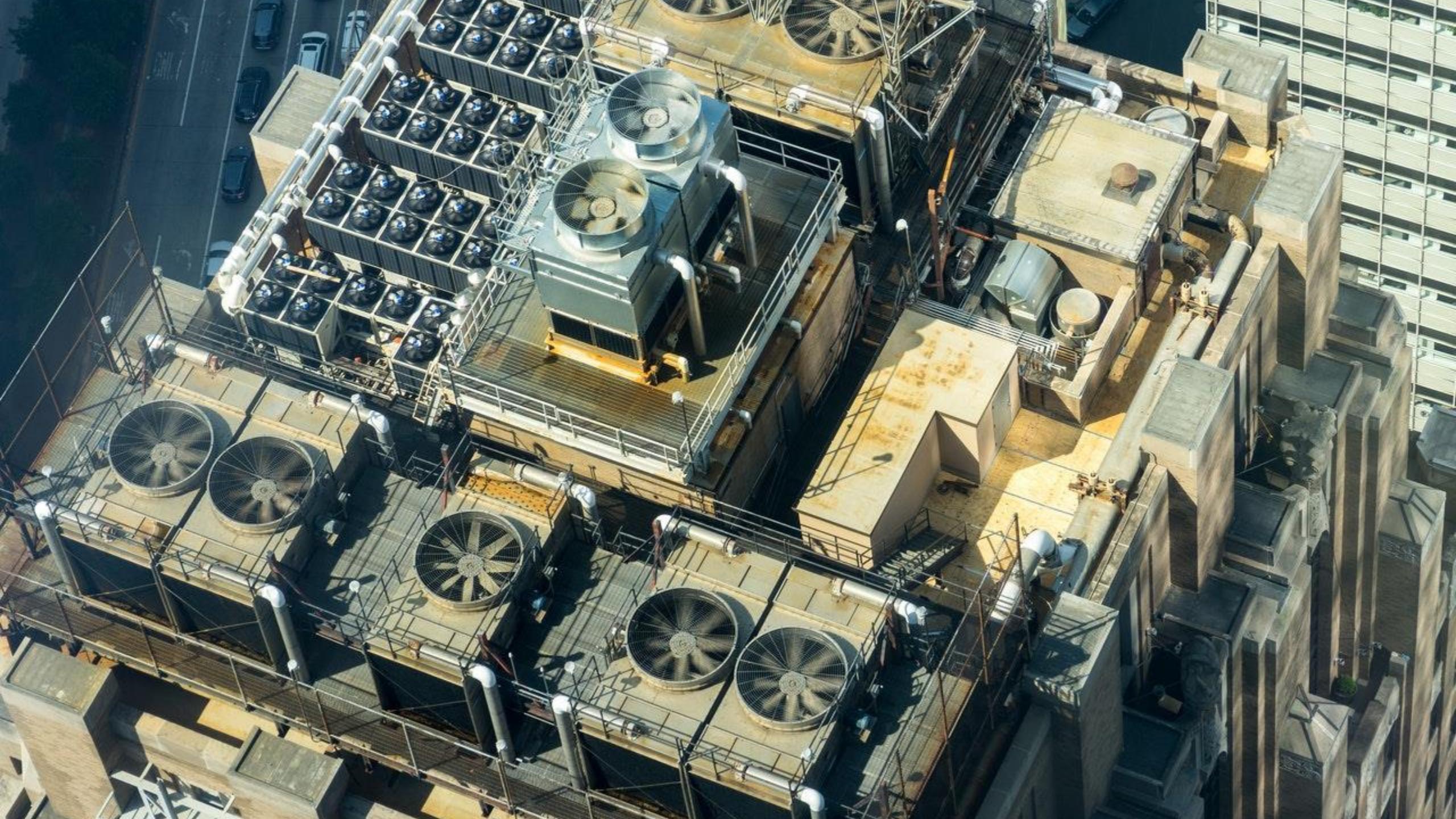




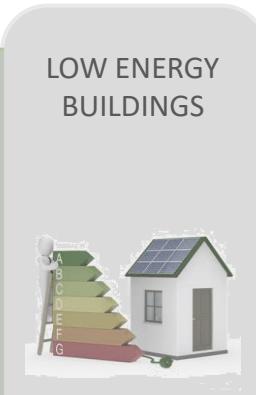
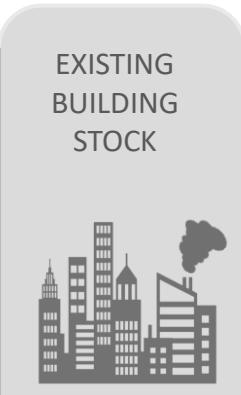
# **Are we really future-proofing our high energy performance buildings?**

**Charlotte Verhaeghe**

**Stijn Verbeke, Amaryllis Audenaert**



# Inleiding



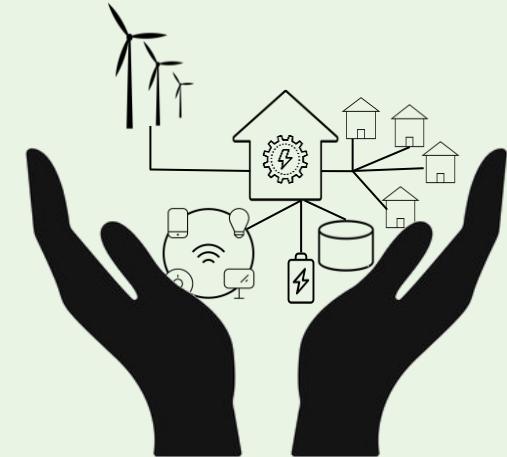
## ENERGY-RENOVATION DECISIONS UNDER **UNCERTAINTY**

### Dynamic context:

- Social
- Technological
- Economic
- Environmental
- Political



## FUTURE-PROOF, HIGH-PERFORMANCE BUILDINGS



- Dealing with doubts about the future
- Impact assessment
- Future-proof concepts

# Research Question(s)

**Are we really future-proofing our high energy performance buildings?**

**Subquestion 1:** Doubts about the future?

**Subquestion 2:** What is “future-proofing” in theory?

**Subquestion 3:** Consistency and importance of “future-proofness” in practice

**Subquestion 4:** “Future-proofing” in energetic renovations

# Doubts about the future?

STEEP

SQ1: What are doubts about the future?

SQ2: What is “future-proof”?

SQ3: Consistency of “future-proofing” in practice

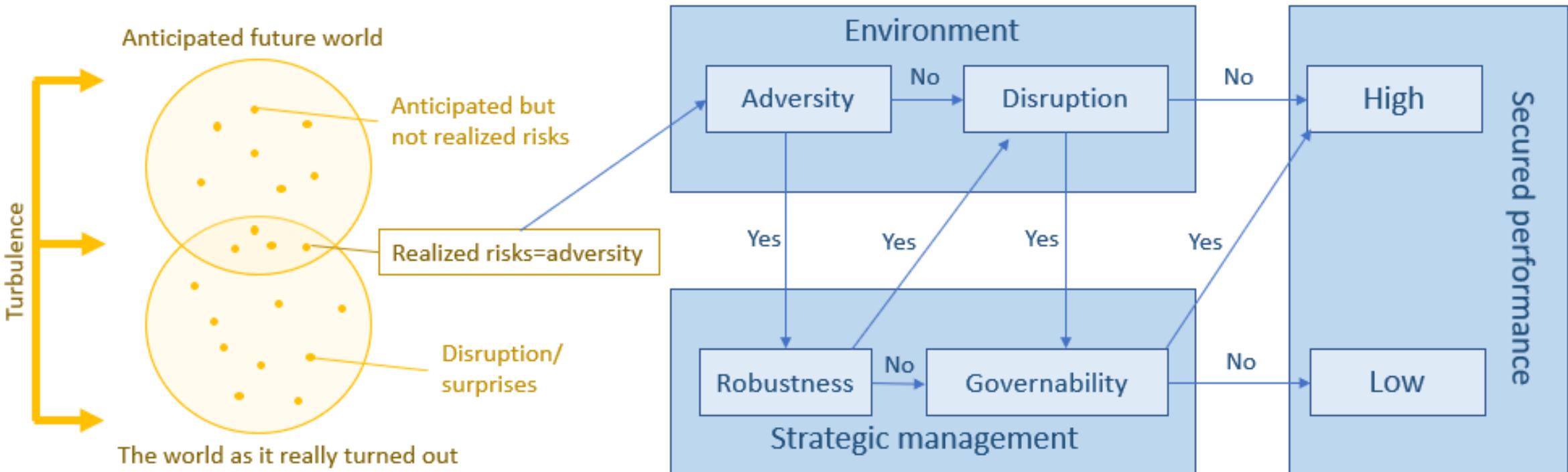
SQ4: “Future-proofing” in energetic renovations

<b>Social</b>	Lifestyle changes (housing unit types, occupant behaviour schemes, new working and living patterns, energy poverty, etc.) Demographic changes (age, gender, race, household sizes, privacy protection issues etc.)
<b>Technological</b>	(Maturity of) innovations (novel energy efficiency measures, RES, construction practices, accuracy in energy consumption data, etc.) Durability (frequency of repair, maintenance, accessibility, building management, construction quality, etc. ) New manners of collaboration (e.g. energy communities, privacy protection, etc.)
<b>Economic</b>	Energy prices and energy tariff structures Scarcity of non-renewable energy resources Technology prices (RES, storage, etc.) Revenue models (e.g. performance contracting, etc.) Economic downturn (e.g. being influenced by taxation changes)
<b>Environmental</b>	Climate change (hotter and drier summers, overheating, urban heat island effect, etc.) Market and customer values towards environment (e.g. engagement towards the environment)
<b>Political</b>	Funding (grants, initiatives, etc. ) Trading policies Energy security Energy and environmental targets (e.g. resulting in building regulations and standards)

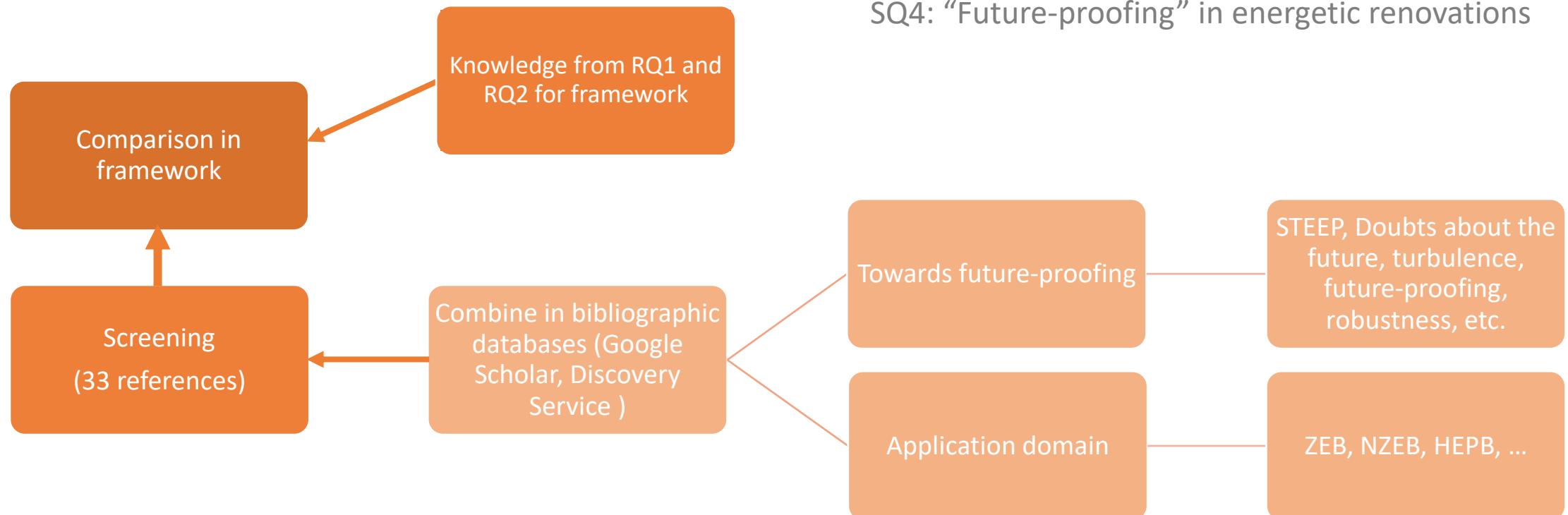
# Future-proofing in theory

SQ1: What are doubts about the future?  
SQ2: What is “future-proof”?

SQ3: Consistency of “future-proofing” in practice  
SQ4: “Future-proofing” in energetic renovations



# Theory versus practice...



SQ1: What are doubts about the future?

SQ2: What is “future-proof”?

**SQ3: Consistency of “future-proofing” in practice**

SQ4: “Future-proofing” in energetic renovations

# Perception of future-proofing

## Authors

Author(s)	Type of source	(Bae, Volt and Boritzas 2019)		X		X		X		X		Future-proof		EPBD	
		(De Wilde 2014)	(Howlett, Malevits, and Hacking 2012)	a	c	X	X	Robust, occupant-proof, climate-change-proof, performance based buildings	Journal	Journal	Journal	Future-oriented, future-proof	Future-proof, climate-robust	Book (PhD)	
DaF	Keyword/naming	(Liu, Shengwei and Chengchu 2017)	(Leyten and Kuners 2006)	a	c	k	p	k	p	k	p	Robust	Robust	Journal	Journal
Social	(Cheng, Wang and Yan 2017)	a	c	k	k	Uncertainty-based optimal	Journal	X	X	X	X	Future-proof, robust	Future-oriented, future-proof	Book (PhD)	X
Technological	(Rysanek and Choudhary 2013)	a	c	f,h	f,h	Robust, optimum under uncertainty	Journal	X	X	X	X	Robust, optimum under uncertainty	Robust	Journal	X
Economic	(Kothredy, Hoss, and Hensen 2015)	a	x	f	k	Robust	Conference	X	X	X	X	Robust	Robust	Journal	X
Environmental	(Kothredy, Hoss, and Hensen 2018)	a	x	f	m	Robust	Conference	X	X	X	X	Robust	Robust	Journal	X
Political	(Alavirad, Mohammadi, and Hoss 2022)	a	k	k	k	Future-proof, robust	Journal	X	X	X	X	Future-proof, robust	Future-proof, robust	Journal	X
	(Georgia-dou, Hacking, and Guthrie 2012)	a,b	c	f,h	o,p	Future-proof, robust	Journal	X	X	X	X	Future-proof, robust	Future-proof, robust	Journal	X
	(Li and Wang 2020)	a	d	d	k	Robust	Journal	X	X	X	X	Robust	Robust	Journal	X
	(Li, Wang, and Tang 2019)	a	d	k	k	Robust	Journal	X	X	X	X	Robust	Robust	Journal	X
	(Chang, Rivera, and Wanelli ista 2011)	f	f	k	k	Uncertainty-based optimal	Journal	X	X	X	X	Uncertainty-based optimal	Uncertainty-based optimal	Journal	X
	(Wang, Qi and Ren 2021)	a	f	k	k	Uncertainty-based optimal	Journal	X	X	X	X	Uncertainty-based optimal	Uncertainty-based optimal	Journal	X
	(Ji, Liang and Xei 2021)	a	f	p	p	Uncertainty-based optimal	Journal	X	X	X	X	Uncertainty-based optimal	Uncertainty-based optimal	Journal	X
	(Westermann and Evans 2021)	a	a	k	k	Uncertainty-aware, robust	Journal	X	X	X	X	Uncertainty-aware, robust	Uncertainty-aware, robust	Journal	X
	(Zhou, Gao, and Hensen 2021)	a	a	d	c,d,e	Robust	Journal	X	X	X	X	Robust	Robust	Journal	X
	(Galle, Poppe and Cambier 2019)	a	a	c	f,j	Robust	Report	X	X	X	X	Robust	Robust	Report	X
	(Mozzani, Salvatore and Vahid 2019)	a	a	h	h	Climate-robust	Journal	X	X	X	X	Climate-robust	Climate-robust	Journal	X
	(Forstel and Miller 2001)	x	x	x	x	Robust, flexible	Journal	X	X	X	X	Robust, flexible	Robust, flexible	Journal	X
	(Hope 2009)	a	a	d,c	c	Robust	Book (PhD)	X	X	X	X	Robust	Robust	Book (PhD)	X
	(Huang, Huang, and Sun 2018)	a	a	d,c	c	Robust	Journal	X	X	X	X	Robust	Robust	Journal	X
	(Lu, Wang and Yan 2017)	a	k	k	k	Risk-benefit-based	Journal	X	X	X	X	Risk-benefit-based	Risk-benefit-based	Journal	X
	(Li and Wang 2021)	a	a	d,c	c	Robust	Book	X	X	X	X	Robust	Robust	Book	X
	(Buckner, Lafrenière, and Denomme 2016)	a	a	d,f,h	f,h	Future-proof	Journal	X	X	X	X	Future-proof	Future-proof	Journal	X
	(Yu, Chen and Sun 2016)	a	k	k	k	...under uncertainties	Journal	X	X	X	X	...under uncertainties	...under uncertainties	Journal	X
	(Galimshina, Moustapha and Shen and Sun 2016)	a	a	d,c	c	Robust	Journal	X	X	X	X	Robust	Robust	Journal	X
	(Nik, Mata and Sasic 2015)	a	a	f,h	d	Robust against climate change	Journal	X	X	X	X	Robust against climate change	Robust against climate change	Journal	X
	(Colly, Keishaw, and Eames 2012)	a	k	k	k	Future-proof against higher temperatures	Journal	X	X	X	X	Future-proof against higher temperatures	Future-proof against higher temperatures	Journal	X
	With Case study	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Epistemic			X											X
	Aleatory	X	X		X	X	X	X	X	X	X	X	X	X	X
	Error														X
	Linguistic														X
	Decisoin														X
	ST/LT uncertainty	LT	LT	ST	LT	LT	LT	ST	ST/LT	ST/LT	LT	LT	LT	LT	LT
	Impact [%]	/	≤78	≤14.4	≤30	≤20	/	≤40	≤45,6	≤13	≤75	/	≤14.4	/	/

# Reference type

# Perception of future-proofing

# STEEP Doubts about the future

# Perception of future-proofing

Author(s)		(Bean, Volt and Dorizas 2019)		(De Wilde 2014)		(Howlett; Malevitzi, and Hacking 2012)		(Ramon 2021)		(Liu, Shengwei and Chengchu 2017)		(Leylev and Kuvers 2006)		(Cheng, Wang and Van 2017)		(Rysanek and Choudhary 2013)		(Kotireddy, Hoes, and Hensen 2015)		(Kotireddy, Hoes, and Hensen 2018)		(Alavrad, Mohammadi and Hoes 2022)		(Georgiadou, Hacking, and Guthrie 2012)		(Kotireddy, Hoes, and Hensen, 2017)		(Li and Wang 2020)		(Li, Wang, and Tang 2019)		(Chang, Rivera, and Waniletta 2011)		(Wang, Qi and Ren 2021)		(Ji, Liang and Xei 2021)		(Westermann and Evans 2021)		(Zhou, Guo, and Hensen 2021)		(Galle, Poppe and Cambier 2019)		(Maazami, Salvatore and Vahid 2019)		(Horfert and Miller 2001)		(Hoptfe 2009)		(Huang, Huang, and Sun 2018)		(Liu, Wang and Yan 2017)		(Li and Wang 2021)		(Buckner, Lafrenie and Denommé 2016)		(Shen and Sun 2016)		(NIK, Mata and Sasic Kalagashidi 2015)		(Coley, Kershaw, and Eames 2012)	
DaF		Social		Technological		Economic		Environmental		Political		Keyword/naming		Type of source		With Case study		Epistemic		Aleatory		Error		Linguistic		Decisoin		ST/LT uncertainty																																			
Focus on																																																															
Impact [%]		/		≤78		≤14.4		≤30		≤20		/		≤40		≤45,6		≤13		≤75		/		≤14.4		/		≤77		≤30		≤71																															
..under uncertainties		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust against climate change		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Future-proof against higher temperatures		Journal		LT		LT		LT		LT		LT		LT		LT		LT		LT		LT		LT		LT		LT		LT																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X		X		X		X		X		X		X		X		X		X		X		X		X																																	
Robust		Journal		X		X																																																									

## Category of doubts about the future

# Perception of future-proofing

Keywords for future-proofing variants

Author(s)	Type of source		Focus on	Impact [%]			
	Social	Technological		Economic	Environmental	Political	DaF
(Benn, Volt and Dorizas 2019)							X
(De Wilde 2014)							X
(Howlett, Maleviti, and Hacking 2012)							X
(Ramon 2021)							X
(Lu, Shengwei and Chengchu 2017)							X
(Leyten and Kurnes 2006)							X
(Geng, Wang and Yan 2017)							X
(Rysanek and Choudhary 2013)							X
(Kotirreddy, Hoes, and Hensen 2015)							X
(Kotirreddy, Hoes, and Hensen 2018)							X
(Alavirad, Mohammadi and Hoes 2022)							X
(Georgiadou, Hacking, and Guthrie 2012)	a,b			c			X
(Kotirreddy, Hoes, and Hensen 2017)	a			f,h			X
(Li and Wang 2020)		a	d				X
(Li, Wang, and Tang 2019)		a	d				X
(Ciang, Rivera, and Waniliesta 2011)			k	k			X
(Wang, Qi, and Ren 2021)			f	k			X
(Li, Liang and Xie 2021)			f				X
(Westermann and Evans 2021)		a	a				X
(Zhou, Cao, and Hensen 2021)		a	a	c,d,e			X
(Florinel and Miller 2001)	x	c	d				X
(Galle, Poppe and Cambier 2019)			f,j				X
(Mozami, Salvatore and Vahid 2019)							X
(Huang, Huang, and Sun 2018)			h	x			X
(Li and Wang 2021)			x	x			X
(Buckner, Lafencie and Demomme 2016)	a	c	d,c				X
(Yu, Chen and Sun 2016)							X
(Galimshina, Moustapha and Shen 2016)	a	d,c	d,f				X
(Shen and Sun 2016)							X
(Nik, Mata and Sasic Kalagatisidis 2015)	a	k	k	k	k		X
(Coley, Kersaw, and Eames 2012)							X
With Case study		X	X	X	X	X	
Epistemic	X	X					
Aleatory	X	X					
Error							
Linguistic							
Decision							
ST/LT uncertainty	LT	LT	ST	LT	LT	ST/LT	LT
Impact [%]	/	≤78	≤14.4	≤30	≤20	/	/

# Perception of future-proofing

## + casestudy?

# Perception of future-proofing

+ casestudy  
↓  
Impact

Author(s)	Type of source		With Case study	Focus on		Impact [%]	
	Social	Technological		Epistemic	Aleatory	Error	
Nik Mata and Sasic (Kalogridis 2015)	a	k	k	x	x	x	/ ≤78 ≤14.4
(Coley, Kersaw, and Eames 2012)							
(Shen and Sun 2016)	a	k	k	x	x	x	..under uncertainties
(Huang, Huang, and Sun 2018)	a	a	a	x	x	x	Robust against climate change
(Li and Wang 2021)	a	c	d,c	x	x	x	Future-proof
(Buckner, Lafencie, and Demomme 2016)	a	c	d,f,h				...under uncertainties
(Yu, Chen, and Sun 2016)							
(Galimshina, Moustapha, and	a	d,c	f,h				
(Shen and Sun 2016)	a	k	k	x	x	x	Robust
(Ramon 2021)							
(Howlett, Maleviti, and Hacking 2012)	a	c					
(De Wilde 2014)	a						
(Bejn, Volt, and Dorizas 2019)							
(Liu, Shengwei, and Chengchui 2017)	a						
(Leyten and Kuipers 2006)		d					
(Geng, Wang, and Yan 2017)	a	c	k				
(Rysanek and Choudhary 2013)	c	f,h	m				
(Kotirreddy, Hoes, and Hensen 2015)	a	k	k				
(Kotirreddy, Hoes, and Hensen 2018)	a	x	f				
(Alaviad, Mohammadi, and Hoes 2022)	a	k	k				
(Georgiadou, Hacking, and Guthrie 2012)	a,b	c	f,h				
(Kotirreddy, Hoes, and Hensen 2017)	a	k	k				
(Li and Wang 2020)	a	d	k				
(Li, Wang, and Tang 2019)	a	d	k				
(Ciang, Rivera, and Waniliesta 2011)	f	k	k				
(Wang, Qi, and Ren 2021)	a	f	k				
(Li, Liang, and Xie 2021)	f	p	p				
(Westermann and Evans 2021)	a	a	k				
(Zhou, Cao, and Hensen 2021)	a	a	f,j				
(Galle, Poppe, and Cambier 2019)	a	d	d				
(Morozami, Salvatore, and Vahid 2019)	c,d,e						
(Florinel and Miller 2001)	x	c	x				
(Hrophe 2009)							
(Li, Wang, and Yan 2017)	a	a	d,c				
(Huang, Huang, and Sun 2018)	a	a	k				
(Li and Wang 2021)	a	c	k				
(Buckner, Lafencie, and Demomme 2016)	a	c	d,f,h				
(Yu, Chen, and Sun 2016)							
(Galimshina, Moustapha, and	a	d,c	f,h				
(Shen and Sun 2016)	a	k	k	x	x	x	..under uncertainties
(Nik Mata and Sasic (Kalogridis 2015)	a	k	k	x	x	x	Robust against climate change
(Coley, Kersaw, and Eames 2012)							Future-proof against higher temperatures

(Bejn, Volt and Dorizas 2019)	x	x	x	x	x	x	x
(De Wilde 2014)	a		x	x	x	x	x
(Howlett, Maleviti, and Hacking 2012)	a	c		p	Future-oriented, future-proof	Journal	x
(Ramon 2021)	f	k	k	p	Future-proof, climate-robust, robust	Book (PhD)	x
(Liu, Shengwei and Chengchui 2017)	a				Uncertainty-based optimal	Journal	x
(Leyten and Kuipers 2006)	d				Robust, optimum under uncertainty	Journal	x
(Geng, Wang, and Yan 2017)	a	c	k		Robust	Conference	x
(Rysanek and Choudhary 2013)	c	f,h	m		Robust	Journal	x
(Kotirreddy, Hoes, and Hensen 2015)	a	k	k		Robust	Journal	x
(Kotirreddy, Hoes, and Hensen 2018)	a	x	f		Robust	Journal	x
(Alaviad, Mohammadi, and Hoes 2022)	a	k	k		Future-proof, robust	Journal	x
(Georgiadou, Hacking, and Guthrie 2012)	a,b	c	f,h		Future-proof, robust	Journal	x
(Kotirreddy, Hoes, and Hensen 2017)	a	k	k		Future-proof, robust	Conference	x
(Li and Wang 2020)	a	d	k		Robust	Journal	x
(Li, Wang, and Tang 2019)	a	d	k		Robust	Journal	x
(Ciang, Rivera, and Waniliesta 2011)	f	k	k		Uncertainty-based optimal	Journal	x
(Wang, Qi, and Ren 2021)	a	f	k		Uncertainty-based optimal	Journal	x
(Li, Liang, and Xie 2021)	f	p	p		Uncertainty-based optimal	Journal	x
(Westermann and Evans 2021)	a	a	k		Uncertainty-aware, robust	Journal	x
(Zhou, Cao, and Hensen 2021)	a	a	f,j		Robust	Journal	x
(Galle, Poppe, and Cambier 2019)	a	d	d		Robust	Report	x
(Morozami, Salvatore, and Vahid 2019)	c,d,e				Climate-robust	Journal	x
(Florinel and Miller 2001)	x	c	x		Robust, flexible	Journal	x
(Hrophe 2009)					Robust	Book (PhD)	x
(Li, Wang, and Yan 2017)	a	a	d,c		Robust	Journal	x
(Huang, Huang, and Sun 2018)	a	a	k		Robust	Journal	x
(Li and Wang 2021)	a	c	k		Risk-benefit-based	Journal	x
(Buckner, Lafencie, and Demomme 2016)	a	c	d,f,h		Future-proof	Book	x
(Yu, Chen, and Sun 2016)					...under uncertainties	Journal	x
(Galimshina, Moustapha, and	a	d,c	f,h		Robust	Journal	x
(Shen and Sun 2016)	a	k	k	x	x	x	..under uncertainties
(Nik Mata and Sasic (Kalogridis 2015)	a	k	k	x	x	x	Robust against climate change
(Coley, Kersaw, and Eames 2012)							Future-proof against higher temperatures

## Perception of future-proofing

In practice

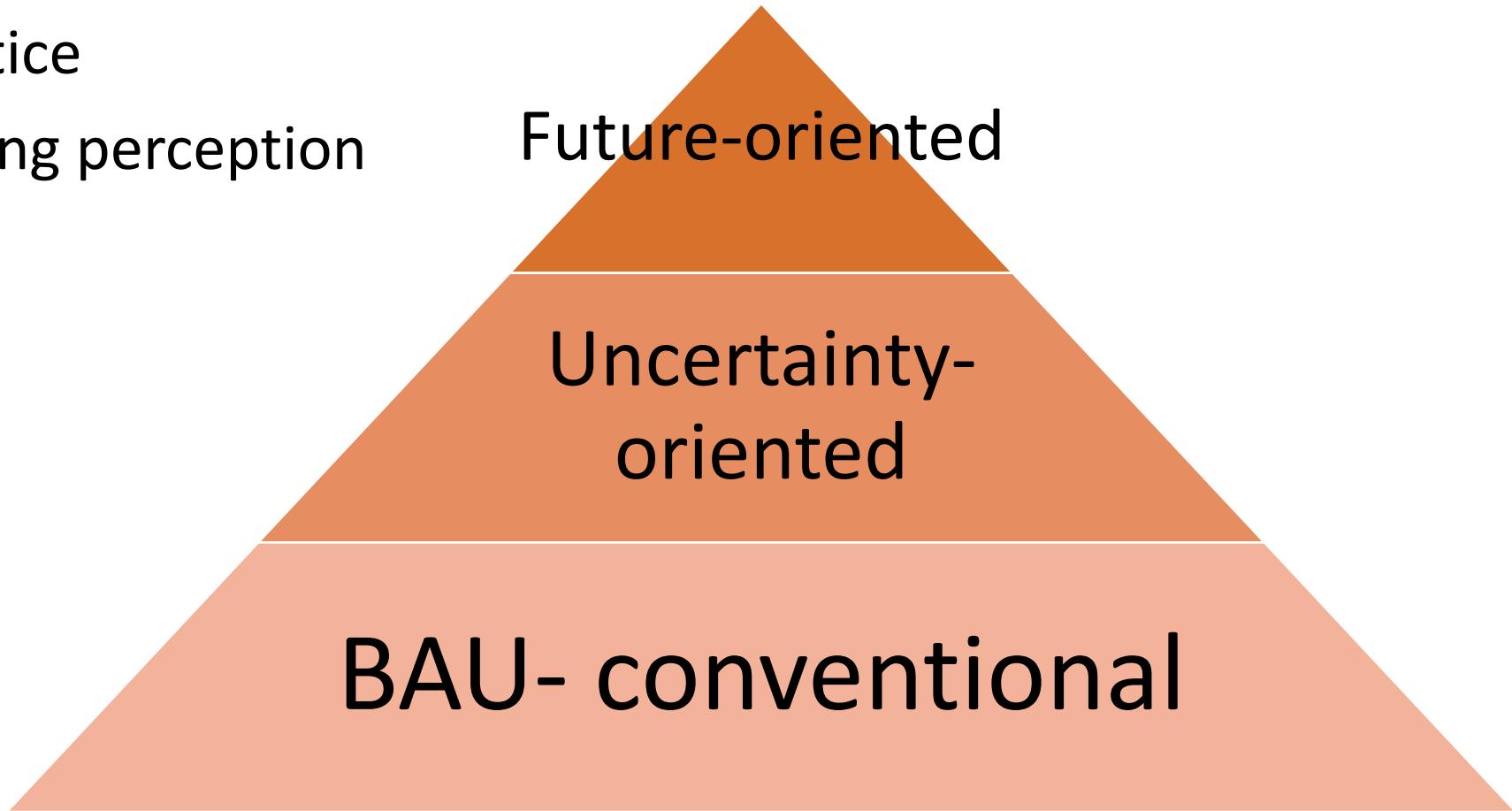
→varying perception

SQ1: What are doubts about the future?

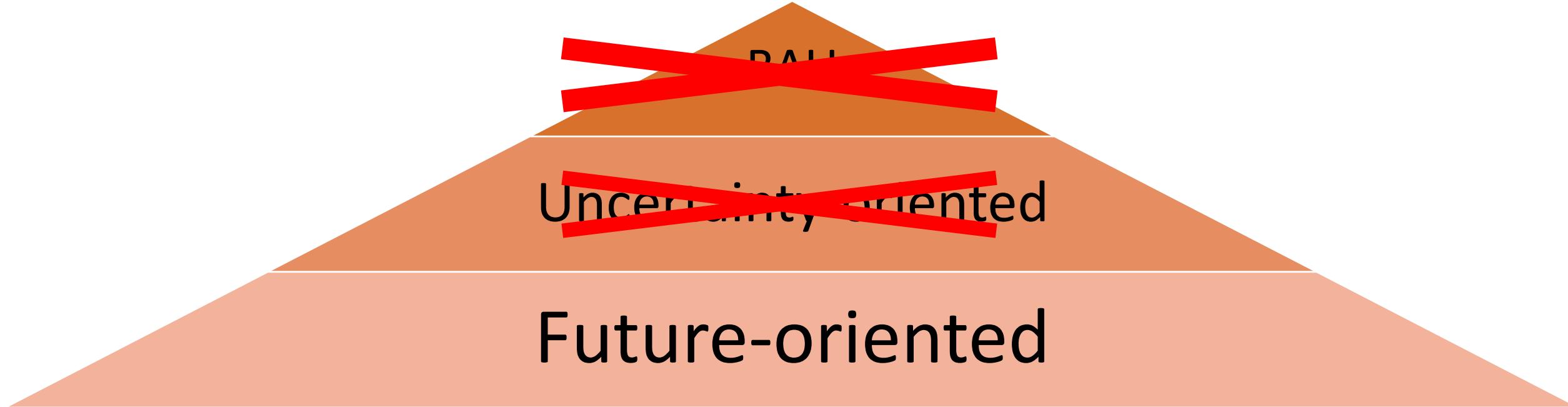
SQ2: What is “future-proof”?

**SQ3: Consistency of “future-proofing” in practice**

SQ4: “Future-proofing” in energetic renovations



## Perception of future-proofing



# Design practice

Focus on **energy technology** for residential buildings

SQ1: What are doubts about the future?

SQ2: What is “future-proof”?

SQ3: Consistency of “future-proofing” in practice

SQ4: “Future-proofing” in energetic renovations

Cohesion	Reserves	Flexibility	Generativity
<p>Shared responsibility (circular business models, e.g. shared ownership, partnerships, ESCO, etc.)</p> <p>Accessibility, readability</p> <p>Holistic design approach (in relation to SDGs, integration with surroundings, etc.)</p>	<p>Buffers (with respect to financial, technologic, and other sources, beyond prevailing regulations, etc.)</p> <p>Emerging technologies (-ready)</p>	<p>Reversibility, simplicity, accessibility, grouping and information on durability of the components, decoupling (and independence), possibility to dismantle, to relocate, divisibility, hierarchically system-based layers, modularity, etc.</p> <p>Diversity</p> <p>Smart (-ready), source control, BACS, etc.</p> <p>Simplicity, passive first, etc.</p> <p>Internal flexibility: open space plan, multi-purpose, multi-functional</p>	<p>Qualitative</p> <p>Quantitative</p>

# Assessment

Focus on **energy technology** for residential buildings

SQ1: What are doubts about the future?

SQ2: What is “future-proof”?

SQ3: Consistency of “future-proofing” in practice

SQ4: “Future-proofing” in energetic renovations

	↓ secured performance	↑ secured performance
Time steps	Static	Dynamic
Sequence of events	Linear	Sequential

# Suggestions for further research

## TO DO

- Doubts about the future:  
how far should we go?
- Refine our research methodologies
  - Is simplification possible?
  - Everything dynamic?

# Besluit

**Subquestion 1:** Doubts about the future?

**Subquestion 2:** What is “future-proofing” in literature?

**Subquestion 3:** Consistency and impact of “future-proofness” in practice

**Subquestion 4:** “Future-proofing” in energetic renovations

Are we really future-proofing our buildings?

**"We still have a long way to go to make renovation designs future-proof, there has however already been a lot of deepening and improvement in the future-proofing-theme in recent years."**

