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Strategic Research & Innovation Agenda (SRIA) for smart buildings

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List of Acronyms

API .... Application Programming Interface
BIM .... Building Information Modelling
BREEAM .... Building Research Establishment Environmental Assessment Method
CAPEX .... Capital expenditures
DGA .... Data Governance Act
EC .... European Commission
EHEA .... European Higher Education Area
EU .... European Union
EPBD .... Energy Performance of Buildings Directive
EPC .... Energy Performance Certificate
GDPR .... General Data Protection Regulation
IA .... Artificial intelligence
IEQ .... Indoor Environmental Quality
ICT .... Information and Communication Technology
IoT .... Internet of Things
KPI .... Key Performance Indicator
LCA .... Life Cycle Analysis/Assessment
LEED .... Leadership in Energy and Environmental Design
OPEX .... Operational expenditures
MS .... Member State
PPI .... Public Procurement of Innovation
R&D .... Research and Development
R&I .... Research and Innovation
SAREF .... Smart Applications REFerence
SME .... Small and medium-sized enterprises
SRI .... Smart Readiness Indicator
SRIA .... Strategic Research and Innovation Agenda
WP .... Work Package

Executive summary

This European Strategic Research & Innovation Agenda (SRIA) for smart buildings aims to provide an overview and key actions for EU support for research, innovation, and market uptake in the field of smart buildings. This report presents the following 10 key R&I priorities:

- **PRIO 1: Standardisation for interoperable products and services** in a building: develop unified ontologies, semantics and interoperability standards.
- **PRIO 2: Standards and business models for connecting smart buildings to the external environment:** data exchange between multiple buildings and with energy grids, assessment methods and standardised protocols for energy flexibility.
- **PRIO 3: Innovation in products and related business models for smart buildings.** E.g. servitisation (comfort-as-a-service), adaptable and expandable automation and control systems, common marketplaces for smart solutions, upgrading legacy equipment, energy performance contracting with performance guarantees.
- **PRIO 4: Endorsing testing facilities and sandboxes for integrated analysis and demonstration of smart buildings:** develop proper benchmarking, common case studies (real buildings and their digital twins), common datasets, regulatory sandboxes, advanced testing facilities and standardised testing protocols to support research and market validation.
- **PRIO 5: Better understanding of co-benefits** (health, comfort, well-being, productivity increase,) and empowering the users of smart buildings: common KPIs, evaluation methods, benchmarks, datasets, user-centric design methods...
- **PRIO 6: Advances in products, services and decision support methods to improve life cycle environmental impacts of smart buildings** and building decarbonisation pathways (repairability, circularity, dismantling and upcycling of components, lower resource consumption, reduced energy consumption of sensors and actuators, electronic waste management,...).
- **PRIO 7: Making better use of the data:** Data-driven performance assessment, digital twins for optimisation of operation and fault-detection of smart buildings, continuous commissioning, data-driven design methods and operation and maintenance automation.
- **PRIO 8: R&I for supporting increased public awareness, end-user acceptance and training of workforce** to support mass adoption of smart building technologies.
- **PRIO 9: Data privacy and cybersecurity in smart buildings:** improving new and legacy equipment, monitoring performance, towards certification of individual products and integrated systems
- **PRIO 10: R&I to support policy developments:** Improve regulations (EU and national) and policy initiatives (Digital Building Logbook, SRI, green public procurement for smart buildings, ...) on smart buildings.

In the section **2 Strategy for operationalisation of 10 key identified R&I Priorities** an executive summary, rationale description and proposed key actions are listed for each of the 10 priorities (PRIOs). The final list of all proposed key actions includes the following:

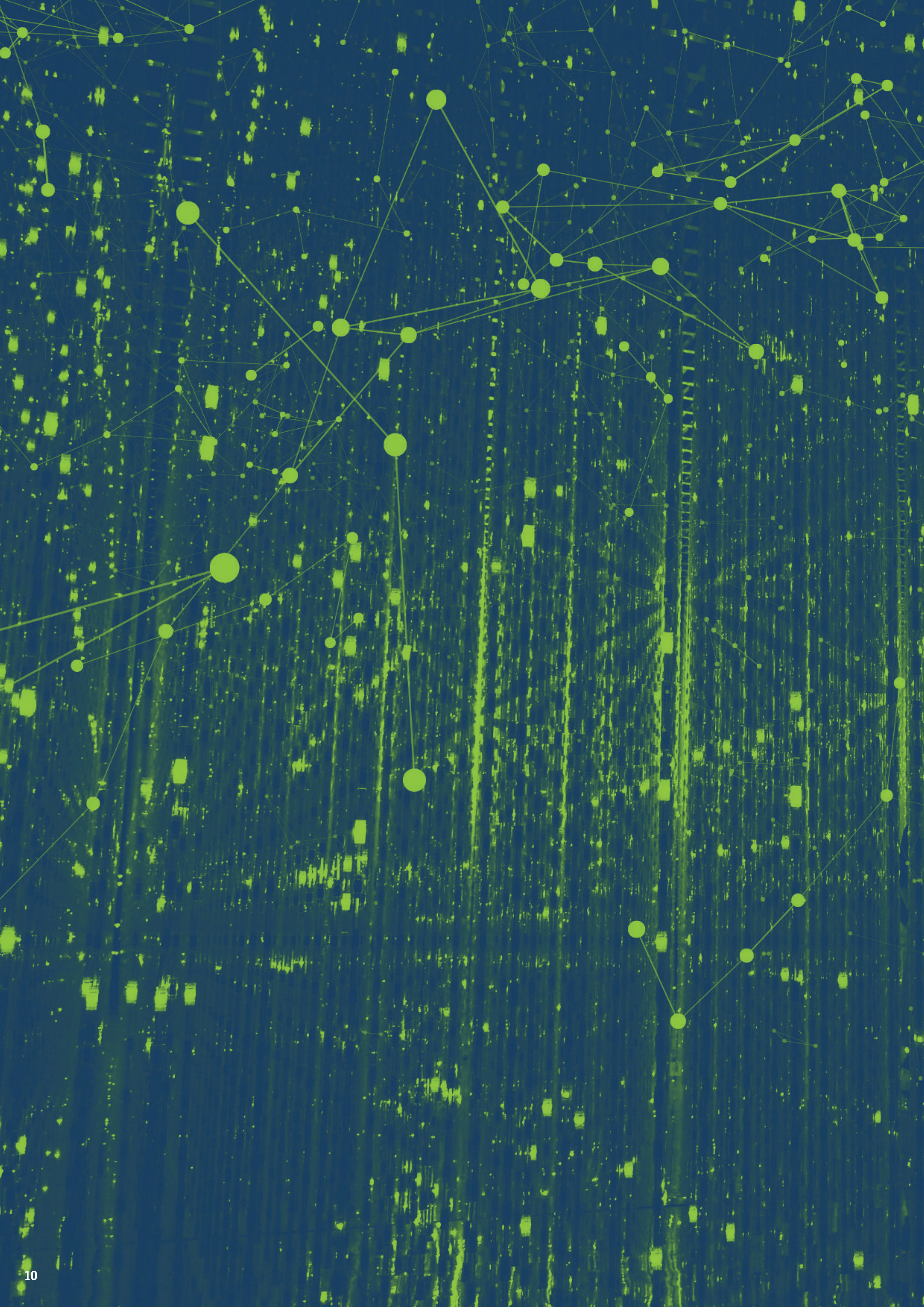
- **Action 1.1 –** Development of a methodology for assessment of semantic interoperability using open, standardised ontologies (aiming at TRL 4-6) - RIA
- **Action 1.2 –** Reference implementation for assessment of semantic interoperability using open APIs and standardised ontologies (aiming at TRL 6-8) - IA
- **Action 1.3 –** Support programme for stakeholders on ontologies standardisation (aiming at TRL N/A) - CSA
- **Action 1.4 –** Interoperability label (aiming at TRL N/A)
- **Action 1.5 –** Marketplace for interoperability services and user-friendly software tools (aiming at TRL 4-6)
- **Action 1.6 –** Citizen lab initiative about interoperability to quickly show benefits of giving access to (certain parts of) their data (aiming at TRL 4-6)
- **Action 2.1 –** Harmonised definition of roles and responsibilities for actors involved in energy flexibility (aiming at TRL 8)
- **Action 2.3 –** Development of a flexibility certification scheme at EU level (aiming at TRL 8)
- **Action 2.4 –** End users as new and valuable partner in the energy flexibility ecosystem of the future (aiming at TRL 4-6)
- **Action 2.5 –** Interoperable data exchange environment to provide power flexibility to the grid (aiming at TRL 4-6)
- **Action 2.6 –** "Ready to service" and "ready to grid" buildings (aiming at TRL 6)
- **Action 3.1 –** Develop new concepts and solutions for occupant centric buildings (aiming at TRL 5-6)
- **Action 3.2 –** Develop and design participatory business models (aiming at TRL 7-8)
- **Action 3.3 –** Legal framework for Deployment of universal digital infrastructure at the EU level (aiming at TRL 6-7)
- **Action 4.1 –** Create EU strategy for physical testing facilities that support the testing of innovations on smart buildings (aiming at TRL 4-6)
- **Action 4.2 –** Implementation of strategic program of living labs for higher TRL applications of smart buildings to be tested in realistic conditions (aiming at TRL 6-9)
- **Action 4.3 –** Development of common testing protocols, benchmarks, and reporting standards (TRL 1-9)
- **Action 5.1 –** Quantification methods for non-energy benefits (aiming at TRL 4-5)
- **Action 5.2 –** Data-driven Smart Buildings' indicators (aiming at TRL 4-5)

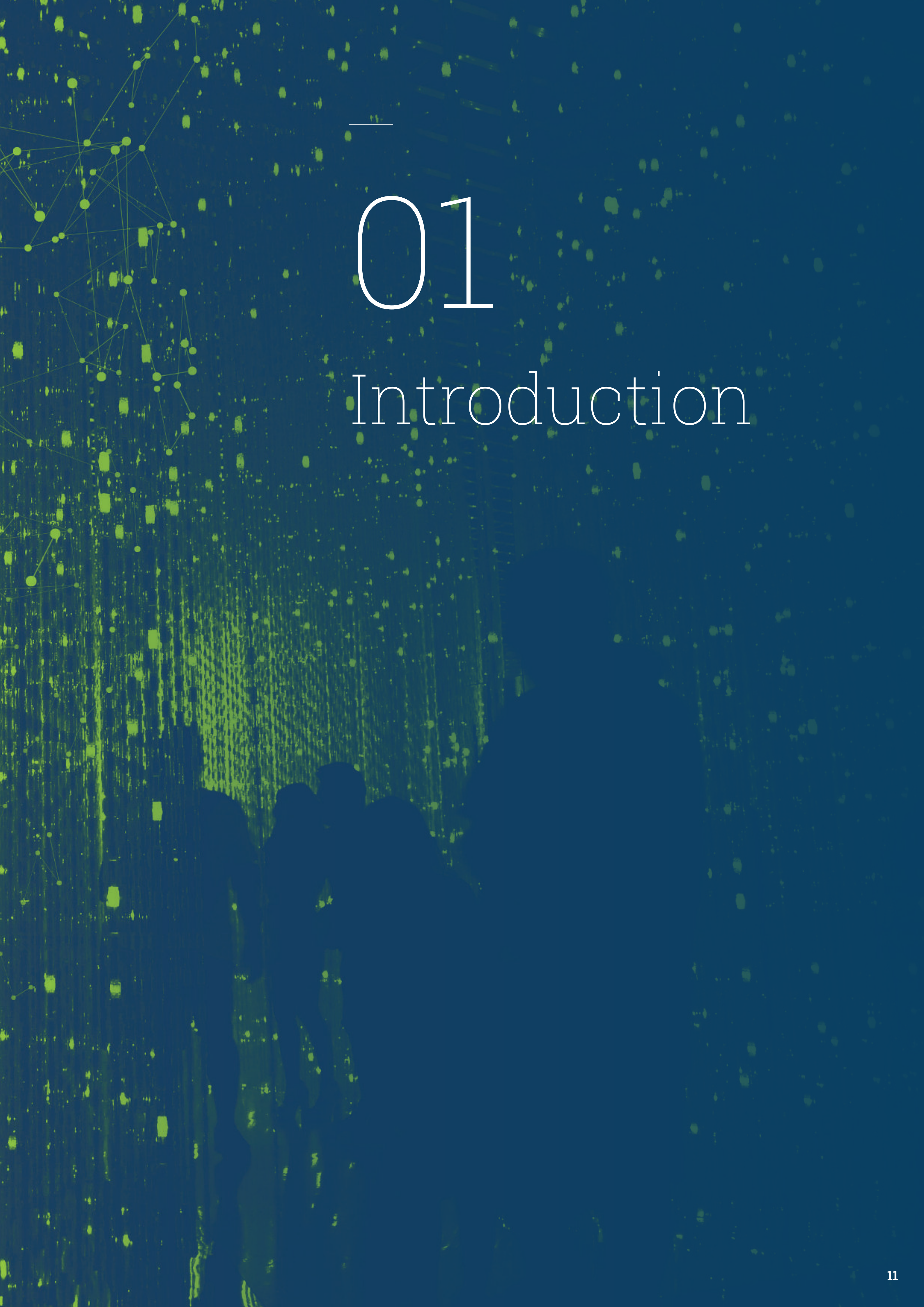
- **Action 5.3 –** Develop & demonstrate new business models (aiming at TRL 6-7)
- **Action 5.4 –** Qualitative Methods-Develop education & awareness raising actions (aiming at TRL N/A)
- **Action 6.1 –** Further development of common Life Cycle Assessment methods and indicators
- **Action 6.2 –** Streamline the use of dynamic data in Life Cycle Assessment approaches
- **Action 6.3 –** Develop methods to assess and limit the impacts of the 'smart' devices
- **Action 6.4 –** Investigate performance gap and rebound effects
- **Action 7.1 –** Expand the data collection (amount/type) (aiming at TRL 4-5) RIA
- **Action 7.2 –** Strive for multi-use data possibilities (aiming at TRL 8-9) RIA
- **Action 7.3 –** Expand the Digital Twin Concept (aiming at TRL 6-7)
- **Action 7.4 –** Encourage/showcase testing of data collecting/usage (aiming at TRL 7-8)
- **Action 8.1 –** R&I to support an increased end-user acceptance of smart building solutions and services (aiming at TRL 8-9)
- **Action 8.2 –** Showcase smart building innovations and their impacts (aiming at TRL 8-9)
- **Action 8.3 –** User acceptance and early adoption (aiming at TRL 7-8)
- **Action 8.4 –** Training on the fly - contextual learning and upskilling for the workforce (aiming at TRL 6-7)
- **Action 9.1 –** Development of regulatory frameworks & legislations and certifications (aiming at TRL 4-6)
- **Action 9.2 –** Develop models and methodologies to strengthen the value chain (aiming at TRL 6-9)
- **Action 10.1 –** Investigate new market design and regulatory options for smart buildings to provide flexibility services to the electricity grid
- **Action 10.2 –** Develop and test potential synergies to improve and simplify existing certification schemes related to smartness and building performances
- **Action 10.3 –** Showcase examples on successful financial and administrative incentives that can speed up the deployment of smart buildings
- **Action 10.4 –** Design principles and rules for improved regulation

In the section **3.1 Ranking priorities by expected outcomes**, a matrix of the 10 PRIOs is presented (Table 1), including a ranking of 16 different expected outcomes and impacts (extracted from the White Papers and Task Forces of the SB4EU project). PRIO 9 Data privacy and cybersecurity in smart buildings and PRIO2 Smart buildings, energy flexibility and external environment are considered the priorities with a broader scope and outcomes for the 16 selected impacts. The five most relevant impacts triggered from the ten priorities are:

- *Better buildings for inhabitants and users*
- *Demonstrate improved performance, feasibility, and reliability of smart building products and services*
- *Data availability and open data exchange amongst stakeholders*
- *Accelerate the technological development process (reaching higher TRL levels faster)*
- *New opportunities for EU businesses, including SMEs*

In the section **3.2 Funding and EU initiatives**, several funding sources are explored. From a joint discussion between members of the consortium and the expert board, Horizon Europe is deemed an appropriate initiative to further elaborate for all priorities discussed in this strategic research and innovation agenda. Also, LIFE calls and national funding are applicable to all priorities according to these poll results, although to a smaller extent than the Horizon Europe programme. National funding is deemed most relevant for making better use of the data for a data driven performance assessment (PRIO 7). Several existing EU initiatives can contribute to that, together with other ways of funding, e.g., national or private. By enhancing the market penetration of smart buildings, this can contribute to reaching the climate goals and become more energy independent.





01 Introduction

Introduction

The SmartBuilt4EU project consortium has drafted this European Strategic Research & Innovation Agenda (SRIA) for smart buildings where in the first steps, a shortlist of 10 key R&I priorities was defined within the Smart Building Innovation Community. Firstly, a gap analysis was conducted in collaboration with the Task Forces of the SB4EU project. As a result of this joint exercise, a total of 179 gaps had been identified.

From this list, a set of ten key priorities for the EU R&I agenda was suggested by the consortium, followed by a public consultation, both with the expert board members and a public survey. The resulting final ten key R&I priorities are listed below represent several research areas.

- **PRIO 1: Standardisation for interoperable products and services** in a building: develop unified ontologies, semantics and interoperability standards.
- **PRIO 2: Standards and business models for connecting smart buildings to the external environment:** data exchange between multiple buildings and with energy grids, assessment methods and standardised protocols for energy flexibility.
- **PRIO 3: Innovation in products and related business models for smart buildings.** E.g. servitisation (comfort-as-a-service), adaptable and expandable automation and control systems, common marketplaces for smart solutions, upgrading legacy equipment, energy performance contracting with performance guarantees.
- **PRIO 4: Endorsing testing facilities and sandboxes for integrated analysis and demonstration of smart buildings:** develop proper benchmarking, common case studies (real buildings and their digital twins), common datasets, regulatory sandboxes, advanced testing facilities and standardised testing protocols to support research and market validation.
- **PRIO 5: Better understanding of co-benefits** (health, comfort, well-being, productivity increase,) and empowering the users of smart buildings: common KPIs, evaluation methods, benchmarks, datasets, user-centric design methods...
- **PRIO 6: Advances in products, services and decision support methods to improve life cycle environmental impacts of smart buildings** and building decarbonisation pathways (repairability, circularity, dismantling and upcycling of components, lower resource consumption, reduced energy consumption of sensors and actuators, electronic waste management,...).

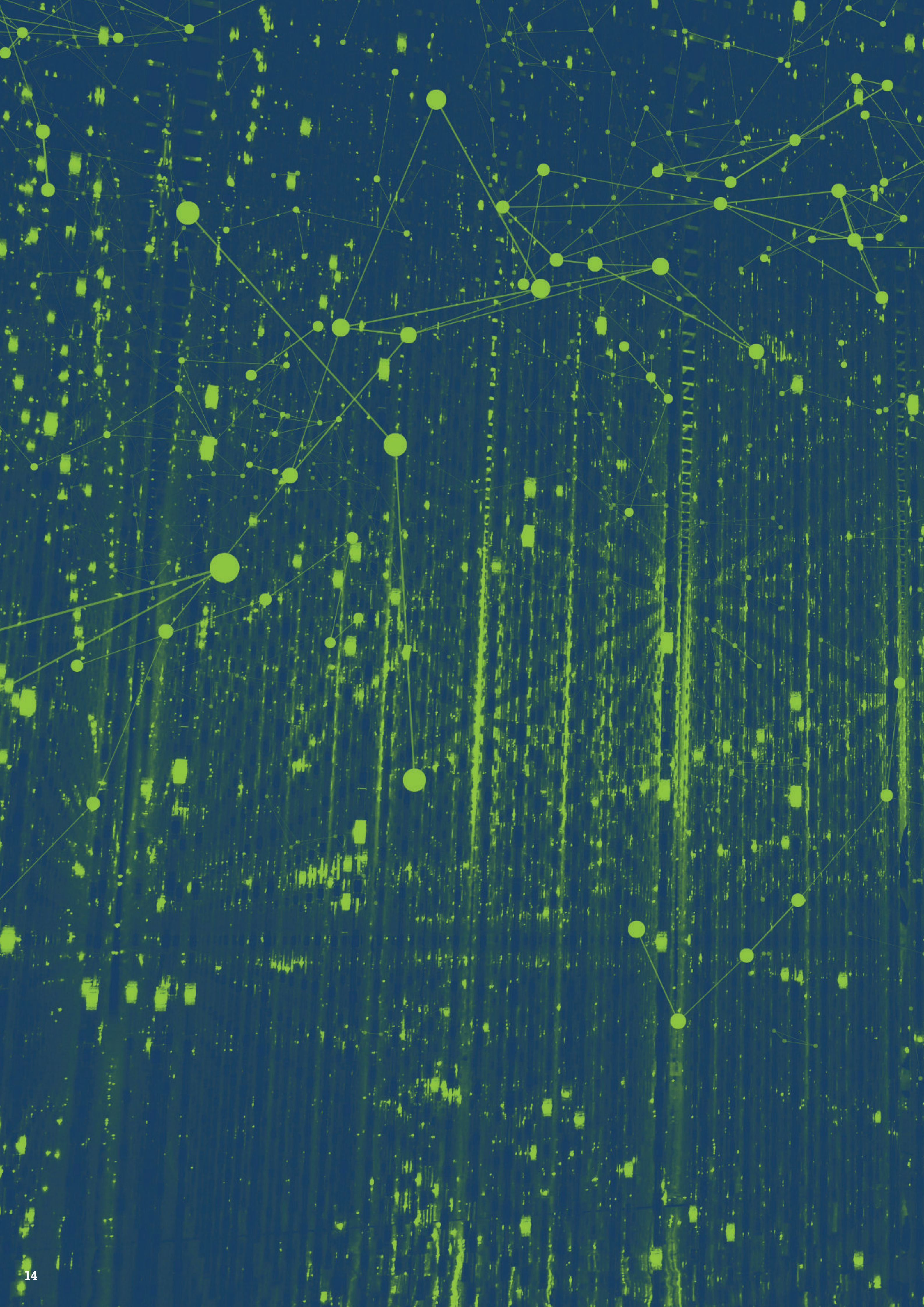
- **PRIO 7: Making better use of the data:** Data-driven performance assessment, digital twins for optimisation of operation and fault-detection of smart buildings, continuous commissioning, data-driven design methods and operation and maintenance automation.

- **PRIO 8: R&I for supporting increased public awareness, end-user acceptance and training of workforce** to support mass adoption of smart building technologies.

- **PRIO 9: Data privacy and cybersecurity in smart buildings:** improving new and legacy equipment, monitoring performance, towards certification of individual products and integrated systems

- **PRIO 10: R&I to support policy developments:** Improve regulations (EU and national) and policy initiatives (Digital Building Logbook, SRI, green public procurement for smart buildings, …) on smart buildings.

In the section *2 'Strategy for operationalisation of 10 key identified R&I Priorities'*, each of the ten priorities has been developed, including executive summary, a background/ rationale section describing the current situation for the different extents, and a list of key actions for implementation. In the section 3 the priorities are ranked according to their expected outcomes and impacts. Furthermore, potential links with ongoing EU initiatives and funding opportunities are investigated. Section 4 presents the conclusions and Annex A presents the matrix of ten key R&I priorities and their possible audiences.



02

Strategy for operationalisation of 10 key identified R&I Priorities

01

Smart building research and innovation priority n°1: Standardisation for interoperable products and services

Executive summary

Interoperability of different systems, not only within a single building, but also across different buildings and domains is key. The interoperability challenge can be addressed at the semantic (information) level, rather than at the technical (syntactical and communication) level, by using standardised ontologies as common vocabularies to share and reason about data. Concrete guidelines and successful stories of semantically interoperable large-scale and replicable implementations are still needed for the practitioners, including a methodology and reference framework for assessment and testing of semantic interoperability that can be used as basis to create an interoperability label at EU level.

Rationale

Buildings and homes are becoming smarter due to the widespread availability of connected devices, sensors, actuators and appliances that can make the life of occupants more comfortable, efficient and automated, saving money, time and energy[1]. However, to reach these goals, interoperability of different systems, not only within a single building, but also across different buildings and across different domains (e.g., smart homes, buildings and energy grids) is key. In this fragmented landscape, it is essential to promote standardised and open interfaces to avoid vendor lock-in and provide various stakeholders (e.g., prosumers, building operators, energy services providers, etc.) with the flexibility to integrate, visualise and analyse data coming from different sources to create/ make use of innovative solutions and added value services. That is where the full potential of combining data from different systems still needs to be unlocked. An example of the needs and benefits of combining building management systems data with sensor data by using open data models and semantic technologies can be found in (Chamari et al. 2022)[2].

By using ontologies as common vocabularies to share and reason about data, it is possible to address the interoperability challenge at the semantic (information) level, rather than at the technical (syntactical and communication) level, as it used to be

[1] https://www.statista.com/topics/2430/smart-homes
[2] Chamari, L., Petrova, E., & Pauwels, P. (2022). A web-based approach to BMS, BIM and IoT integration: a case study. *CLIMA 2022 Conference*. https://doi.org/10.34641/clima.2022.228
[3] Daniele, L., Solanki, M., den Hartog, F., Roes, J. (2016). Interoperability for Smart Appliances in the IoT World. In: The Semantic Web- ISWC 2016. Lecture Notes in Computer Science, vol 9982. Springer, Cham. https://doi.org/10.1007/978-3-319-46547-0_3

in the past (Daniele et al. 2016)[3]. Recently, the IoT industry started to understand the impact that ontologies can have to enable the missing interoperability, also as a result of significant standardisation efforts such as ETSI SAREF[4]. (Fierro et al., 2022)[5] provide an overview of ontologies/ metadata schemas, in addition to SAREF, that can be used to integrate smart buildings data, including W3C BOT[6] and Brick[7]. Industry Foundation Classes (IFC) is another important open international standard for BIM data used by the various participants in the construction and facility management sectors, which is also available as if cOWL ontology. The challenge with these ontologies is that the vast majority of industrial practitioners are not familiar with semantic technology and do not have an incentive to adopt it, as they believe the learning curve is too steep.

Information on ontologies appears to them abstract, scattered over the Internet and not easily applicable. Therefore, concrete guidelines and successful stories of semantically interoperable large-scale implementations that can be (easily) replicated are essential for the uptake by the industry. In this context, promotion, experimentation and roll-out of interoperability innovation based on mature, standardised and sustainable ontologies is of paramount concern. Other important aspects concern the development of software tools that are usable also by non-ontology experts (i.e., the vast majority), together with interoperability Plug & Play solutions that are hassle free and do not require technical assistance (e.g., architect or service integrator). Showcase to the market exemplary projects that prove the added value of interoperable products and services, together with marketplaces for interoperable services based on semantic data from ontologies like SAREF, BOT, Brick etc. is also needed.

Besides the R&I gaps mentioned above, some additional "Go-to-market" gaps require major attention, such as assessing, testing and certifying semantic interoperability using ontologies[8], which is acknowledged as an extremely important and, at the same time, challenging task by itself and also in relation to the Smart Readiness Indicator (SRI), raising the question whether and how it could play a role as a potential extra feature around the already existing core features of the SRI methodology. Some initiatives recently started to address this semantic interoperability assessment challenge, such as the proposed Code of Conduct (CoC) for interoperability of energy

[4] https://saref.etsi.org/

[5] Fierro G., et al.: Building Information ModelsSurvey of metadata schemas for data-driven smart buildings (Annex 81). International Energy Agency. CSIRO Publisher 2022). Available at https://annex81.iea-ebc.org/publications

[6] https://w3c-lbd-cg.github.io/bot

[7] https://brickschema.org/

[8] Semantic interoperability using ontologies as opposed to traditional technical interoperability via specific protocols and data models offered by existing home automation solutions (e.g., KNX, Zigbee, Matter, etc.), for which certification schemes are already available for manufacturers (incurring certification costs).

smart appliances (ESA) for/with manufacturers promoted by DG ENER and the Joint Research Centre (JRC)[9], which investigates the use of SAREF as common ontology to create the semantic bridge amongst various existing protocols, leveraging a methodology for testing semantic interoperability developed by the JRC[10]. However, major efforts are still needed in this direction, also to extend the scope from smart appliances (home premises) also to building systems and energy systems.

Proposed key actions

Action 1.1 – Development of a methodology for assessment of semantic interoperability using open, standardised ontologies (aiming at TRL 4-6) - RIA

- converge on mature, standardised and sustainable ontologies for the smart homes, appliances and buildings that are supported and evolved by standard organisations or industry consortia, such as (combinations of) SAREF, BOT and Brick.
- make it simple, starting from a minimum level of interoperability, adding more advanced functionality in subsequent iterations
- understand at market level the integration of ontologies into the data management system of the industries that need them. Starting from a list of practical use cases where the real problems are examined and then try to show what is being done and fine-tune it. In other words, understand how using semantics can be useful to industrial partners.
- define relevant use cases to address different groups of market segments and stakeholders. Employ these use cases to demonstrate completeness of ontologies, indicating possible incompleteness to the supporting bodies (e.g., ETSI SmartM2M TC, W3C Linked Building Data group, etc.)
- building upon and extend existing initiatives, e.g., methodology based on SAREF developed by the JRC at Smart Grid Interoperability Laboratory in Petten (NL) for testing semantic interoperability in the interface between smart homes and smart grids.

Action 1.2 – Reference implementation for assessment of semantic interoperability using open APIs and standardised ontologies (aiming at TRL 6-8) - IA

- based on the agreed assessment methodology developed in Action 1.1
- based on existing related initiatives, e.g., Code of Conduct (CoC) for interoperability of energy smart appliances (ESA) for/with manufacturers promoted by DG ENER and JRC
- open APIs and tools required for assessment
- open, mature, standardised ontologies required for assessment
- development of common EU open source kernel (reference implementation)
- possible different instantiations of the same kernel to accommodate specifics/ regulations of different Member States

Action 1.3 – Support programme for stakeholders on ontologies standardisation (aiming at TRL N/A) - CSA

- Upskilling programme for practitioners on standardisation in semantic interoperability and the use of ontologies in practice
- Promote use of existing open, standardised ontologies that are fully compliant with the specifications published by their supporting standardisation bodies. Discuss a timeline of possible developments to the current ontologies (with the supporting bodies) to address the issues for different market segments, which may be different

[9] https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances
[10] https://joint-research-centre.ec.europa.eu/laboratories-and-facilities/smart-grid-interoperability-laboratory_en

depending on the market segment group. This can then be communicated to the community such that they can align their developments/investments on that.

- Educate to standardisation by design, creating awareness of existing standardisation workflows for stakeholders
- Support for adoption and extension of existing tools (e.g., the ETSI portal for the SAREF community with collaborative repository and compliance pipeline; various toolboxes developed in European projects, such as InterConnect and MODERATE; etc.)

Action 1.4 – Interoperability label (aiming at TRL N/A)

- Based on methodology in Action 1.1 and reference implementation in Action 1.2
- Set up exemplary projects showcasing the added value of smart building certification assessing the level of interoperability (e.g. Ready2Service certification, Smart Score)
- The label may describe different levels of interoperability (i.e. natively at device level / IoT, or at cloud service level)

Action 1.5 – Marketplace for interoperability services and user-friendly software tools (aiming at TRL 4-6)

- Showcase to the market exemplary projects that prove the added value of interoperable products and services
- Development and/or showcase marketplaces for interoperable services based on semantic data from standardised ontologies
- Collect success stories that are replicable, making available repositories and tools for others to build upon
- Development of software tools that are usable also by non-ontology experts (i.e., the vast majority)
- Interoperability Plug & Play solutions that are hassle free and do not require technical assistance (e.g., architect or service integrator)

Action 1.6 – Citizen lab initiative about interoperability to quickly show benefits of giving access to (certain parts of) their data (aiming at TRL 4-6)

- small scale experiments (lighthouse) including citizens (building owners) to demonstrate almost immediate return from 1-2 services enabled by an interoperable ecosystem
- include investigation of (standardised) ontologies for users and their preferences

02

Smart building research and innovation priority n°2: Smart buildings, energy flexibility and external environment

Executive summary

To reach a climate neutral Europe in 2050, integration of renewable energy sources into the grid is key. To exploit the full potential of new energy flexibility solutions, smart buildings need to be connected with their environment (e.g., other buildings and the grid). However, essential challenges still need to be tackled. From a regulatory side, new market roles have to be defined and harmonised, especially concerning flexibility service providers and aggregators. From a technical side, an interoperable environment for actors and standards from different domains (e.g., smart appliances, built environment and grid) needs to be validated and demonstrated. Finally, business models that remunerate the value of building flexibility to the end-users are yet to be identified.

Rationale

Within the European Commission's strategy to reach a climate neutral Europe in 2050, the integration of more renewable electricity into the power grids constitutes a key pillar. But a higher penetration of renewables into the electric grids constitutes a challenge, due to the intermittent and hardly predictable nature of some Renewable Energy Sources (RES) – such as wind and solar – and the technical constraints of the existing electricity networks. Consequently, capturing the flexibilities offered within the energy system (flexibilities in generation, demand and storage) constitutes a significant lever to enable the integration of more RES at lower operational cost.

While demand side mechanisms are already operational to exploit flexibilities in the industrial sector, buildings from the commercial and residential sectors are still far from being used at their full flexibility potential. Today, smart technologies enter more and more into those buildings, providing new means to capture the power system flexibility potential offered by equipment and end-user behaviour, with added value both for the building users and the grid. However, this flexibility potential is spread across myriads of buildings, each being a source of a small amount of flexibility. Therefore, the connection of smart buildings with the external environment, such as other buildings and the grid, is essential to exploit the full flexibility potential of this segment.

To identify pathways towards the increase of flexibility provision by smart buildings, open challenges still lie in the assessment and quantification of the power flexibility potential of smart buildings and related services to the grid; the investigation of the role of individual buildings vs. blocks of buildings in achieving a flexible power grid; energy storage capabilities and norms; and the definition of clear roles and responsibilities for the various stakeholders involved, from building owners, building operators and occupants, to new market participants such as Flexibility Service Providers (FSP) and aggregators, which are roles that are frequently used interchangeably, as they present overlapping functions. From a certification point of view, an additional open issue is how to check the compliance of buildings to provide flexibility and how the Smart Readiness Indicator (SRI) can contribute to this.

From the technological side, the optimal level of integration of technologies and services to provide building-to-grid flexibility still needs to be reached, also making use of external data sources, such as multi - Scale Interoperable Geographic Information and Systems (GIS) and Building Information Modelling (BIM) for flexibility service purposes. Moreover, a fully interoperable data exchange environment to provide power flexibility to the grid – which also considers the concept of digital twin - is needed to clarify which specific (anonymised) data need to be exchanged in order to enable flexibility services, taking into account the fragmented standardisation landscape that characterises the demand side flexibility end-to-end value chain (see study on ensuring interoperability for enabling Demand Side Flexibility, 2018[11]).

A final important challenge is the lack of business models that remunerate the value of building flexibility to the end-users. The added value of flexibility must be clearly explained and visualised to the end-users (e.g., via intuitive interfaces that leverage AI predictions and ontology-based knowledge graphs), fostering their engagement in a co-creation fashion, where the end user becomes a new and valuable partner in the energy flexibility ecosystem of the future, and is provided with actionable intelligence on whose basis to make informed decisions.

Proposed key actions

Action 2.1 – Harmonised definition of roles and responsibilities for actors involved in energy flexibility (aiming at TRL 8)

- From building owners, building operators and occupants, to new market participants on the grid side, such as Flexibility Service Providers (FSP) and aggregators (which are frequently used interchangeably, as they present overlapping functions and technological skills)
- Explore multi sided market approaches, from consumer level to local service

[11] Study on ensuring interoperability for enabling Demand Side Flexibility, TNO, DNV-GL, ESMIG for the EC, 2018 https://op.europa.eu/en/publication-detail/-/publication/a61d67de-9ecd-11e9-9d01-01aa75ed71a1

providers, aggregator. This implies bidirectional flows (from service provider to end-users and vice versa).
- Assess the value of flexibility for buildings as FSP: further demonstration of demand response programmes at building level, validation of the level of flexibility delivered, determination of its value for the grid.
- Explore, technically and economically, the contribution of storage and electric vehicles as components of the smart building providing flexibility.

Action 2.2 – Regulation for flexibility market (aiming at TRL N/A)
- Build new market regulation to enable flexibility services and local energy markets. New market agents have to be defined and regulated, i.e. FSP and aggregator, and conflicts with current market participants have to be identified and solved. Regulation should also support the proposal of flexibility assessment and certification scheme (see next action 2.3).
- EU-wide harmonisation of the regulation and the way it is implemented in each Member State. In particular, regulation in border areas should allow flexibility exchange among countries.
- Regulatory sandboxes are needed to allow checking new business models and regulations in relevant environments involving real buildings and occupants.

Action 2.3 – Development of a flexibility certification scheme at EU level (aiming at TRL 8)
- Flexibility certification as part of the overall building performance certification methods to assess and quantify the power flexibility potential of smart buildings and related services to the grid.
- Common and harmonised definitions of flexibility products should facilitate the development of such a certification scheme.

Action 2.4 – End users as new and valuable partner in the energy flexibility ecosystem of the future (aiming at TRL 4-6)
- Engagement of end users (prosumers) as new and valuable partner: co-creation of flexibility services with the stakeholders identified in Action 2.1
- Standardisation in contracts: the grid connection and exploitation dimensions for prosumers should be a standardised part in the energy supply contract.
- Identify business models that remunerate the value of building flexibility to the end-users.
- Added value of flexibility to be clearly explained and visualised to the end-users (e.g., via intuitive interfaces that leverage AI predictions and reasoning using ontology-based knowledge graphs), as the majority of end-users do not have any idea about their energy consumption/production and how they can optimise it while preserving their comfort and preferences.
- Investigate the issues of ethics and artificial intelligence applied to building flexibility services, in relation to the AI regulatory framework that the EC is designing.[12]

Action 2.5 – Interoperable data exchange environment to provide power flexibility to the grid (aiming at TRL 4-6)[13]
- Standardised approaches allowing to qualify smart appliances' characteristics and capabilities (load, generation) within a building to any service related to power grid.

[12] https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai

[13] *"In some areas of the energy sector, such as electric vehicles, photovoltaic installations and heat pumps, digital and smart technologies are already in place and need support to scale up. In other areas our energy system is just beginning to reap the benefits of digitalisation. In the coming months and years, the Commission intends to take various steps to boost digital energy services while ensuring an energy-efficient ICT sector, including: helping consumers increase control over their energy use and bills through new digital tools and services, with a strong governance framework for a common European energy data space;..."* Commission sets out actions to digitalise the energy sector to improve efficiency and renewables integration.
https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6228

- Focus on the Smart Grid Architecture Model (SGAM). There is the need for alignment among the communication standards from the Utility, Telecom and Home appliances industries in order to reach semantic interoperability.
- Accelerate the harmonisation of key data models and ontologies such as the IEC CIM (widely used by DSOs) and SAREF/ SAREF4ENER (widely adopted by smart appliance manufacturers)[14] to move the fragmented landscape of standards and protocols towards semantic-based interoperability, enabling discovery of flexibility services and deployment of new generation knowledge and AI solutions.
- Further develop solutions that provide the optimal level of integration for existing different technologies (sensors, storage, connectivity, software).
- Further standardisation of protocols to exchange flexibility between buildings and grid operators (including through flexibility aggregators). This includes the harmonisation of existing standards on building level flexibility between Member States.
- Investigate how to collect and store detailed sub-metering data with high resolution for different building typologies, taking into account GDPR-issues.
- Test and quantify the digital grid interoperability.

Action 2.6 – "Ready to service" and "ready to grid" buildings (aiming at TRL 6)

- Consider the building flexibility services at the early stage of building design, in a standardised manner. This also includes the process of end-user involvement in the design phase to ensure their future engagement for flexibility.
- Design technologies/ equipment / hardware / IT so they include options for flexibility (i.e. no further investment / updates of technologies when connected to grid).
- Define incentives to help early adopters to support the higher cost of new technologies (while the followers will benefit from lower prices due to market expansion).
- Investigate the automation level (SRI) required for buildings to be able to provide flexibility services, and how to take existing buildings to this level.

[14] Based on a recommendation already done in the context of the Study on ensuring interoperability for enabling Demand Side Flexibility by TNO, DNV-GL, ESMIG for the EC in 2018

03

Smart building research and innovation priority n°3: Innovation in products and related business models for smart buildings

Executive summary

To support the transition towards energy efficiency in homes and buildings without compromising the comfort and well-being of individuals, there is a need for a paradigm shift in both technological solutions that make sense, are cost and energy efficient, and new user-centric business models that support this transition. How, for example, can we move towards "comfort as a service", how can we ensure existing and new home automation systems are flexible and adaptable to seasonal needs of users, how can we ensure energy performance contracting and performance guarantees. All of these while rather than compromising on individual comfort, by actually enhancing it.

Rationale

Building owners and in particular building users are exploring different energy saving alternatives while at the same time trying to ensure that comfort and well-being are not compromised. Users today want choices on whose basis they can make informed decisions on what actions they can take for example for improving energy efficiency and enhancing indoor comfort. There is a need for a shift from a building as a space to a place of well-being, from a physical asset for working and living to a service. Just as there has been a shift in the software industry from software as a product to software as a service, there is a need to move from a building as a product to a building as a service - e.g. providing comfort-as-a-service, enhancing well-being-as-a-service, ensuring optimal performance-as-a-service, and much more.

Transitioning to a building-as-a-service requires both technological solutions and supporting business models. Traditional legacy systems and equipment are difficult to scale-up and connect with other smart technological solutions without significant efforts. As an example it is difficult to optimise systems from different vendors especially where there are limits to interoperability and lack of compliance to data exchange standards. At the same time, we are noticing significant breakthroughs such as the emergence of frameworks allowing the development of future digital platforms as common ecosystems of digital services that will support innovation, commerce, etc. and reference architecture frameworks for digital construction platforms supporting co-creation, interoperability and importantly enabling one-stop-shop marketplaces for meaningful products and services for buildings.

As we undertake this paradigm shift towards user-centric smart and energy efficient buildings, there is still a lack of understanding and existence of relevant business models to support these. In order to ensure the fitness to the climate neutrality proposals, solutions should extend their goals, in order to address environmental and social issues and aim for wider stakeholder engagement.

Since the vast majority (75%) of the EU's building stock classified as energy inefficient[15], it is apparent that proliferating existing business models will not suffice, but rather new innovative schemes should be developed. Some of recently emerged innovative financing schemes involve on-bill financing and energy savings obligation, alongside crowdfunding, the latter still being scarce. However, full energy transformation extending beyond sheer financial gains will not be possible, unless new solutions are co-created and co-designed, involving a wide variety of key stakeholders and end-users. These will extend the benefits of the newly created models to the whole construction ecosystem and will boost the mutual learning and information flow between all key parties. One of the desired outcomes of such a process should be empowering the occupants into smart prosumers, capable of co-designing services adapted to their variety of needs.

Proposed key actions

Action 3.1 – Develop new concepts and solutions for occupant centric buildings (aiming at TRL 5-6)

- Co-create new ideas and concepts around building-as-a-service and living-as-a-service offering with building owners and users => what are their wishes, needs, and expectations from such a paradigm shift
- Discuss and elaborate with smart solution and service providers how they can provide their products in a "service"-oriented form. Roadmaps, implementation action plans and appropriate business models need to be co-defined
- Validate and test the "building-as-a-service and living-as-a-service" concepts in living labs and where possible, large scale demonstrators
- Listen to end-user feedback in tested solutions, observe how the change has happened, valorise on the key findings and then adapt, replicate and scale-up

Action 3.2 – Develop and design participatory business models (aiming at TRL 7-8)

- Defining key stakeholders, their needs and roles in smart buildings value chain
- Once needs are assessed, the co-creation process should start with raising their awareness on the existing business models, their constraints and benefits. These

[15] https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en

should not only be expressed in financial gains, but also in % of reduction in CO_2 emissions

- Enable these groups to exchange their experience and discuss desired solutions, which will be the foundation of the future business models. Special attention should be paid to the following aspects: a) target performance; b) new models of ownership; c) service flexibility (bundles of services as opposed to basic services, leveraged according to the user preferences) d) the concept of comfort and its role in innovative business model development
- Enhance these solutions with the selected technologies, such as blockchain and tokenization and receive the feedback in terms of their fitness to stakeholder preferences, transparency, inclusiveness, etc. Special focus should be placed on automated management system
- Deploy pilots for testing the enhanced versions; Creating a standardised smart building assessment framework

Action 3.3 – Legal framework for Deployment of universal digital infrastructure at the EU level (aiming at TRL 6-7)

- Define targets and the necessary preconditions for successful deployment of the infrastructure
- Propose the legal measures that could potentially support meeting these goals, such as tax reduction, subsidising, efficient administrative processes
- Develop Green Building certifications for Smart Building

04

Smart building research and innovation priority n°4: Endorsing testing facilities and their benchmarking for integrated analysis and demonstration

Executive summary

Endorse the development of physical and digital test facilities for integrated analysis and demonstration of smart buildings. The conception of advanced testing facilities in real life settings with real users can support research and market validation of smart building products and services. Such research infrastructure should be strengthened further by EU harmonised testing protocols, the development of EU wide acknowledged benchmarks, regulatory sandboxes, and knowledge sharing of case studies with open datasets.

Rationale

By deploying open innovation methodologies, testing facilities have proved to have several benefits for the different stakeholders; these benefits include bridging the innovation gap between technology development and the uptake of new services & products and allowing for early assessment of the socio-economic implications of new technological solutions[16]. By their intrinsic nature, most of the smart building technologies cannot be tested in conventional academic laboratories, but require realistic settings of real buildings, which can prove solutions for various aspects of sustainability challenges in cities[17]. Testing facilities include Test Beds, Fab Labs, Home Labs, Living Labs and Regulatory sandboxes; all these experimentation spaces can generate useful evidence and learnings to support innovation and regulatory governance[18].

Involving all relevant stakeholders from quadruple helix actors (public and private sector, academia, and society) is of crucial importance, but nevertheless user engagement has demonstrated to be a key on successful processes, since the user-driven methodology brings the users early into the creative process in order to better discover new and emerging behaviours and user patterns[19]. Likewise, testing facilities

[16] European Commission- Information Society and Media. Living Labs for user-driven open innovation. An overview of the Living Labs methodology, activities and achievements. January,2009. ISBN 978-92-79-10358-2 DOI 10.2759/34481
[17] Timo von Wirth, Lea Fuenfschilling, Niki Frantzeskaki & Lars Coenen (2019) Impacts of urban living labs on sustainability transitions: mechanisms and strategies for systemic change through experimentation, European Planning Studies, 27:2, 229-257, DOI: 10.1080/09654313.2018.1504895
[18] Kert, K., Vebrova, M. and Schade, S., Regulatory learning in experimentation spaces, European Commission, 2022, JRC130458.
[19] P. Evans et al. Living Lab Methodology Handbook. User Engagement for Large Scale Pilots in the Internet of Things (U4IoT) Consortium, 2017.

allow organisations to analyse their products' processes by exploring and testing all aspects, from design and maintenance to cost effectiveness, and engineering methods exploitation.

By developing new testing procedures in real case studies, it is possible to appropriately monitor, evaluate and validate the technology from a socio-technical viewpoint for a later commercialization stage. The different possible risks developed from smart buildings' innovations can be mitigated by extensive testing in real buildings and their digital twins. In addition, enriching buildings, districts and cities' digital twins with data from urban living labs can support the creation of more realistic replicas that underpin decision making proceedings[20]. This also includes utility, effectiveness, and optimal conditions of use of new smart systems and risks related to market adoption validation.

To support the development, technical and functional validation and finally demonstration of smart building products and services, the market needs advanced test labs, facilities and EU harmonised standardised testing and assessment protocols and reporting. Developing a harmonised EU benchmarking for smart buildings requires a robust and reliable testing framework that can allow objective assessments of smart building services and smart buildings as a whole. Such a framework would encourage the use of synchronised format for comparability of data, that includes ontology and semantics for devices, equipment, and assets. With shared assessment metrics, benchmarks can test performance, as well as the security and safety features of applications or systems.

Proposed key actions

Action 4.1 – Create EU strategy for physical testing facilities that support the testing of innovations on smart buildings (aiming at TRL 4-6)

- Promoting the involvement of stakeholders from quadruple-helix model to enable the implementation of technical and social innovations within the testing facilities
- Support to SMEs and research institutes with early data access and validations;
- Increase the number of testing facilities at different scales: at room level, building level, building block level and even street or district level.
- Adoption of high-quality digital twins: leveraging testing innovations in other boundary conditions through calibrated digital energy twins

Action 4.2 – Implementation of strategic program of living labs for higher TRL applications of smart buildings to be tested in realistic conditions (aiming at TRL 6-9)

- Create EU vision on various testing facilities: various climatic zones, renters vs owners, frontrunners and DIY experimenters vs laggards; residential vs non residential; new buildings vs existing structures;
- The testing of many applications requires regulatory sandboxes, enabling to test innovations beyond current legislation; e.g. allowing peer to peer sharing of electricity or heat and cold as part of a test setup, or allowing temporary installation of equipment without burdensome building permits, etc.;
- Besides more permanent / long-lasting living labs, support the validation in exemplary projects, showcasing the added value of interoperable equipment.

[20] Hristov, Peter & Petrova-Antonova, Dessislava & Ilieva, Sylvia & Rizov, R.. (2022). ENABLING CITY DIGITAL TWINS THROUGH URBAN LIVING LABS. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLIII-B1-2022. 151-156. 10.5194/isprs-archives-XLIII-B1-2022-151-2022.

Action 4.3 – Development of common testing protocols, benchmarks, and reporting standards (TRL 1-9)

- The development of common testing protocols allows an objective assessment of smart building services and smart buildings as a whole;
- An important aspect of defining protocols is the definition of benchmarks, with the need to identify the non-smart default behaviours which serves as a ‘business-as-usual’ point of comparison. Those benchmarks need to be developed for different types of services, types of buildings and various contexts.
- This could lead to the development and management of an open EU database of demonstrations/ showcases which includes: time series data of before/after metered energy data and other measurements (comfort, occupant behaviour,…), info on financial costs and benefits (CAPEX and OPEX), standardised details on user types, building type, local context (from culture to climate), etc.

05

Smart building research and innovation priority n°5: Better understanding of co-benefits

Executive summary

Building monitoring, control, and real-time data, adjusting the indoor environmental conditions to occupant needs, can provide additional co-benefits, on top of positive energetic impacts. Enhancing thermal and visual comfort sensation, or improving indoor air quality (IAQ), provide benefits such as better concentration, productivity, cognitive performance, stress reduction and even reduce sick leaves in office buildings. Quantification methods coupled with qualitative assessments such as the SRI are required to better understand the wide range of outcomes that smart technologies can have on the built environment. Furthermore, new business models tailored to the building typology and its users can be developed.

Rationale

The concepts concerning the user's experience in indoor spaces and environmental quality are multifaceted (Han, 2018). Rohde et al (2019) propose a categorisation which clearly differentiates between the concepts of 1. comfort, 2. health and 3. well-being. When it comes to indoor health and comfort in schools and offices, there is a need to develop models which correlate IEQ standards with end-user needs. Bluyssen (2020) has developed an IEQ model aiming not only at addressing the negative impact of the indoor environment, but its positive effects too, as there seems to be a current gap between the current IEQ standards and end-users needs (Bluyssen, 2020).

There are a number of labels, ratings and certifications schemes. To name a few these include, the BREEAM rating scheme, the LEED rating system, the WELL Building Standard, the FITWELL Standard, the IEQ-Compass, and comfort classification indexes. However, researchers discovered that buildings awarded with these labels do not necessarily score better in terms of occupant satisfaction (Paul and Taylor 2008; Altomonte et al. 2019; Reuter et al. 2020). Therefore, smart technologies in buildings can help overcome the static nature of the aforementioned approaches, with regards to assessing qualities of indoor environments.

Key smartness features of buildings include the ability to have 1. flexible and adaptable settings, which translate into real-time monitoring of key parameters of the occupant's perception of comfort and 2. local control, which translates into automated and user-driven controls of the parameters. AI based and Machine Learning offer promising possibilities when it comes to individual comfort models, however there are still significant gaps and a long way ahead. There are currently several theme-related EU projects (UtilitEE project, SPHERE project, BIM SPEED project, eTEACHER project, MOBISTYLE project, Cultural-E project, Homes4Life project, ALDREN project, SHAPES project) as well as several initiatives and innovations.

A wider implementation of smart buildings technology is expected to produce energy savings in a cost-effective manner and to improve indoor comfort, health and wellbeing, improving the indoor environmental quality conditions. Furthermore, in a future energy system with a large share of distributed renewable energy generation, smart buildings will be the cornerstone for an efficient interaction with a smart grid thanks to resources such as demand side energy flexibility.

The EPBD amendment (directive 2018/844 of the European Parliament and of the Council of 30 May 2018) promotes the implementation of building automation and electronic monitoring of technical building systems, supports e-mobility and introduces the SRI, for assessing the technological readiness of the building and the ability to interact with the occupants and the grid. The aim of the SRI is to raise awareness of the benefits of smarter building technologies and functionalities and make these benefits more evident for building users, owners, tenants, and smart service providers.
In addition, the Commission has proposed today to align the rules for the energy performance of buildings with the European Green Deal and decarbonise the EU's building stock by 2050. The Commission proposes that as of 2030, all new buildings must be zero-emission. To harness the potential of faster action in the public sector, all new public buildings must be zero-emission already as of 2027. This means that buildings must consume little energy, be powered by renewables as far as possible, emit no on-site carbon emissions from fossil fuels and must indicate their global warming potential based on their whole-life cycle emissions on their Energy Performance Certificate[21].

Proposed key actions

Action 5.1 – Quantification methods for non-energy benefits (aiming at TRL 4-5)

- Evidence-based quantification of benefits related to SRI scores: how much are occupant comfort, convenience, health, and energy savings increased when a smart functionality is added?
- Harmonised methods to calculate the most common indicators, integrating new KPIs related to non-energy benefits according to Level(s) framework.

[21] European Green Deal: Commission proposes to boost renovation and decarbonisation of buildings. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6683

- Develop global methods and sensitivity algorithms linking (measurement) data and (comfort /wellbeing) KPIs.

Action 5.2 – Data-driven Smart Buildings' indicators (aiming at TRL 4-5)

- Develop low-cost and plug-and-play sensors for energy and IEQ monitoring as well as innovative solutions to interface with legacy equipment and upgrade smartness/ optimise the operation of buildings.
- Strength the development of open-access databases of monitored smart buildings' indicators (sensors and continuous occupants' feedback).
- Investigate how to use synergies and re-use building data in the evaluation of co-benefits, i.e. make the assessments data-driven and continuous, use shared databases.
- Make the building logbook mandatory, with some items related to IEQ aspects, simplify regulation so it is easy to understand and verify.

Action 5.3 – Develop & demonstrate new business models (aiming at TRL 6-7)

- Develop & demonstrate new business models taking into account co-benefits: global contract linking/ binding all stakeholders to the targeted performance - 'dynamic contract' based on performance as well on the usage values (e.g. comfort, health and safety).
- Create a common and updated Smart Building assessment framework: how to "sell & package" SB best? What is the 'best' business model depending on the type of building and type of user.
- Develop a strategy to deal with the fragmented offer in the value chain
- Identify living labs and equip them with trust-worthy measurement tools to improve testing and validation.
- Develop a user-centric standard that could be adopted at building's early design phase and based on European values and perspectives.

Action 5.4 – Qualitative Methods-Develop education & awareness raising actions (aiming at TRL N/A)

- Develop training, demos and social businesses cases towards building occupants, facility managers, electricians and installers on the relation between building solution performances and well-being perception.
- Develop strategies and methodologies to deal with the difficulties of
    - Collecting data about comfort, health and wellbeing.
    - Difficulty of defining the subjective and evolving perception, depending on culture, lifestyle, ageing etc.
- Defining the concept of co-benefit and dealing with the difficulty of monetising a concept that is not directly related to energy savings.
- Lead awareness raising actions of occupants, property managers and insurers about smart technology benefits on well-being in buildings, necessary to create market demand (though education, information).

06

Smart building research and innovation priority n°6: Advances in products, services and decision support methods to improve life cycle environmental impacts of smart buildings

Executive summary

Buildings become a major target for environmental improvement as the building sector accounts for nearly 40% of the world's energy consumption, 30% of raw material use, 25% of solid waste, 25% of water use, 12% of land use, and 33% of the related global greenhouse gas (GHG) emissions[22].
The way we live in the built environment needs to become more sustainable - and even go beyond sustainability, towards sufficiency and "regenerative" buildings that will both restore and improve the natural environment (and humans likewise). As humans spend about 90% of their time in enclosed spaces[23], smart buildings are key in addressing these challenges while delivering high quality of life, secured indoor environment quality, and improved services to their occupants. Moreover, the EU's new circular action plan[24] paves the way for a cleaner and more competitive Europe. The EU's transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs. It is also a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss.

Rationale

Several environmental impacts of buildings are generated during the operation phase, and the main impacts come from energy use (fossil fuels) and acting on climate change. For residential buildings, the operational energy can indeed vary between 70% and 90% of the whole life cycle energy consumption of a building, whilst the embodied energy generally ranges between 10% and 30%[25].
This proportion changes significantly for high-performance buildings. For example, in net zero energy buildings (nZEB), the share of embodied energy ranges between 69

[22] Based United Nations Environment Programme (2009). Buildings and Climate Change: Summary for Decision Makers. https://wedocs.unep.org/20.500.11822/32152
[23] According to the results of the National Human Activity Pattern Survey (NHAPS) conducted in the US and Canada. KLEPEIS, N., NELSON, W., OTT, W. et al. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J Expo Sci Environ Epidemiol 11, 231–252 (2001). https://doi.org/10.1038/sj.jea.7500165
[24] Circular economy action plan. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
[25] Ingrao, C., Messineo, A., Beltramo, R., Yigitcanlar, T., Ioppolo, G. (2018) How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance, Journal of Cleaner Production https://doi.org/10.1016/j.jclepro.2018.08.080

and 100%[26]. However, nearly 70% of Europe's national building stock will still be in place in 2050[27] and is made up mostly of bu70ildings with low energy efficiency that were constructed before the European Directive on the energy performance of buildings came into effect[28].

Smart systems, actuating on the overall performance of buildings, mainly target these operational impacts in a building lifecycle. Curbing carbon emissions in buildings will eventually have a positive impact on ecosystems quality, as well as on human health and wellbeing. Nonetheless, significant effort and consideration should also be placed on preserving resource availability (i.e. decrease mineral resource depletion induced by the demand for construction materials).

Life cycle assessment (LCA) can be used to quantify life cycle environmental impacts of buildings. This methodology enables one to apply a complete life cycle perspective that combines materials (the embodied building impacts) and building operation (e.g. water and energy consumption). It can be implemented and updated at each key lifecycle stage a building is going through, e.g. design, retrofitting, change of energy providers. Moreover the advent of digital twins, sensed dynamic data, data analytics methods and smart buildings with actuation systems make also possible innovative approaches in relation with LCA, for improving the performance and simplifying the use of smart buildings management systems.

Challenges associated with LCA in the operational stage stem from several factors, including a variation in operational energy demand, energy system evolutions, building use/occupancy patterns, and building and environmental regulations. Furthermore, (Fnais et al, 2021)[29] highlighted the importance of addressing the temporal and spatial dimensions associated with LCI by developing regionalized databases and dynamic data to enhance the accuracy of LCA results.

However, a key limitation inherent to the building industry lies in the lack of information and standardisation, usually preventing this kind of innovative approaches to broadly penetrate the industry and its economic practices. This remark links to priority n°1 and the need for standardised data models and information & communication protocols. Additionally, smart technologies can also support the change of paradigm, from "less bad" to "more regenerative" built environment and apply across all of the phases of the building's lifecycle.

Proposed key actions

Action 6.1 – Further development of common Life Cycle Assessment methods and indicators
Additional effort is needed to improve LCA methods and frameworks applied to buildings lifecycle, with a specific focus on smart systems:

- Develop harmonised approaches to LCA at EU-level, including standardised impact databases, in cooperation with the industry.

[26] Chastas, P., Theodosiou, T., Bikas, D. (2016) Embodied energy in residential buildings-towards the nearly zero energy building: A literature review, Building and Environment. 105: 267–282. https://doi.org/10.1016/j.buildenv.2016.05.040
[27] IEA, Building Energy Efficiency Policies, International Energy Agency (2018). https://www.iea.org/beep/
[28] Ballarini, I., Corgnati, S.P., Corrado, V. (2014) Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project, Energy Policy. 68: 273–284. https://doi.org/10.1016/j.enpol.2014.01.027
[29] Fnais, A., Rezgui, Y., Petri, I. et al. The application of life cycle assessment in buildings: challenges, and directions for future research. Int J Life Cycle Assess 27, 627–654 (2022). https://doi.org/10.1007/s11367-022-02058-5

- Define streamlined LCA workflow, including environmental data or impact estimations for smart products.
- Reflect LCA of smart buildings and their components into Level(s), the EU common language for improving the sustainability performance of buildings, and provide guidance on the role and impact of smart systems.
- Share results as open datasets, using building data semantics.
- Run experiments and demonstration activities in pilot buildings to show the usefulness, effectiveness, and optimal conditions of use of new smart systems minimising environmental impacts, in line with needs from the industry, and with shared assessment metrics.

Action 6.2 – Streamline the use of dynamic data in Life Cycle Assessment approaches
Assessment frameworks and decision-making tools for the operational performance of smart buildings should rely on dynamic data and improve LCA approaches, and in particular:

- Develop decision-support systems that leverage dynamic data, machine learning, and optimization methods for real-time assessment of design options, monitoring, optimization, and control of buildings.
- Approaches that promote the concept of semantics to integrate and contextualise existing domain models (e.g., BIM), LCA tools, and inventory databases to streamline the LCA process and provide holistic accounts of environmental impacts of buildings and districts.

Action 6.3 – Develop methods to assess and limit the impacts of the 'smart' devices

- Develop harmonized approaches to balancing the impacts of infrastructures, equipment and devices for smart buildings, especially in terms of repairability, circularity, dismantling and upcycling of components.
- Investigate novel methodologies to optimise the infrastructures and devices needed to operate smart services, by using innovative engineering and simulation approaches as well as by leveraging on data analytics and AI techniques.

Action 6.4 – Investigate performance gap and rebound effects
As smart home development has never been primarily concerned with environmental impact, there is also cause for concern that it creates a demand for previously unwanted products and services (Darby, 2018), and therefore generates more impact than what smartness allows to reduce in the operation phase of the building.

- This is a known phenomenon termed rebound effect. The estimations of the rebound effect in research vary, according to the type of house and smart systems installed, but also according to the behaviour of the users (as smart and automated systems also include a consistent user behaviour component) and the modelling approach used to study it. This requires holistic methodologies to address and assess it.

07

Smart building research and innovation priority n°7: Making better use of the data for a data-driven performance assessment

Executive summary

Building monitoring and control, and the use of real-time data, has the potential to greatly improve building quality and comfort and reduce the building's energy use[30 31]. The collected data could be combined with prediction models and integrated in data-driven performance assessment, e.g. by using and enhancing digital twins. Feedback from new data into existing schemes should help to enhance these digital twins and underlying models, where specific focus could be on tackling human and data biases. Furthermore actual data can help with fault prediction and aid future design methods.

Rationale

Achieving building performance as foreseen in the design stage is a recognized challenge. Research conducted in the field has shown widespread low occupant satisfaction with indoor thermal environments (Brager et al. 2015). Also, user-friendliness of installations is often perceived as an issue with building users. Building monitoring, control, and real-time data can thus play an important role in reducing the performance gap between design and operation and improve the overall design, commissioning and operational performance of buildings in interaction with the climate, the users and the wider energy system. Furthermore, this will help to improve the models for future projects.

However, data-driven approaches face a significant number of challenges to be efficient, such as the data collection, the harmonisation of protocols, the further development of tools, the expansion of the digital twin concept and the showcasing of good practices. Firstly, an extensive data collection is required, in terms of amount, types and also quality of the data which is invaluable to broaden the scope of the digital applications for buildings. This for instance to further gain insights and enable interactions on user wellbeing and preferences, development or upgrading of tools such as self-learning data-driven services and improved prediction and modelling on aspects like space occupancy, occupant behaviour, well-being and co-benefits.

[30] Bing Dong, Vishnu Prakash, Fan Feng, Zheng O'Neill, A review of smart building sensing system for better indoor environment control, Energy and Buildings, Volume 199, 2019, Pages 29-46, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2019.06.025.
[31] D. A. Winkler, A. Yadav, C. Chitu and A. E. Cerpa, «OFFICE: Optimization Framework For Improved Comfort & Efficiency,» 2020 19th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), Sydney, NSW, Australia, 2020, pp. 265-276, doi: 10.1109/IPSN48710.2020.00030.

Digital platforms can cover all stages of a building's life cycle and may also serve for joint collaboration and communication between various stakeholders - also exceeding the building sector boundaries. However, such platforms require harmonisation of protocols for data exchange to facilitate systematic integration of data from various data sources and are essential to allow multiple end-uses of the platform. Such digital platforms need to be robust in terms of inclusiveness, connectivity and accessibility, interoperability, cybersecurity and data protection. Advancements in the digital twin concept as a virtual representation of buildings together with tools of advanced data analytics and machine learning methods can form the new basis for "Building as a Service " in which services provided by the building are continuously optimised in interaction with the user and the surroundings.

Furthermore, there is a need for showcasing of good practices for instance in living labs and large scale demonstrators to test and validate new products and services with active participation of various stakeholders.

Proposed key actions

Action 7.1 – Expand the data collection (amount/type) (aiming at TRL 4-5) RIA

- Develop/upgrade tools and processes to collect data on wellbeing and identify priorities for occupants;
    - develop non-intrusive sensors;
    - use existing devices from occupants such as smartphones;
    - user key cards (at work);
    - focus groups on QoL;
    - serious games.
- Including co-benefits and externalities in the optimisation equation as well as validated models of occupant behaviour.
- Develop low-cost and plug&play sensors for energy and comfort monitoring as well as innovative solutions to interface with legacy equipment.
- Apply Artificial Intelligence, prediction, and modelling, to help fill the quality gap on real data collected.
- Systematically integrate in demonstrators the monitoring of occupancy and weather data together with building parameters to ensure data quality.

Action 7.2 – Strive for multi-use data possibilities (aiming at TRL 8-9) RIA

- Develop and maintain common, up-to-date and reliable databases providing costs for materials and equipment over the whole life cycle (similar to LCA databases).

- Develop affordable and intuitive digital platforms, covering all stages of a building's life, for co-construction with all stakeholders, collaboration and communication, user involvement and decision-making (including simulation functionalities, gamification, etc.).
- Strengthen the development of open-access databases of monitored buildings.
- Create a European platform for local authorities to exchange best practices of data governance.
- Propose a harmonised method to calculate the most common comfort indicators.
- Develop global methods & sensitivity algorithms linking (measurement) data and (comfort / well-being) KPIs. This includes the use of AI and self-learning systems.
- Develop new approaches and services to allow for the local storage of data and local execution of data operations, and at the same time permit the blending of external data sources to increase the added value of data-driven services (involving technologies such as blockchain, edge computing, etc.).
- Develop an open source and free cybersecurity software solution for smart buildings.
- Define how to share openly and harmonise the data: how to collect data from multiple sources? how to harmonise the data from different nature?
- Reach better communication and interconnection among smart building apps and technologies so they get more efficient and easy to use.

Action 7.3 – Expand the Digital Twin Concept (aiming at TRL 6-7)

- Improve human models for thermal comfort simulations. That means an anthropometric big effort in many EU countries to have specific values for temperature and ventilation problems. Wearables can help achieve this goal.
- Explore beyond building digital twin to enable new occupancy models. Examples from industrial sectors where Digital Twins are more advanced (e.g. manufacturing) shall be leveraged to increase the flexibility of building. Digital Twins and potentially introducing an orchestrating entity managing different instances of building digital twins to enable «Building as a Service» - i.e. adapting the behaviour of a building and its interaction with the user based on the setting. This includes the further development of intuitive and self-learning (AI-based) systems.

Action 7.4 – Encourage/showcase testing of data collecting/usage (aiming at TRL 7-8)

- Review/test and select different data sharing models to demonstrate and disseminate good practices.
    - Including all value chain stakeholders and users in the building lifetime.
    - Tailored to the building typology as data and value chain differ.
- Develop Open Labs and test sites (going beyond the building scale), easily accessible to SMEs, to facilitate the validation of new products and services while encouraging the use of open standards and frameworks and the involvement of users (also embracing the community with low technical training)
- Deploy living labs (permanent pilots) giving open access to real data on building's monitoring and user perspectives.
- Implement large scale demonstrators with emphasis on the active participation of end users, from the design phase. This implies engagement strategies relying on Secure Shell Protocol (SSH), and the use of techniques such as gamification.
- Develop, contribute to and/or promote open access historical databases providing historical sensed data and user feedback, such as the ASHRAE Global Thermal Comfort Database II, which consists of thermal comfort data from subjective comfort votes and objective instrumental measurements, enabling accelerated research applications.

08

Smart building research and innovation priority n°8: Supporting mass adoption of smart building technologies

Executive summary

Smart building technologies enable energy efficiency, sufficiency, security and adaptation to climate change within and across buildings. Despite their benefits, factors such as the lack of awareness of their added value (e.g. improve building control, reduce environmental footprint, etc.)or their return on investment and the limited workforce training needed to install and manage the new technologies is hindering their mass adoption. Artificial Intelligence will be a key technology for the wider adoption of smart buildings and, for that, building trustworthy AI will create a safe and innovation-friendly environment for users, developers and deployers[32].

Rationale

Some of the main issues hindering the quick and mass adoption of smart building technologies include limited public awareness of the benefits of the technologies, limited end-user acceptance of the technologies - in particular those that require changes in users' habits; additional efforts required to learn and use these technologies; potential use of personal data; and perceive new value from its use; performance expectancy -, and insufficient contextual training of the workforce to install, deploy, operate and maintain the smart building technologies.

When showing new technologies or solutions, most vendors glorify the technology and what it can do, but do not necessarily communicate in a meaningful and understandable way to the general public as to how the adoption of the technology will actually benefit the end-user. What value will it provide as compared to existing solutions that are in use? What will be the return on investment? Is it really worth it, or is it just another one-off cost or a marked-up subscription? Users today are conscious decision makers who want to know before deciding if whatever they are procuring or subscribing to creates any added value to them and if this added value is worth investing in.

A key question worth asking is, will technological adoption drive end-user change, or will end-user values and needs drive technological adoption and use. Users demand technologies that are non-intrusive, easy to implement and use, simplify their lives, do

[32] A European approach to artificial intelligence. https://digital-strategy.ec.europa.eu/en/policies/european-approach-artificial-intelligence

not require significant lifestyle changes and provide better well-being, and create new tangible and intangible value for the end-user.

As new technologies become available, training of the workforce in the installation, deployment, operation, and maintenance of these technologies is of paramount importance. Training however, needs to be contextual and where and when needed. With rapid updates to software based solutions and connectivity to different systems and appliances, it may at times become a challenge to only have periodic training. Last, but certainly not least, there is a need for certifications in trainings.

There is a need to make use of the UTAT (Unified theory of acceptance and use of technology) model to better understand what motivates and drives users to accept and use new technologies.

Proposed key actions

Action 8.1 – R&I to support an increased end-user acceptance of smart building solutions and services (aiming at TRL 8-9)

- Perform consolidated return on experience regarding co-creation processes and valorise the outcome to the end users: what (in past projects and experience) was the actual user's influence on final design? How to show them that they have impact?
- Investigate the fast evolution of behaviours, perceptions and expectations of the next generation of users (millennial, generation Alpha) in their relation to information, communication and automation technologies.
- Develop systems to collect human feedback on comfort perception all along the occupation phases in a non-disruptive manner.
- There is a need for clear and protective (EU-based data hosting) ***data governance principles***: how can we create trust in smart solutions in buildings with respect to data privacy? European level (or at least national level) regulation demanding data collectors and data providers to ensure data security and allow for transparent access to authorised stakeholders.
- ***Standardise user interfaces*** for all providers of smart building solutions and APIs to allow multiple solutions/services to be connected and visualised in a user specific dashboard/interface, building on the work of the DIGIPLACE project.

Action 8.2 – Showcase smart building innovations and their impacts (aiming at TRL 8-9)

- Demonstrate and showcase new smart building technologies and solutions in an easy to understand and comprehend form - e.g. through videos, animations, showcasing during events for the general public
- Identify and share value to user of new smart building technologies highlighting what benefits users will gain from adoption of the technology, it's ease of use, value to end-users, value to the environment, and how it will support users in reducing their building's energy and operational costs

Action 8.3 – User acceptance and early adoption (aiming at TRL 7-8)

- Actively engage users in the living labs and large scale demonstrations - from design, to implementation, and use of the solutions
- Update the solutions based on user feedback and co-create new use cases where relevant
- Make solutions adaptable to specific need and usage patterns, replicable, and scalable for different end-users

Action 8.4 – Training on the fly - contextual learning and upskilling for the workforce (aiming at TRL 6-7)

- Make use of digital learning and training tools to train smart building technology implementation workforce, and demonstrate in practice with real-cases

- Provide on demand, contextual learning solutions to the workforce - e.g. maintenance support through augmented reality solutions, hands-on video training, live access to manuals, on-site training with innovative approaches, etc.
- Provide on-demand certification to the workforce and check certifications before the workers can start installing, deploying, operating or maintaining solutions - one solution maybe to have a smart skills passport (digital) that shows the certifications a worker has and only allows them to perform a certain task if they are qualified and trained to do so.

09

Smart building research and innovation priority n°9: Data privacy and cybersecurity in smart buildings

Executive summary

Data privacy and cybersecurity in smart buildings are key topics given the increasing deployment of IoT devices in buildings, and their associated risks[33]. Priority 9 (a) explores the current state of the art in relation to data privacy and cybersecurity in smart buildings, (b) makes suggestions for key actions, and (c) considers potential outcomes and impacts.

Rationale

Smart Buildings rely on standardised and open technologies, often communicating through wired or wireless networks using a wide range of protocols. Some of these protocols are common and shared with other information and communication technologies, as well as Cyber Physical systems (CPS). Conversely, Smart Buildings rely also on specific communication protocols, including BACNet, KNX, ZigBee, EnOcean, and Z-Wave (Ciholas et al., 2019). Furthermore, risks are exacerbated by the fact that Smart Buildings can also rely on Internet-based communication to provide facility managers and users remote maintenance and control capabilities (Praus and Kastner, 2014). Besides technological details, commercial and office buildings tend to host several organisations.
As a consequence, Smart Buildings tend to be more exposed to regular IT networks than other CPS such as Industrial Control Systems, where the engineers in charge of the manufacturing system network have a better overview of the interconnections and may have more options to segregate networks using specific cabling, firewalls, VLAN, air gaps, and other isolation solutions (Ciholas et al., 2019). Even in cases where a smart building involves one organisation responsible for the entire facility, the building tends to fall out of the regular network security assessments and plans.

Cybersecurity is based on many standards such as ISO 27002:2013, Federal Information Processing Standard (FIPS) 201, Advanced Encryption Standard (AES) (Technology, 2017), and Triple Data Encryption Algorithm (3DES) that provide lower costs while ensuring high levels of security and performance (Alshammari et al., 2020). More specifically with regard to cybersecurity, and as pointed out by the EU projects

[33] "The strategy for data focuses on putting people first in developing technology, and defending and promoting European values and rights in the digital world". https://digital-strategy.ec.europa.eu/en/policies/strategy-data

CyberSec4Europe and Eratosthenes, there is an increasing interest to establish a general basis for European security certification and labelling led by ENISA through the cybersecurity act (CSA). The CSA emphasises the need for security approaches addressing the lifecycle of any ICT product, service or process for the definition of a cybersecurity certification framework. Therefore, agile self-assessment schemes and test automation environments should be created and evolved to ensure products have a minimum-security level appropriate for a context where they are used.

Although there currently are many well-known cybersecurity standards, some of the challenges are not addressed, and the fragmentation between them makes the homogenization and comparison between products certified difficult. They also use subjective metrics and none of them addresses the challenges related with the dynamism of security, involving a completely heavy recertification in case there is a security change. They also use subjective metrics and none of them addresses the challenges related with the dynamism of security, involving a completely heavy recertification in case there is a security change.
The ETSI approach only gives some high-level guidelines and ARMOUR focuses mainly on the evaluation process, so further connection among the evaluation process and the life cycle changes is still required. One of the most common examples of IoT includes technologies and applications intended to support the deployment of 'smart home' systems and devices. Common threats include: Hackers, Data breach / identity theft, Man-in-the-Middle, Distributed Denial of Service (DDoS), Permanent Denial of Service (PDoS).

The most common causes of cyber-related vulnerabilities generally fall into one of the following five areas: poor product design, non-secure communication protocols, inadequate authentication procedures, limited software updating/patching, improper implementation or device/application use: ENISA developed guidance to secure smart infrastructures from cyber threats, by highlighting good security practices and proposing recommendations to operators, manufacturers and decision makers. ENISA listed more than 80 good practices for IoT and identified the following gaps: fragmentation in existing security approaches and regulations, lack of awareness and knowledge, insecure design and/or development, lack of interoperability across different IoT devices, platforms and frameworks, lack of economic incentives to implement secure design and programming, lack of proper product lifecycle management "Data is the new gold".

According to Deloitte (2018), technology and data companies have already shown a keen interest in building systems automation for newly-constructed and existing buildings. To ensure trust in data sharing and in line with GDPR, the roles of data processors and data controllers need to be clearly assigned. However, how end-users can concretely remain in control of their data remains unclear, with no clear data governance

framework. The (fine) distinction between personal data and non-personal data is also important: regulation 2018/1807 indeed considers that any information not linked to an identified or identifiable individual becomes non-personal.
The Authorized Public Purpose Access (APPA) approval process, proposed by the World Economic Forum (WEF) in 2021, brings interesting insights. Data has become an essential component of tomorrow's business foundation, and those who can use this data in a profitable way to provide new services will be well-positioned for future success.

But, quoting Deloitte, benefiting from it will require settling the question of who controls the data. The projects FLEXcoop and HOLISDER jointly highlighted the challenges related to 'walled garden' approaches, i.e. equipment manufacturers offering data services in a vertically integrated cloud solution, with user data and equipment control being then fully captive to the manufacturer's solution. This lack of interoperability with other solutions prevents the development of new data-driven services, such as flexibility. That is where semantic based approaches will be pivotal in the future (see PRIO1 and PRIO2). Semantic interoperability builds on top of existing manufacturers' cloud solutions (including their security mechanisms) without changing them, but rather using standardised ontologies as common vocabularies to make them interoperable with others - for the data they decide to share, for example to enable energy flexibility via a third party Energy Management Service (EMS) - still preserving their competitive advantage (for the data they decide to keep into their solution). An essential requirement for this to succeed is that specific vertical (manufacturers') solutions should expose open APIs to enable (part of) their data to be mapped to the ontology of choice (e.g., H2020 InterConnect project service adaptors). A change of paradigm, from vertically integrated and centralised cloud solutions, fully captive, towards locally stored data (thanks to e.g., edge computing) managed by a third trust party is needed towards this new way of collaboration for creating innovative data-driven services.

Proposed key actions

Action 9.1 – Development of regulatory frameworks & legislations and certifications (aiming at TRL 4-6)

- Address the lack of common and agreed upon trust models and liability frameworks. Certification labelling not globally accepted.
- Set up a strategic data flexibility framework, which clearly states data rights and requirements for data quality and integrity and defines the role of trusted third party as warrant of cybersecurity and data privacy.
- Make available comprehensive, recognised and easy-to-use open standards: easily reusable, with clear compliance requirements, including minimal requirements for security & privacy by design, with easily implementable guidelines, coordinated with other domains (e.g., openBIM) and involving all actors of the value chain.

Action 9.2 – Develop models and methodologies to strengthen the value chain (aiming at TRL 6-9)

- Address the lack of trust from end-users (related to data security, privacy, risk of being hacked, etc.)
- Build new methodologies to develop easy-to-use open standards and ensure they get recognised and adopted by the different stakeholders.
- Review/test and select different data sharing models to demonstrate and disseminate good practices (with whole value chain approach and according to building typology).
- Develop governance models to ensure structured access to data and information based on the user's roles and responsibilities.

10

Smart building research and innovation priority n°10: R&I to support policy developments

Executive summary

Research and legislative adjustments are needed to support the improvement of regulatory and financial tools favouring building smartness as a key factor of building performance. New market design and regulatory options should be explored for smart buildings to provide flexibility services to the electricity grid. Existing certification schemes related to smartness and building performances should be adjusted towards more convergence and simplicity. New dimensions need to be integrated into regulation, such as co-design with users, interoperability, or data security and sharing.

Rationale

Buildings' performance levels and their monitoring across Europe are implemented today by national certification and information-sharing schemes. In 2002, the EU Directive on the energy performance of buildings (EPBD) introduced the **Energy Performance Certificates** (EPCs) as an indicator of the energy performance of buildings. The following recasts of the Directive detailed and strengthened the procedure, and EPCs became together with minimum energy performance requirements a major policy instrument in the strategy to improve energy efficiency in buildings.

The 2018 revision of the EPBD introduced the **smart readiness indicator** (SRI), as an assessment scheme to raise awareness about the benefits of smart building technologies. An SRI rating scheme and calculation methodology were designed and are currently being tested in some volunteering Members States (Austria, Czech Republic, Denmark, France, Finland and Croatia).

In 2021, the EC adopted a proposal to further revise the EPBD, as part of the 'Fit for 55' legislation package. The proposal includes various smart buildings related suggestions, such as the development of a framework for **Renovation passports** that would help owners planning a staged renovation of the building; the implementation of a common scheme for rating the smart readiness of non-residential buildings above 290 kW, and the setup of **integrated and interoperable national databases on building energy performance**, using the data gathered through the above-mentioned tools (EPCs, renovation passport, SRI). Are also mentioned, the requirements for **continuous electronic monitoring** (including indoor air quality monitoring) and **effective control functionalities** for new and/or renovated buildings.

While some targeted regulatory instruments that are already developed have clear benefits, some aspects are yet not or hardly addressed:

- The energy flexibility potential of buildings is not fully exploited due to a lack of clear regulatory and contractual frameworks enhancing innovation.
- The EPC and SRI tools provide so far static indicators of building performances and need to evolve towards a more dynamic assessment. Convergence efforts are also needed between the different schemes to enable a simple and pragmatic implementation.
- There is still a lack of evidence on the economic benefits of the EPC and SRI instruments for building owners.
- Some technical or social aspects are not yet integrated to regulation (or not implemented by Member States yet),
    - requirements to co-design solutions with users,
    - interoperability,
    - data sharing, …

Additional research is necessary to support policy makers adapting existing and creating new EU and national policies, enabling the uptake of more innovative policies.

Proposed key actions

Action 10.1 – Investigate new market design and regulatory options for smart buildings to provide flexibility services to the electricity grid

- Set up regulatory sandboxes to test new concepts, business models and regulatory options, including certification schemes, enabling power flexibility services by smart buildings, or related new market actors (e.g. flexibility aggregators). This should also cover demonstrations of energy communities.
- Develop standardised contract models for smart energy services, including the clear descriptions of roles, responsibilities and rewards of prosumers, and linked with national standards.
- Investigate how to harmonise the implementation of the EU regulation on electricity markets at national levels, with regards to the definition and set up of energy communities.

Action 10.2 – Develop and test potential synergies to improve and simplify existing certification schemes related to smartness and building performances

- Explore how to make building performance certification (including but not limited to energy) evolve from a static to a dynamic indicator, including real time control, procedures, and relevant data feed to end-users. This also includes the definition of standards for real time rating (sampling rate, units, sensors…).

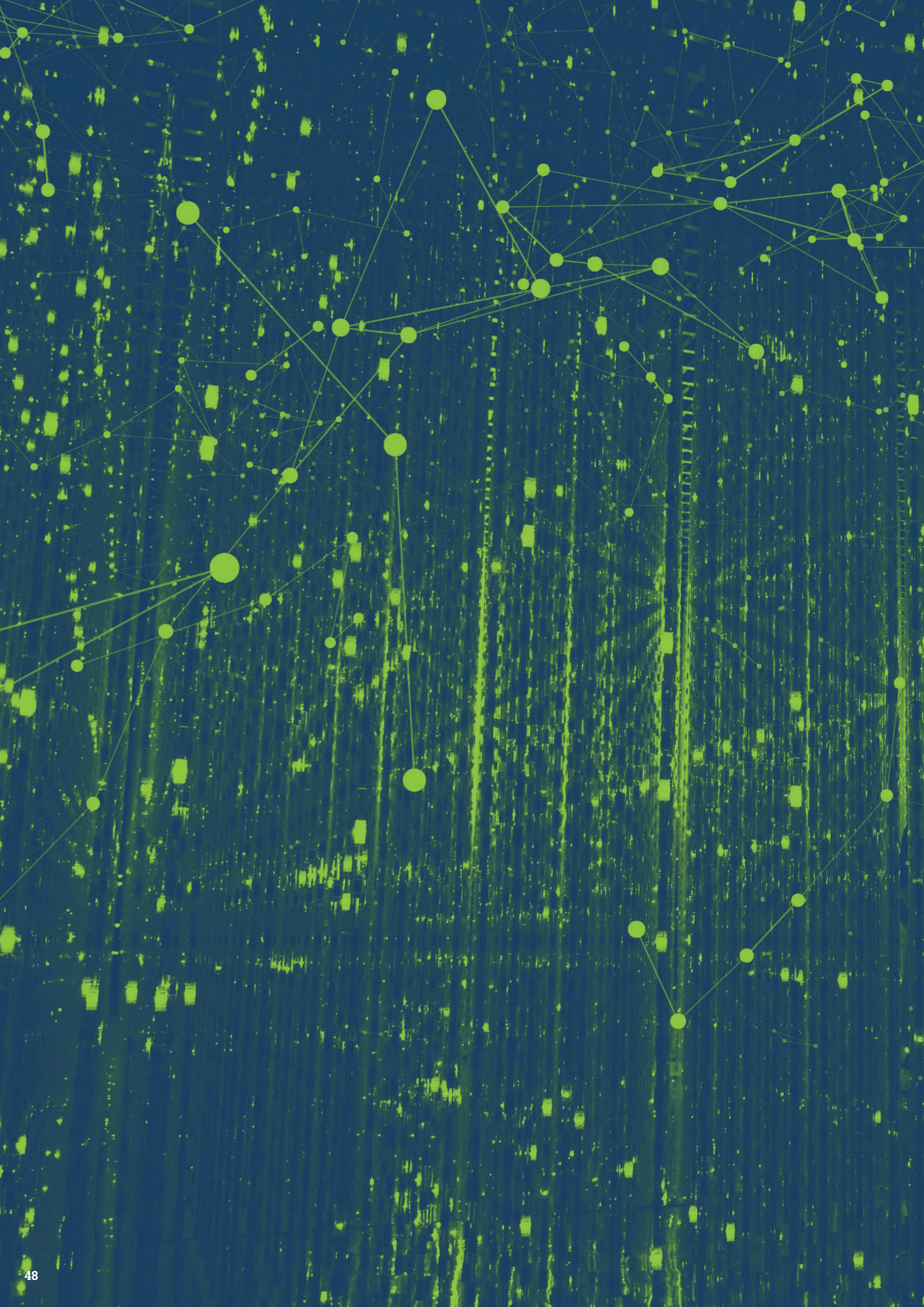
- Test the feasibility and ease-of-use of integrating smart readiness indicator and interoperability requirements with the EPC framework, Digital Building Logbook and Building Renovation Passport, as suggested in the proposal for the revision of the EPBD .
- Develop and test a harmonised European approach to calculate the smart readiness indicator. This implies that SRI pilot projects be conducted in every Member State (at least one public building per MS).
- Further investigate the complementarity of public regulation instruments (e.g. SRI) and private certification schemes (e.g. R2S) to strengthen the market value of smart buildings.

Action 10.3 – Showcase examples on successful financial and administrative incentives that can speed up the deployment of smart buildings

- Build evidence on the sustainability of building smartness in relation to the EU Taxonomy, based on data from smart building systems, in order to trigger investments in smart buildings.
- Analyse successful financial and administrative incentives at local/national levels related to the smartening of buildings (in view of energy efficiency, indoor environment quality, etc) so as to propose scaling up and replication plan in all EU countries.
- Develop new public procurement procedures including dedicated 'smart lots' as well as pre-commercial procurement with performance targets.
- Test financial instruments directed towards private building owners (both residential and non-residential) and supporting the multiplication of smart home equipments and devices also in cases where deep renovation is not an option.

Action 10.4 – Design principles and rules for improved regulation

- Design/harmonise principles for a regulatory framework on data access and data sharing in buildings and districts (see also prio 1), considering in particular data security, privacy and consent, in line with the new Data Governance Act and the strategy for common European Data Spaces.
- Provide R&I evidence of its benefits to support the enforcement of open standards through regulation.
- Propose updates to the existing building regulations (including the upcoming EPBD recast) in view of integrating some minimum levels of interoperability and smartness, with a minimum set of parameters to be measured to monitor building performance (not limited to IAQ as mentioned in the EPBD recast, i.e. also energy efficiency for instance).
- Explore how to integrate the user-centric dimension into regulation, i.e., the participation of users from the design phase and along the whole (smart) building life cycle.



03

Outcomes and EU initiatives

3.1
Ranking priorities by expected outcomes

This SRIA has presented over 40 key actions for the ten priorities, and several of them cover similar aspects of smart buildings. For the elaboration of this SRIA, experts from the consortium and expert board assigned and evaluated each priority for their expected outcomes and impacts, assigning values ranging from 0 to 3. This score scale ranged from 0 that equals to not significant contribution to the highest value of 3 that means high contribution for the expected outcomes and impacts resulting from the following:

- Reduced uncertainties and risks in developing smart buildings products and services
- Accelerated technological development process (reaching higher TRL levels faster)
- Reducing time to market, bridge the valley of death from technological development to market uptake
- New opportunities for EU businesses, including SMEs
- Demonstrated improved performance, feasibility, and reliability of smart building products and services
- Data availability and open data exchange amongst stakeholders
- Knowledge sharing and collaboration between industry and academia/RTOs
- Improved public understanding of the added value of smart buildings
- Improved regulation on EU and national/regional level
- Lower energy use and lower environmental impacts in the built environment
- Reducing risks and improving trust with investors
- Opportunities for high quality jobs in EU MS
- Improving integration of buildings in the (local) energy grid
- Increasing data-privacy and reducing cybersecurity risks
- New cost-effective solutions for improving the existing building stock
- Better buildings for inhabitants / users (health, comfort, wellbeing, reduced energy costs,...)

These 16 elements were selected from the discussions and the White Papers prepared by the Task Forces in the project. As displayed in the Table 1, the priorities have been listed from a higher impact of these elements to the lowest impact value (descendant order). *PRIO 9 Data privacy and cybersecurity in smart buildings* and *PRIO2 Smart buildings, energy flexibility and external environment* are considered the priorities with a broader scope and outcomes for the 16 selected impacts. The five most relevant impacts triggered from the ten priorities are:

- *Better buildings for inhabitants and users*
- *Demonstrate improved performance, feasibility, and reliability of smart building products and services*
- *Data availability and open data exchange amongst stakeholders*
- *Accelerate the technological development process (reaching higher TRL levels faster)*
- *New opportunities for EU businesses, including SMEs*

Table 1. Priorities listed by expected outcomes and impacts

3.2
Funding and eu initiatives

Relevant EU initiatives

To further elaborate on the actions identified for the different priorities, alignment with ongoing EU initiatives needs to be explored. The most important ones related to research and innovation and market uptake are briefly introduced below.

Horizon Europe

Horizon Europe is the EU's key funding programme for research and innovation with a budget of €95.5 billion. It tackles climate change, helps to achieve the UN's Sustainable Development Goals and boosts the EU's competitiveness and growth. The programme facilitates collaboration and strengthens the impact of research and innovation in developing, supporting and implementing EU policies while tackling global challenges. It supports creating and better dispersing of excellent knowledge and technologies[34].

Funding opportunities under Horizon Europe are set out in work programmes. Relevant components of the Work programme 2023-2024 are amongst others 'climate, energy and mobility', and 'widening participation and spreading excellence, and reforming and enhancing the European R&I system'. The work programme for 2023-2024 focusses on security, resilience and a sustainable recovery following the COVID-19 pandemic and places a special emphasis on actions that contribute to a safe and secure Europe, reducing energy dependencies, in light of the ongoing military invasion of Ukraine. A minimum of 35% of the funding is available to climate objective supporting the commitment to make the EU the world's first climate-neutral continent by 2050[35].

Furthermore within the Horizon Europe Programme, five missions are identified that have measurable goals related to them, aiming for concrete results by 2030. The missions support the Commission priorities such as the European Green Deal and the New European Bauhaus[36]. Specific for Smart Buildings, the mission on Climate neutral and Smart Cities is most relevant. Within this mission three new calls are foreseen to achieve the goals set under the mission that will cover a wide range of subjects,

[34] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en
[35] https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2023-2024/wp-1-general-introduction_horizon-2023-2024_en.pdf
[36] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe_en
[37] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en

including positive clean energy districts[37], to which smart buildings can contribute.

The Horizon Europe programme is often subject of a public consultation which gives the opportunity to give feedback on the ongoing and previous (e.g., Horizon 2020) programmes and shape the R&I priorities for upcoming calls.

LIFE calls

The LIFE Programme is the EU's funding instrument for the environment and climate action, under support of CINEA, the European Climate Infrastructure and Environment Executive Agency. CINEA's mission is to support stakeholders in delivering the European Green Deal through high-quality programme management[38]. Within the LIFE Programme regular calls are organised, with different types of grants possible. The LIFE Programme for 2021-2027 consists of four main pillars: 'Nature and Biodiversity', 'Circular Economy and Quality of Life', 'Climate Change Mitigation and Adaptation' and 'Clean Energy Transition'. Within the sub-programme on Clean Energy Transition the focus is on contributing to creating market and regulatory enabling conditions in the EU territories for the energy transition through a building policy and regulatory framework, rolling out technology, services and business models, attracting private finance, mobilising local and regional investments and engaging and empowering consumers[39].

EIT accelerator

The European Institute of Innovation & Technology (EIT) is an independent body of the European Union set up in 2008 to deliver innovation across Europe. The EIT brings together leading business, education and research organisations to form dynamic cross-border partnerships. These are called Innovation Communities and each is dedicated to finding solutions to a specific global challenge. EIT Innovation Communities develop innovative products and services, start new companies, and train a new generation of entrepreneurs[40].

Within specific communities, accelerators can be set up, that consist of thematic EU-funded programmes implemented through partners and have a specific focus on start-ups to take them to the next level.

[38] https://cinea.ec.europa.eu/index_en
[39] https://cinea.ec.europa.eu/system/files/2022-05/EU%20Info%20Days%202022_Intro%20LIFE%20Call%202022_AB-CS-final.pdf
[40] https://eit.europa.eu/

Priorities linked to EU initiatives

During an interactive call with members of the consortium and the expert board, a poll was held to define which initiative they thought was most relevant for each priority introduced in this SRIA. Besides the EU initiatives introduced in the previous paragraph, also EU tenders and national and private funding were considered relevant for some priorities and suggested as potential funding option to the consortium and the expert board. The option Other was also offered to indicate other funding options, but this was not indicated for any of the priorities.

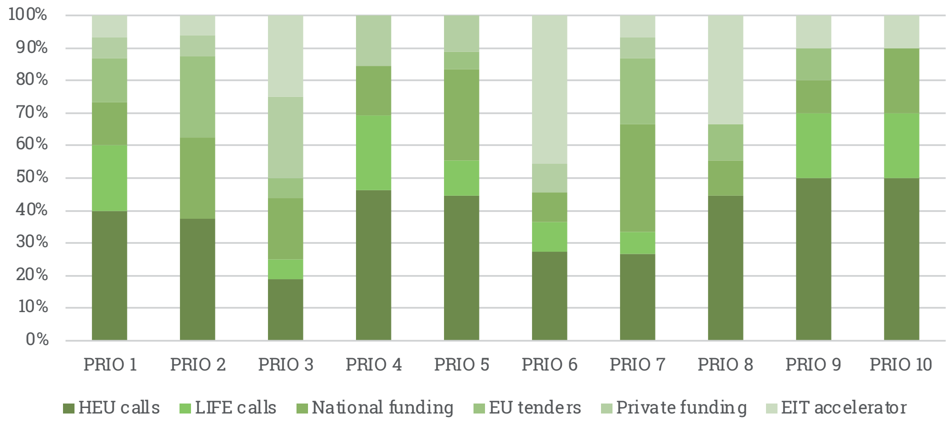


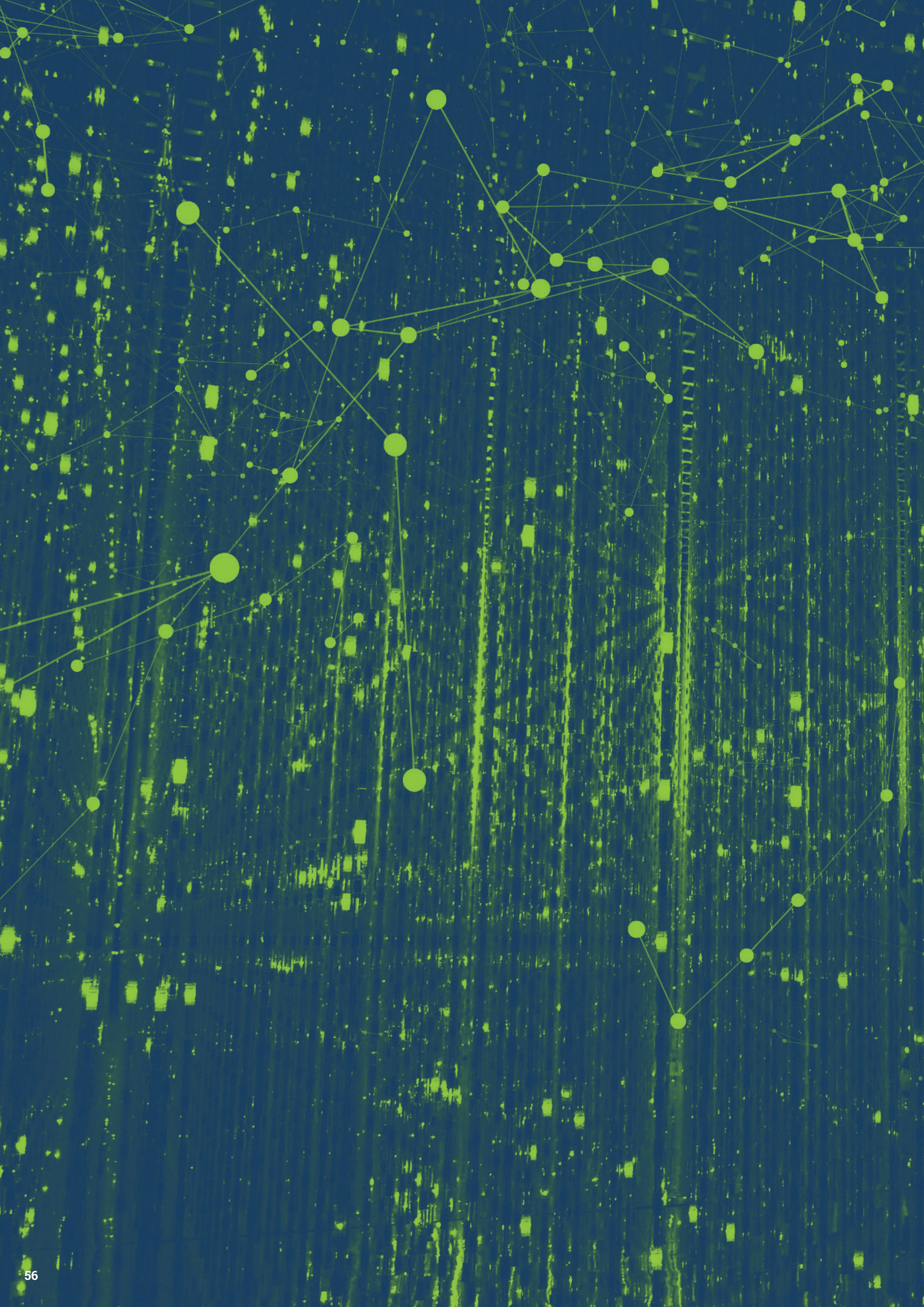
Figure 1: Potential linkages of priorities with EU initiatives

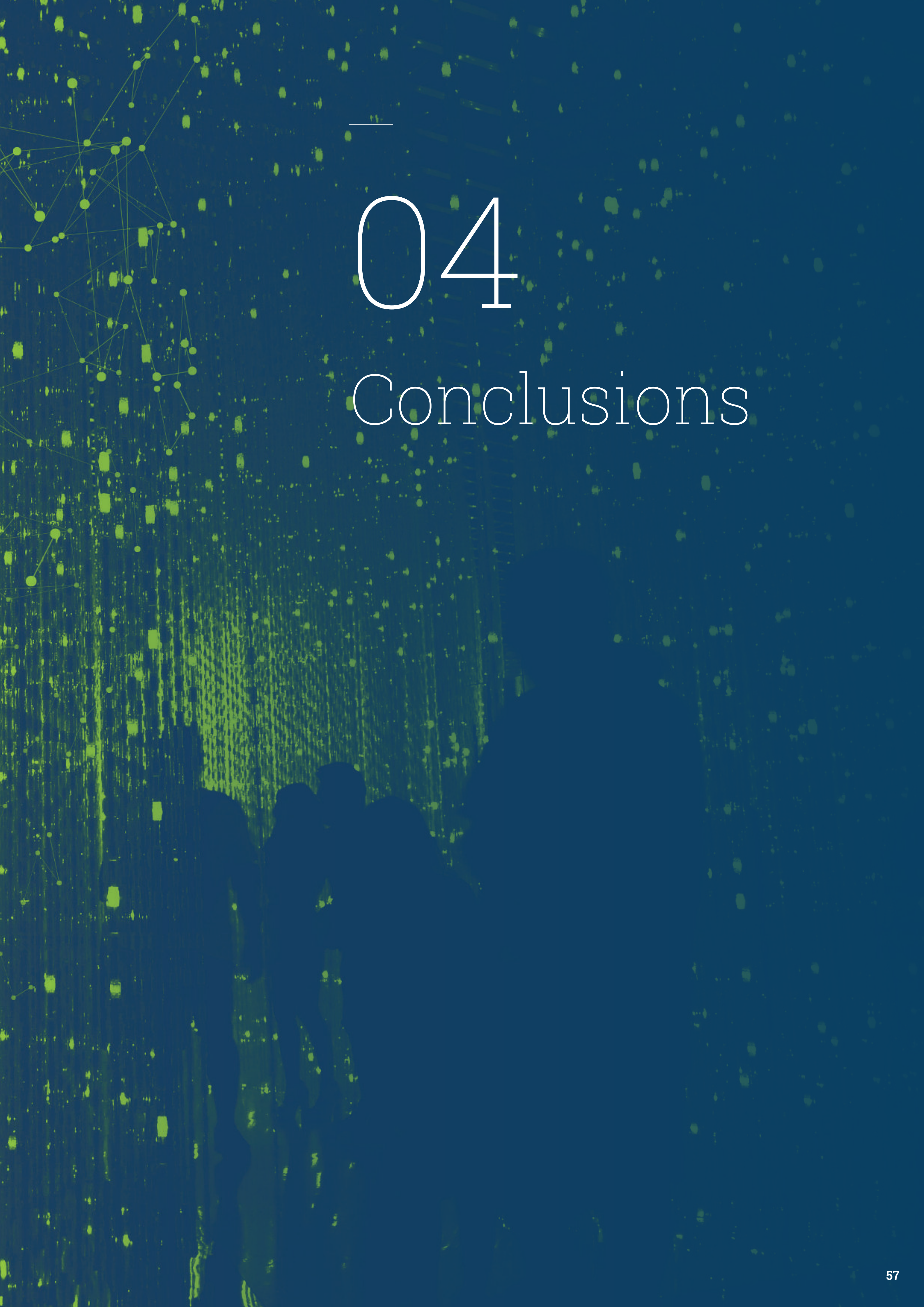
As shown in Figure 1, Horizon Europe is deemed an appropriate initiative to further elaborate for all priorities discussed in this strategic research and innovation agenda. Also LIFE calls and national funding are applicable to all priorities according to these poll results, although to a smaller extent than the Horizon Europe programme. National funding is deemed most relevant for making better use of the data for a data driven performance assessment (Prio 7).

EIT acceleration is considered interesting for eight out of ten priorities, not for endorsing testing facilities and their benchmarking (Prio 4) nor for better understanding of co-benefits (Prio 5). It is deemed most useful for advances in products, services and decision support methods to improve life cycle environmental impacts of smart buildings (Prio 6), supporting mass adoption of smart building technologies (Prio 8) and innovation in products and related business models for smart buildings (Prio 3).

EU tendering can be expected to be relevant for the priorities with already highest TRL. The poll indicated here that Prio 2 on smart buildings, energy flexibility and external environment, and Prio 7 on making better use of the data for a data driven performance assessment are most likely to be allegeable for such EU tendered research projects.

Private funding is, just like EIT acceleration, not indicated for priorities 4 (testing facilities) and 5 (co-benefits). For other projects, the poll participants see a rather limited role for such private funding, besides for prio 3 on innovation in products and related business models, which can be considered closely link to industry and thus explain the link with private funding shown in the poll.





04

Conclusions

Conclusions

The term 'smart' is often linked to data, so it is not surprising that many of the actions identified for the priorities also concern data. However, several aspects are involved. There is the aspect of gaining more and better data, which could be done by setting up tests, e.g., living labs, sandboxes, … but also by using data that is already out there, e.g., collected by building occupants' smartphones, or setting up digital twins. Testing facilities could focus on different scales, technologies of different TRL's and look into strategy, benchmarks and protocols.
Besides looking into creation and usage of data, they could also contribute to testing regulations and policies, innovative product development and help contribute to user acceptance.

To make better use of the available data, we need to look into multi-purpose use of it. Furthermore, a unified harmonized standard is needed to combine multiple data sources. This is not only necessary within the building itself, but across several buildings, to contribute to grid flexibility for example, which is highly required with the increase of renewable energy sources within the electricity system. Already several standards are in place, but 'unified' is the keyword here. With standardization, focus should be on ontology to address interoperability at the semantic level.

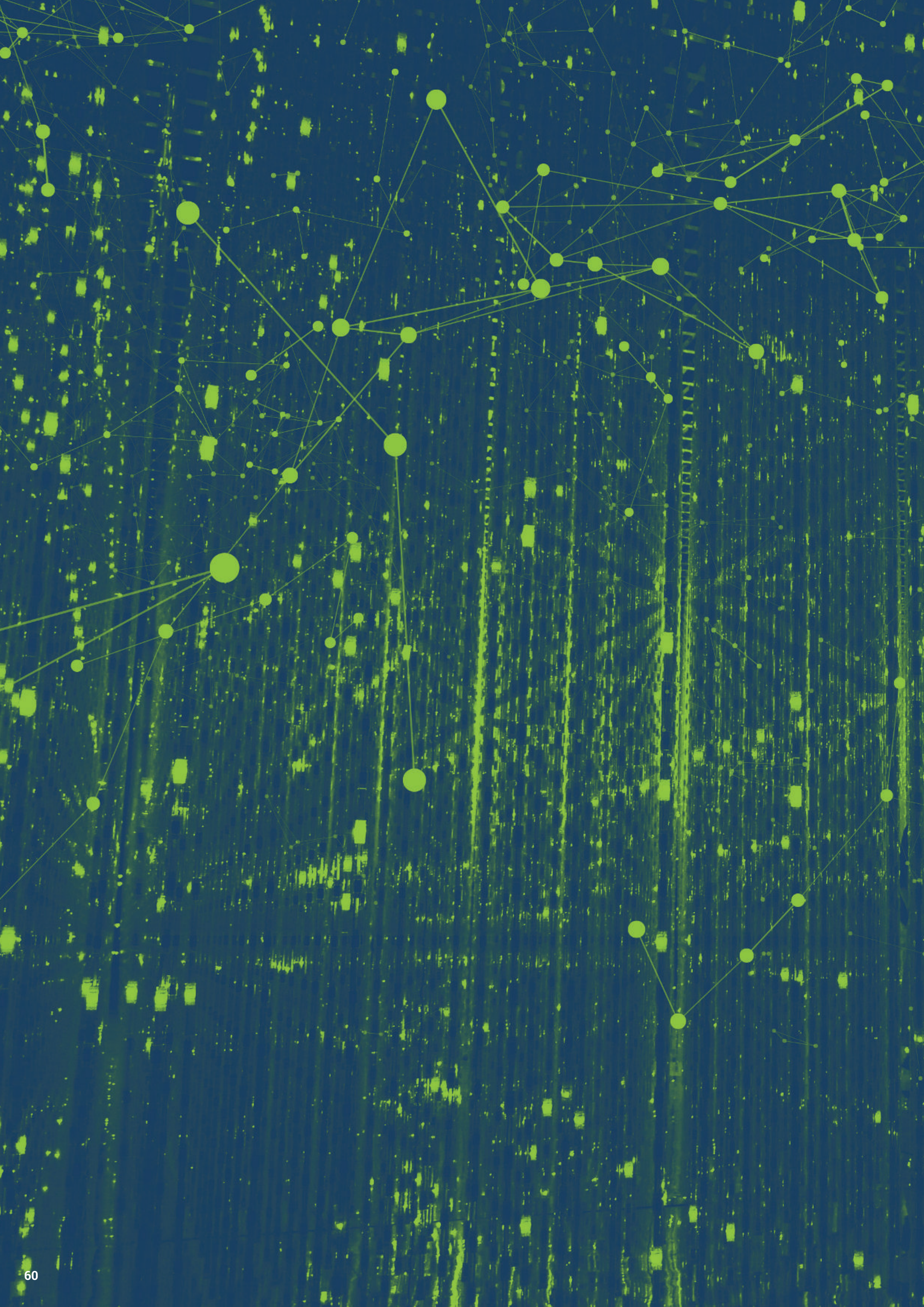
As many data are involved, also data privacy and cyber security remain important attention points.

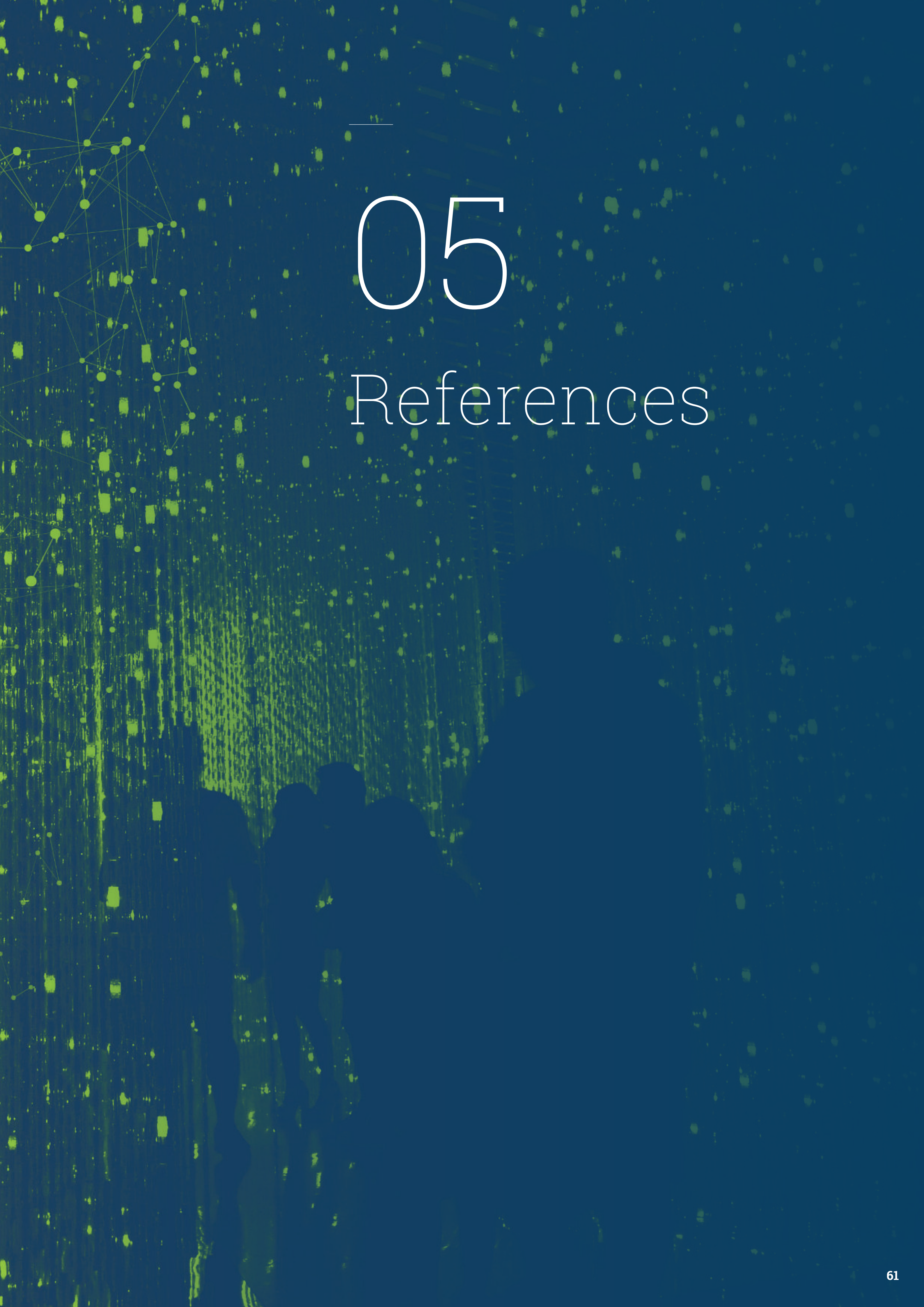
To ensure user acceptance, and thus increase the changes of mass adaption, more public awareness needs to be created. This could be done by sharing the outcomes of the testing facilities, but also make sure to emphasize the co-benefits for the building users. These co-benefits are already included and quantified in the Smart Readiness Indicator, but could be showcased more, for example through citizen labs. Business models should also emphasize the benefits of smart buildings for the end users, e.g. remuneration of the grid flexibility.

Integrating an occupant-central aspect into smart building research, contributes to a more holistic approach. To this, also life cycle assessments contribute, with the aim to limit the total impact of a smart building.

Besides user-centric actions, also sufficient focus should be on the workforce needed to install the smart appliances in the buildings. Sufficient qualified installers need to be available, which involves first and foremost convincing them of the added values of building smartness and furthermore providing on the fly training.

As shown by the priorities selected for this Strategic Research and Innovation Agenda, and the actions related to them, further research is required to strengthen smartness within the built environment. Several existing EU initiatives can contribute to that, together with other ways of funding, e.g., national or private. By enhancing the market penetration of smart buildings, this can contribute to reaching the climate goals and become more energy independent.





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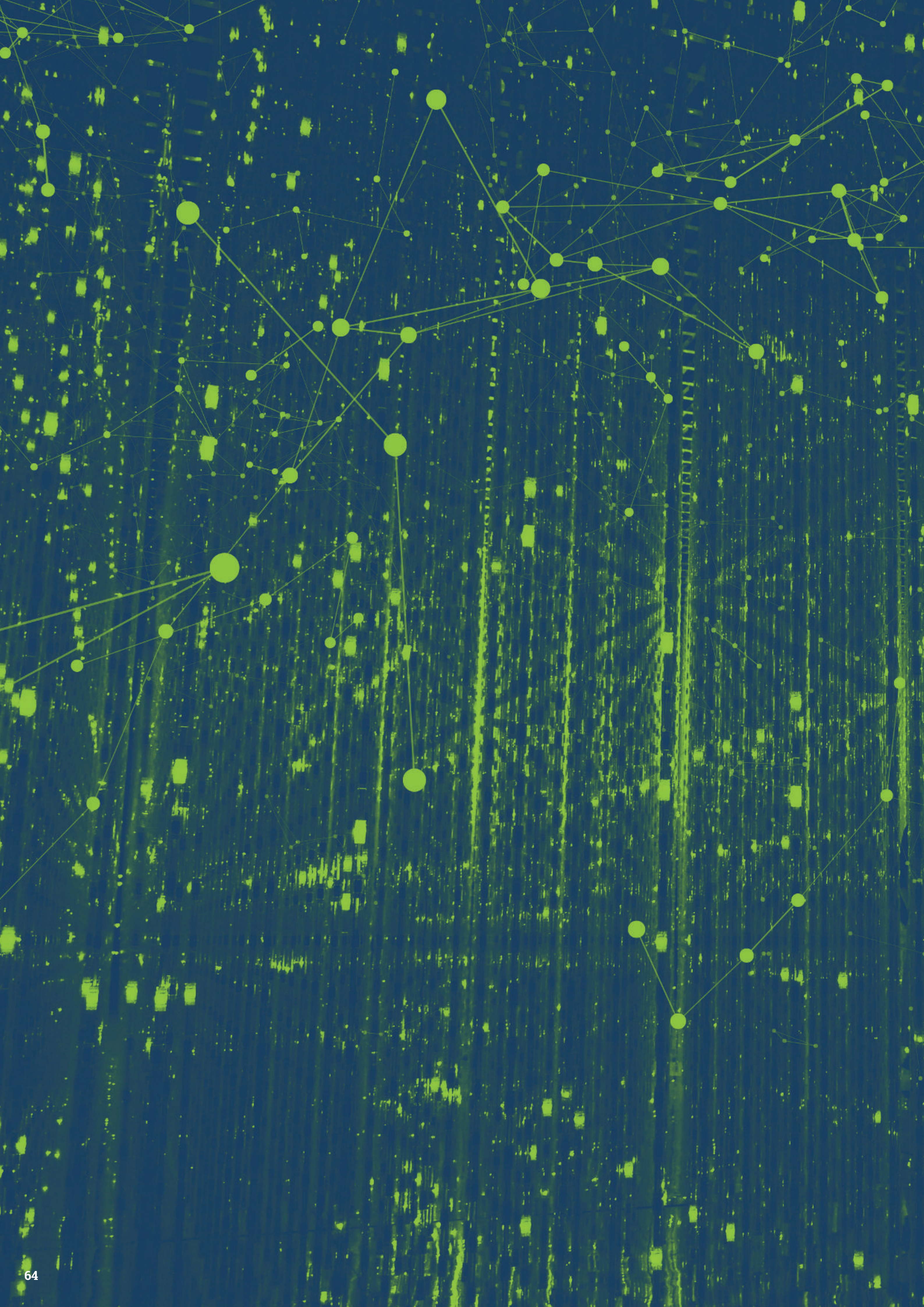

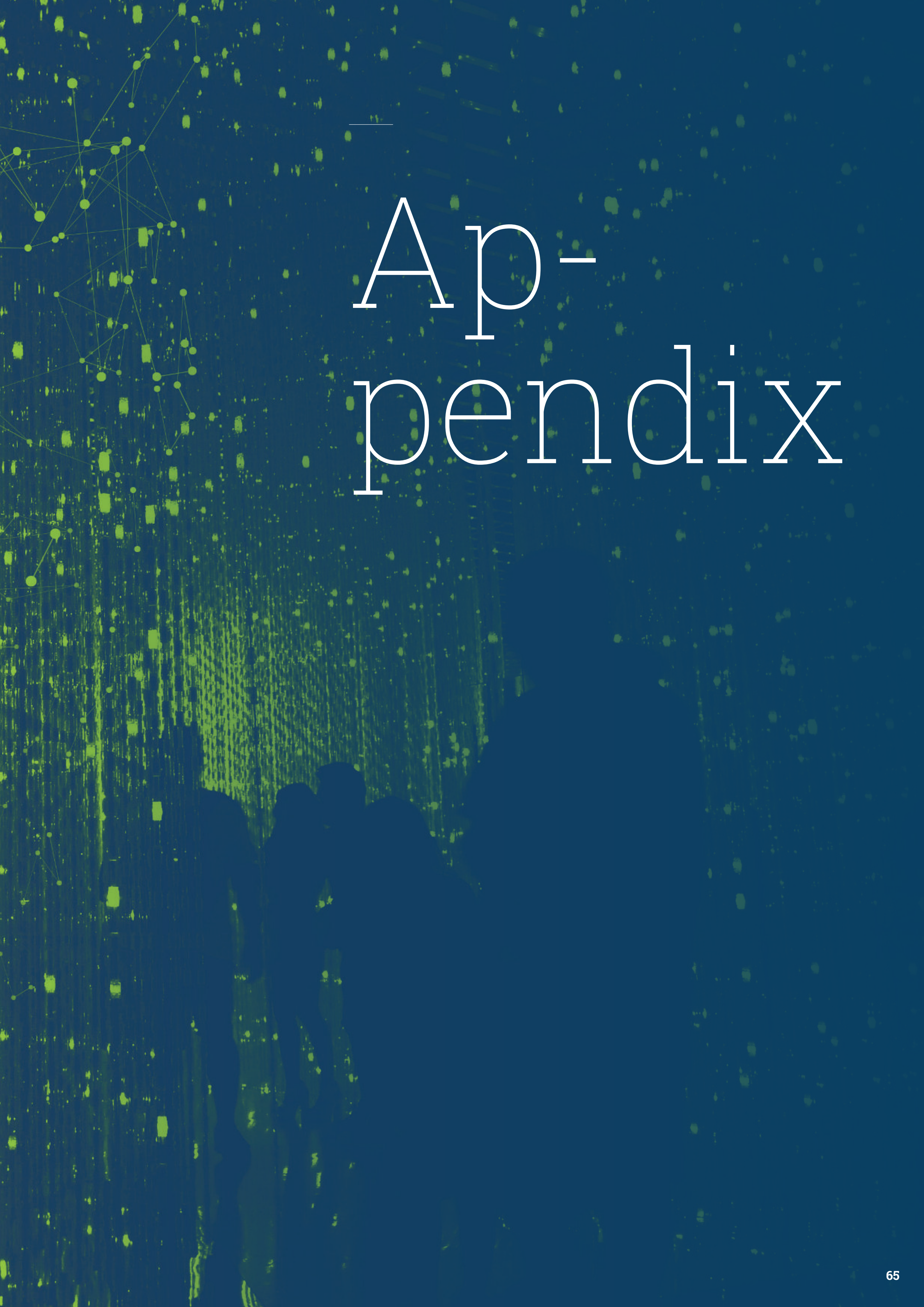

Ap-pendix

Appendix A
Ten key R&I priorities and their possible audiences

R&I PRIORITY

PRIO1
Standardisation for interoperable products and services in a building: develop unified ontologies, semantics, and interoperability standards

PRIO2
Standards and business models for connecting smart buildings to the external environment: data exchange between multiple buildings and with energy grids, assessment methods and standardised protocols for energy flexibility

PRIO 3
Innovation in products and related business models for smart buildings. E.g. servitisation (comfort-as-a-service), adaptable and expandable automation and control systems, common marketplaces for smart solutions, upgrading legacy equipment, energy performance contracting with performance guarantees

PRIO4
Testing facilities, benchmarking and living labs for integrated analysis and demonstration of smart buildings: develop proper benchmarking, common case studies (real buildings and their digital twins), common datasets, regulatory sandboxes, advanced testing facilities and standardised testing protocols to support research and market validation

PRIO5
Better understanding of co-benefits (health, comfort, well-being, productivity increase,...) and empowering the users of smart buildings: common KPIs, evaluation methods, benchmarks, datasets, user-centric design methods...

PRIO6
Advances in products and services to improve life cycle environmental impacts of smart buildings (repairability, circularity, dismantling and upcycling of components, lower resource consumption, reduce energy consumption of sensors and actuators, electronic waste management,...)

PRIO7
Making better use of the data: Data-driven performance assessment, digital twins for optimisation of operation and fault-detection of smart buildings, continuous commissioning, data-driven design methods

PRIO8
R&I for supporting increased public awareness, end-user acceptance and training of workforce to support mass adoption of smart building technologies

PRIO9
Data privacy and cybersecurity in smart buildings: improving new and legacy equipment, monitoring performance, towards certification of individual products and integrated systems

PRIO10
R&I to support policy developments: Improve regulations (EU and national) and policy initiatives (logbook, SRI, green public procurement for smart buildings, ...) on smart buildings

POSSIBLE AUDIENCES

	building owners	building occupants	facility managers	architects	engineers	local policy actors	national/EU policy actors	contractors	manufacturers	standardisation bodies	Academia / research	training and education
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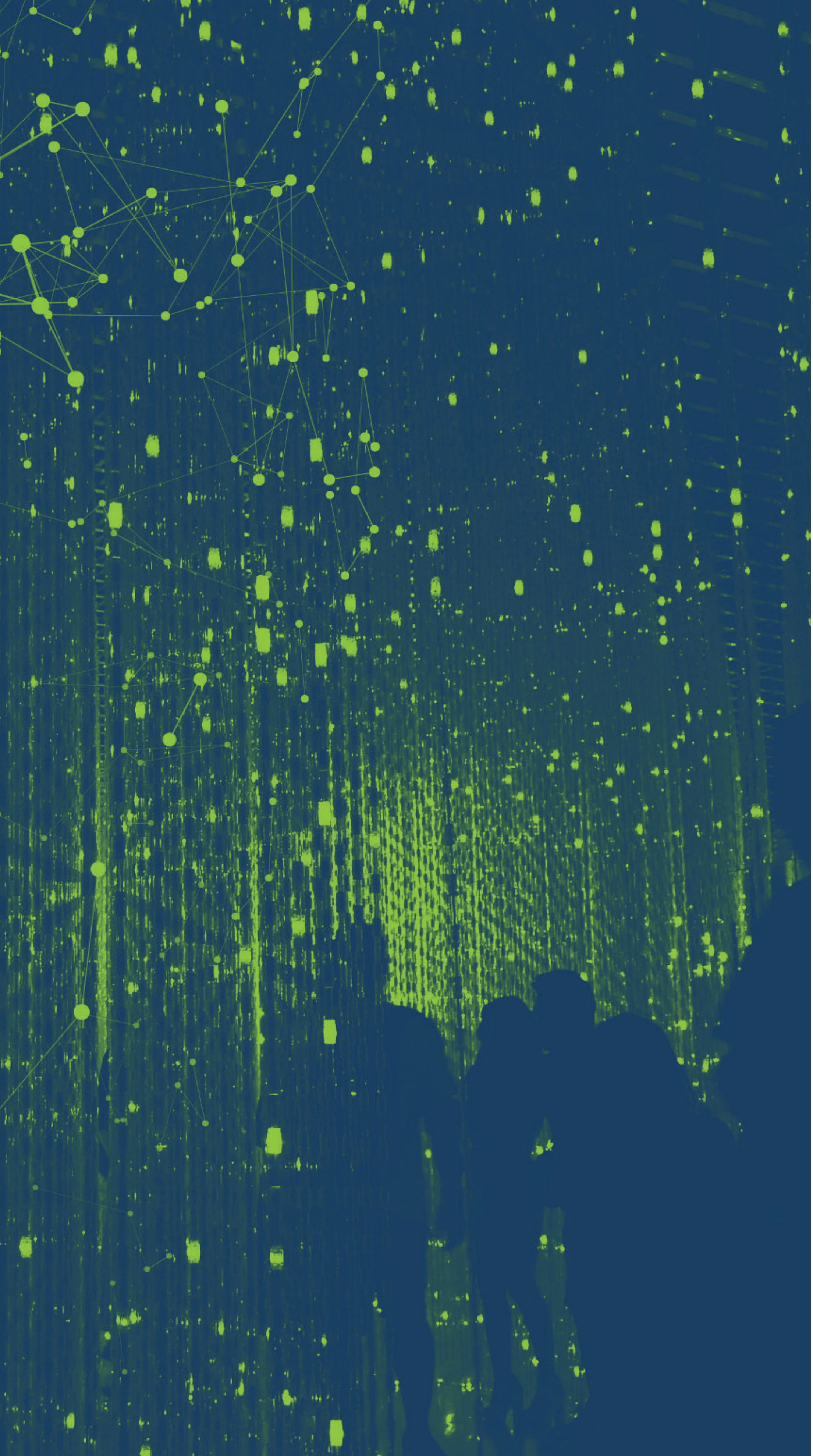

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