffusion of specific innovations are assessed.
Quality Audit	Assessment citations relative to Journal Impact Factor (2017) Assessment research findings relative to gap in literature identified

Table AII.
Systematic review protocol

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