



RESILIENCE ENGINEERING ASSOCIATION

Resilience Engineering 20 years

Progress, challenges and opportunities -
Notes from Porto meeting

14th – 16th October 2024 Porto
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This report is dedicated to Richard Cook and Robert L. Wears, whose contributions to the advancement of Resilience Engineering theory and practice and their encouragement of young talents, are gratefully acknowledged.

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Abstract: In 2024, the Resilience Engineering Association (REA) celebrates the 20th anniversary of creating Resilience Engineering as a field of theory and practice by strategically reflecting on the progress made. To this end, the REA has implemented diverse initiatives, including publishing a book and collecting contributions on progress, challenges, and opportunities for further developing and applying Resilience Engineering.

Because of contributions from diverse people to Resilience Engineering, the REA invited individuals to send summaries to be considered contributors to the book. Based on these contributions, the REA invited a small group to a "think tank" style gathering in Porto. Discussions and contributions provided critical views on 1) progress on various fronts: foundational, conceptual, tools, and pragmatics; 2) challenges RE faces moving forward; and 3) opportunities for how RE can contribute to the future.

This report summarizes discussions at the Porto meeting. It provides a window into specific developments undertaken by diverse individuals around the world. It represents an open invitation to contribute to further developments and benefit from the collective intelligence of the REA's vibrant community.

Authorship: This document has been prepared by organisers and facilitators, collecting inputs from participants. This document was produced with the assistance of generative AI tools for editing, grammar and clarity. The content remain those of the authors and participants to the event¹.

Acknowledgements: Special thanks to Pedro Ferreria for hosting a memorable event and all participants of the meeting. The idea to prepare a meeting report was originated with Christopher P. Nemeth. This report is the result of cooperation among event participants. All the participants contributing to the writing, organized and re-organized the notes. The whole workshop fostered great discussions that ended up with notes summarized in this document. Special thanks to John Allspaw for providing all AI transcripts, a valuable source of information and to Laura Maguire for her initiative on using MIRO to capture new insights from the [resilience engineering in software community](#).

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¹ European Commission (2024). [Living guidelines on the responsible use of generative AI in research](#).

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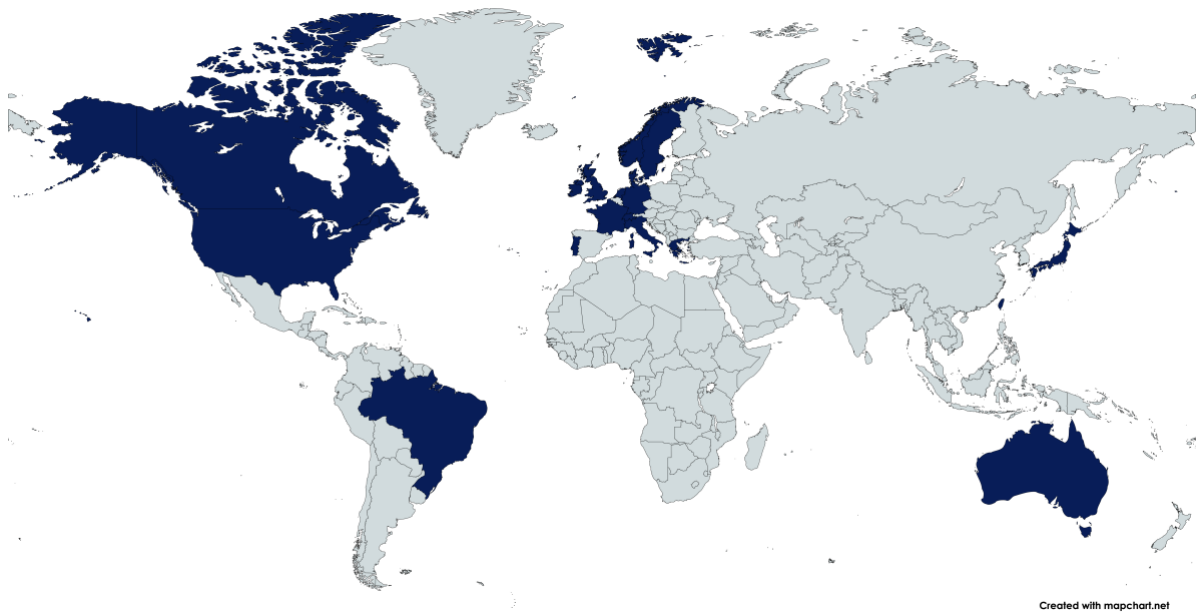


Figure 1. World Map of Participant Countries

RE 20 years meeting participants



Figure 2. RE 20 years meeting participants

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RE 20 years organising team

Beth Lay, David Woods, Eric Rigaud, Erik Hollnagel, Ivonne Herrera, Mike Rayo, Pedro Ferreira, Arie Adriensen

Foreword from David Woods

In 2000-2003 following space mishaps and then a fatal accident, NASA engaged in debates about how to recognize system level weaknesses before accidents occurred. One contribution was the nascent idea that resilience was a property of systems that could be the basis for proactive safety (Woods, 2003 testimony to US Congress on Safety at NASA; Cook et al., 2000; Woods and Shattuck, 2000). Then NASA's program shifted to planning new manned space missions and the replacement vehicle for the Space Shuttle was cancelled, and as a result what would have been the first research project to demonstrate a resilience lens for proactive safety disappeared.

What to do next? Based on Erik Hollnagel's idea of the efficiency-thoroughness trade-off, which complemented the acute-chronic trade-off emerging from the NASA work, and other frustrations we shared with progress toward proactive safety, I called and asked him: is this new direction worth pursuing and is the tentative name of Resilience Engineering and Erik agreed on both points which led us to see what others thought about the new ideas via the landmark first symposium on Resilience Engineering in 2004. The enthusiasm from the discussions then led to the first book which appeared in 2006. And now 20 years on from the first symposium.

The progress and challenges themes were conceived to produce a new landmark capturing how RE has matured and can be seen as a new kind of systems engineering field or subfield. However, RE is a quite different systems view and one that encompasses different layers of human systems, the different layers of technological capabilities, and grounding these in the complexities of operations in the face of uncertainty, time pressures, and surprise. RE is a different view of human and technological systems view that centers on adaptive capacities – how adaptive units interact as events disrupt plans in progress, coordinating over distributed roles and players, built-on/working with various technological capabilities, in systems that serve human purposes.

The name in the beginning was Resilience Engineering though a different form of systems engineering. What makes RE engineering? [To see one treatment of the foundations go to [LINK1](#) or [LINK2](#).]

- An engineering field is based on concepts, principles, laws derived from empirical results that cut across the various natural laboratories where, for us, complexity and adaptation play out over roles, time, change, and scales – how people adapt to cope with complexities. Of the many lines of inquiry that use and highlight the word resilience today, our line of inquiry has the most substantial, broadest generalizable empirical pattern base. We have laws such as law of fluency and law of stretched systems. Our empirical base has developed from methods quite different reductionist methods. Our observations and studies are centred on processes over time – verbs, and what effects what can be done, not nouns with the mirage of tabulations over categories. Many scientific fields and many forms of techniques and tools are quite capable of studying 'verbs', and capable of studying potentials, how adaptive capacity is a potential for action in the future, as are we. While rephrased from 2004/2006, a central point as always

been ‘resilience is a verb in the future tense’. We have many empirical techniques of value for pragmatic use that also provide opportunities for continuing learning about/test the general patterns to build the capability for resilient performance when surprises inevitably occur.

- An engineering field has formal scientific foundations. These foundations make it possible to derive the laws and empirical generalizations in the field. These foundations are formal with principled connections between theorems and first principles. The science base also directs and grounds modelling and simulation methods that provide important tooling/tools for use in pragmatic system engineering efforts. The foundations provide guidance and guard rails on how to make trade-offs and compromises necessary in systems engineering practice. Even more importantly, the formal foundations provide the teeth to say what cannot be compromised because the science tells us the problems and costs that will arise predictably from the wrong compromises. RE now has formal scientific foundations in theorems and theories (e.g., Theory of Graceful Extensibility, Woods, 2018). From these first principles one can derive the empirical laws discovered from studying how people adapt to cope with complexity.
- An engineering field has tools and techniques, and engineering practices provide tooling to make these techniques more effective, accessible, and less costly for practical projects. The formal and empirical engineering foundations make clear what is needed for effectiveness and then what costs are necessary to achieve goals in constrained projects. The tools, techniques and supporting tooling make deploying the knowledge base more effective and less costly without undermining the scientific knowledge base, even as that base continues to develop and change with learning from experience.
- An engineering field has an approach to architect/design systems. Resilience Engineering encompasses both architecting and design roles with respect to building effective, highly adaptive systems, competent and extensible rather than competent and brittle. The tools, techniques, and tooling support facilitate how general knowledge in the field is brought to bear in specific settings with specific hard and soft constraints, navigating multiple trade-offs, extensive interdependencies, and conflicting goals, while balancing short-term and longer-term perspectives. The tools, techniques, and tooling produce tangible system properties that support adaptive capacities. Our role as architects offers systems development a great deal now. As architects we have the possibility of order of magnitude effects on systems. However, RE still needs better tooling to increase the effectiveness to cost ratio.
- Engineering practice leads to questions about impact which challenges methods for measurement. Progress on measurement is intimately tied to and dependent on the science base. The measurement problem is intense not because we can't measure adaptive capacities (we can though we need to be better), but because of formidable barriers from oversimplification tendencies, folk models, and intense short-term faster, better, cheaper pressure. Note the irony that one of the critical empirical and formal findings at the beginning of RE is about mis-managing fundamental trade-offs (the Essentials chapter in 2006

book, NASA's mishaps 2000-2003, the Robust yet Fragile theorem in 2000; ETTO, and more), and these findings apply to the exercise and sustainment of Resilience Engineering itself. As Resilience Engineering and its formal science (e.g., TGE) explains, this irony is and must be the case for us and for all areas attempting to architect and design systems as change in many forms continues, e.g., new threats, disturbances, capabilities, technologies. Measurement of adaptive capacities is a problem, an area that has made progress, and an opportunity critical to the future of Resilience Engineering all at the same time.

- An engineering field needs all the above to make trade-offs necessary in engineering practice without compromising on the fundamental knowledge. While those funding a building may have many criteria for the building's architect, the engineering perspective must respect the physical and dynamic constraints on the structure given use, weather, extreme events even when the consequences of the engineering basics seem orthogonal to desires, only to add time, steps, tests, costs. Balancing the conflicts and trade-offs is a large part of engineering practice and engineering for resilient performance is as fundamental as any other engineering discipline.
- RE is quite different and yet still a kind of systems engineering. We need to explain how it guides architecting, designing, operating systems even as it reframes what systems are and what they do. The science base is a new synthesis across multiple lines of inquiry that, in the end, tie to biological systems of which human systems, with all of their technologies, are a part. The potential for action is like engineering, but for the human system realm within the biological sphere. The human realm includes all of technology as people always have created and wielded tools of all kinds, though not all the human realm is about technology and how we use technology given human purposes. Thus, to simplify, we can say it is a kind of engineering for all the layers in the human-technology 'stack' (quite a tangled layered network or TLN) built on the science of adaptive systems across the biological sphere.

Again, our own results about growth and complexification highlight the trap RE faces: increasingly essential and desired as an end yet squeezed into a corner by oversimplification tendencies of people. Even when we have been a substantial part of the operations or development – which we have been – sustaining our work has been difficult.

And we arrive back at the genesis of the Progress and Challenges (and now Opportunities) project: What does our field offer? What makes our field relatively unique? What do we know? And how do we bring this knowledge base to bear in practical system engineering and operations settings? I am energized to work with all on the project – especially after being sidelined by health issues this fall – cataloguing the progress, the new challenges as the world have continued to change, and the opportunities for Resilience Engineering as societies struggle in a world of increasing complexities even as new capabilities grow.

A 20-year journey...



Figure 3 Resilience Engineering activities symposiums, collaborations, books, publications

Young talents across the years

An important activity is nurturing future talent and promoting new contributions to RE progress. An infographic of the Young Talents' participation history and distribution is available via this [link](#). (For more details on the Young Talent Programme, see section 8.4).

We thank all Young Talents for their contribution: **Antonio Javier Nakhil Akel**, 2023, Sapienza University of Rome; **Birte Fagerdal**, 2023, University of Stavanger; **Christine Jefferies**, 2023, Ohio State University; **Francesco Simone**, 2023, Sapienza University of Rome; **Helene Degerman**, 2023, Linköping University; **Ivenio Teixeira de Souza**, 2023, Federal University of Rio de Janeiro; **Maria Calero Gonzalez**, 2023, University of Nottingham; **Mirela Schramm Tonetto**, 2023, Universidade Federal do Rio Grande do Sul; **Peng He**, 2023, Civil Aviation University of China (CAUC); **Steven Foster**, 2023, Clemson University; **Ann-Therese Hedqvist**, 2021, Linnaeus University in Kalmar; **Arie Adriaensen**, 2021, KU Leuven; **Atif Ashraf**, 2021, Texas A&M University; **Bruna Gayer**, 2021, Universidade Federal do Rio Grande do Sul; **Claudia Disconzi**, 2021, Universidade Federal do Rio Grande do Sul; **Karl Hybinette**, 2021, Karolinska Institutet; **Lida Z. David**, 2021, TU Twente; **Natalie Sanford**, 2021, CARe/King's College London; **Nichole Pereira**, 2021, Queen's University; **Shanee Honig**, 2021, Ben-Gurion University of the Negev; **Chia-Hsin Cheng**, 2019, Taipei Medical University; **Dustin T. Weiler**, 2019, University of Wisconsin; **Elizabeth Lawson**, 2019, University of Exeter; **George Franklin Edwards III**, 2019, Virginia Tech; **Guillermina Penaloza**, 2019, Universidade Federal do Rio Grande do Sul; **Jukrin Moon**, 2019, Texas A&M University; **Laura Maguire**, 2019, Ohio State University; **Morgan Reynolds**, 2019, Ohio State University; **Natalia Ransolin**, 2019, Universidade Federal do Rio Grande do Sul; **Vanessa Becker Bertoni**, 2019, Universidade Federal do Rio Grande do Sul; **Changwon Son**, 2017, Texas A&M University; **Daniel Eisenberg**, 2017, Arizona State University; **Jop Havinga**, 2017, Griffith University; **Justyna Tasic**, 2017, Nanyang Technological University; **Lauren R. McBurnett**, 2017, Arizona State University; **Linda de Vries**, 2017, Chalmers University of Technology; **Marlon Soliman**, 2017, Universidade Federal do Rio Grande do Sul; **Mia McLanders**, 2017, University of Queensland; **Raphaela Schnittker**, 2017, Monash; **Riccardo Patriarca**, 2017, Sapienza University of Rome; **Armando Graziano**, 2015, World Maritime University; **Claire Vanbelle**, 2015, CRTD, CNAM; **Jonathan Day**, 2015, City University London; **Julia Alengry**, 2015, CRTD, CNAM; **Mario Pierobon**, 2015, Cranfield University; **Matt Alders**, 2015, CARe/King's College London; **Noel Hengelbrok**, 2015, Lund University/Tennessee Dept. of Children's Service; **Ron Gantt**, 2015, University of Alabama at Birmingham; **Sudeep Hegde**, 2015, University of Buffalo; **Tomomi Aoyama**, 2015, Nagoya Institute of Technology; **Dianka Zuiderwijk**, 2013, TNO; **Eva Simonsen**, 2013, Chalmers University of Technology; **Gesa Praetorius**, 2013, World Maritime University; **Kati Walker**, 2013, Ohio State University; **Kenneth Igbo**, 2013, Swinburne University of Technology; **Kristin Laugaland**, 2013, University of Stavanger; **Matthieu Branlat**, 2013, (Currently SINTEF), Ohio State University; **Miranda Cornelisse**, 2013, Griffith University; **Willy Siegel**, 2013, TU Twente.

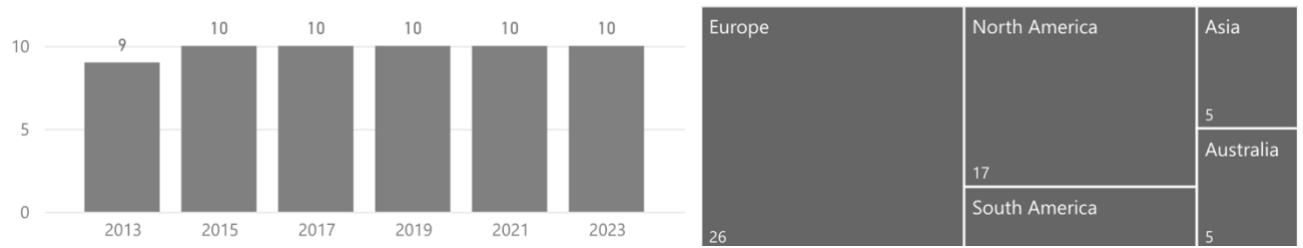


Figure 4 Young Talent Participation

1. Introduction

1.1. Purpose of the document

This report describes the process behind and results from the Resilience Engineering 20 years meeting (RE20), held in the Douro Valley in Portugal on 14-16 October, 2024. The purpose of the event was to facilitate knowledge sharing and experiences providing a critical view on progress, challenges and opportunities.

1.2. Intended readership

This report is entirely for external readers. It includes researchers and practitioners engaged in RE as well as people curious about resilience engineering.

2. Preparation and planning

The RE20 meeting built on the following guiding principles:

- Invite diverse perspectives (create space for each person to have a voice)
- Design a flexible system (create space / slack to be flexible)
- Create autonomy (people select where they contribute)
- Defer to expertise (make space for experts to share)

Some notes on the planning of the RE20 meeting:

- Prior to the event a wide invitation was sent to people engaged in RE. These participants submitted an abstract on diverse RE themes and practices sharing their experiences.
- A mind map of submissions was elaborate to define and organize themes.
- Facilitators were recruited among participants. Their role was to facilitate focused discussions and co-creation.
- The approach was to divide the group into diverse teams that benefit from complementary and contrasting expertise, experience, and schools of thought related to RE.
- A charrette process was selected to go deep on topics in small groups rotate to explore three topics:
 - Progress: how RE has advanced in recent years, key developments and innovations - what is unique to RE
 - Challenges: what are key challenges faced in RE, and
 - Opportunities: where do the opportunities lie for advancing RE in the future) then go wide to collaborate and query emergent questions from larger group.

- Topic explorations were shaped by pre-designed questions. The purpose of the questions is to create “soak time”, and then collaborative exploration. During the discussion facilitators ensured space for sharing theory, practices, and case studies.
- The open space method complemented the charrette, as it brought participants together to identify and prioritize items for further discussion and possible collaborations. These items became potential themes for breakout sessions. Participants had the freedom to vote and join diverse discussions. While the charrette is organised in detail, the open space recognised that participants will develop a richer contribution to their selected topic. It followed the following steps:
 - At the start of the process participants organised post-its resulting from charrette sessions (progress, challenges and opportunities). All were invited to organise and prioritize items for further discussion
 - The breakout session started with a duration of 30-90 min. Participants joined sessions that they deemed relevant for themselves. Participants were asked to follow the “law of two feet” which is that if they find themselves not contributing to the breakout session, they could use their feet and walk to another session. In this way, participants had full responsibility over learning and contribution.
 - Closing the open space with one participant from each group summarizing the discussion around the specific theme.

3. Introduction and welcome

Introduction

by Elizabeth Lay (President REA, Forge works, USA)

Much has changed with what we know and think about resilience in the 20 years since the inception of Resilience Engineering (RE). The definition of Resilience Engineering evolved from being about failure triggered by surprise events with a focus on safety to how well a system can gracefully extend to handle events that challenge boundaries of operation (Woods) and adjust functioning prior to, during, or following disturbances, changes and opportunities to sustain operations under both expected and unexpected conditions (Hollnagel).

The timing seemed right to reflect on and explore progress, opportunities, and challenges with Resilience Engineering with the outcome of publishing a book. The specific objectives for the meeting were:

- Objective 1: Bring together academics and practitioners to explore and discover new insights relevant to RE. Build relationships such that people continue to collaborate beyond the event.
- Objective 2: Create the beginning content for a book to include themes, insights, and organization. Plan how the book will be completed.
- Objective 3: Seed the continued existence and growth of REA. Set strategic direction. Prioritize where we will put our energies. Set expectations for REA Leadership.

Our ultimate purpose is to create a “picture” of RE in terms of unique contributions, tangible progress (fundamental and pragmatic knowledge), and continuing and new challenges and opportunities, all oriented to help people in a changing world cope with and out manoeuvre complexity.

Expected outcomes from the event:

- Provide a beginning basis and to structure RE 20 years past, present, future book
- The engagement with the RE community on a wider scope was also discussed as a key element for future developments. This should generate not only input prior to the meeting, but also a feedforward opportunity in the aftermath of the workshop. The purpose would be to integrate more diverse perspectives on the issues to be reflected upon and foster a continued discussion within the RE community beyond the meeting itself.

The Resilience Engineering Association (REA) was the primary sponsor of the meeting with additional financial support from Forge Works.

Welcome

by Pedro Ferreira (RE 20 event Host, Novellus, Portugal), Mike Rayo (REA Secretary, Ohio State University, OSU, USA)

After a rather adventurous bus ride from the city center of Porto to heart of the beautiful Douro Valley, we began our meeting by welcoming all of the Porto attendees. Our hope was that, by bringing all of the attendees together in the same spot, and selecting a spot that allowed for reflection and an escape from distraction, we jointly experience a series of moments that would forge us together, provide clarity and energize us to return home and sustain the energy needed to create the set of RE20 materials that would crystallize the last 20 years of RE, and set us on a fruitful future course.

We started with deliberate work to help everyone get to know each other better, starting off with attendees pairing off and learning enough about each other so that they could introduce their counterpart to the rest of the meeting attendees.

We then communicated to the attendees why they were invited to the meeting. We knew that each of them had something to say about RE, and something to contribute to RE's progress. We also knew that they were not satisfied about the current state of RE, knew about RE's challenges, and were actively seeking opportunities for RE to continue to grow and thrive. In selecting the RE20 meeting attendees, we strived for diversity of ideas, diversity of backgrounds, and diversity of expertise. Everyone on the organizing committee, from the newest RE member to the RE founders, brought passion and firm ideas about who should be invited.

The end of our welcome pointed to the future. We encouraged the attendees to start charting the future of RE, and let them know that REA's resources were there to support doing it!

4. Fostering creative sessions

4.1. Introduction to Day 1

Session moderation: Laura Maguire (Trace Cognitive Engineering – TCE, CA) and Dave Provan (Forge Works, Australia). Report contribution: Laura Maguire

Prior to the kickoff brainstorming and discussion session, the facilitators provided introductory comments to ground the activities in both the immediate goals (to share perspectives and determine book content) and also broader goals (strengthen collaborative networks, identify high interest topics for 2025 REA Symposium). The opening comments stressed that the purpose of the exercise was not consensus but rather generating ideas, looking for connections and overlap, and tolerating differences of ideas. With that, the groups self organized around the topics they were most drawn to (Progress, Challenges, and Opportunities). Each group rotated throughout the afternoon where they were given a brief synopsis of the discussions in the group prior then built off and elaborated on the ideas presented.

4.2. Introduction to Day 2

Session moderation and report contribution: Lida Z. David (University of Twente, NL) and Eric Rigaud (MinesParis)

The primary goals of Day 2's Charrette process were to deepen the themes identified on Day 1 and pinpoint overarching connections across progress, challenges, and opportunities. The final themes to emerge would form the basis for collaborative book chapters. Debate was encouraged over consensus, urging participants to engage critically. Following a briefing on the day's objectives, the facilitators of each topic (progress, challenges, opportunities) summarised the previous day's insights, refining ideas to guide teams toward deeper discussion and the creation of integrated themes. With this preparation, round two of the Charrette process began.

5. Progress

Session moderation: Martina Ragosta (SINTEF, Norway) and Mike Rayo (OSU, USA).

Report contribution: Mike Rayo

The progress charratte sessions focused on how has Resilience Engineering has advanced in recent years, including key developments and innovations that have been achieved. This was reflected in part to a question posed to the attendees before the RE20 meeting: *What is unique to Resilience Engineering?* RE has made progress in a number of different areas. It was interesting that, in addition to areas of progress that the facilitators expected the RE20 meeting attendees to bring up, there was also strong support for a number of areas of progress that were unexpected, including the network of RE training institutions, strengthened connections between RE and related disciplines, and how the RE community itself has matured.



Figure 5 Participants reflecting on and reorganising RE progress

5.1. Strong foundational concepts

RE has strong theoretical grounding that includes Laws, Theories, and Patterns, with the vast majority intended to reveal something about complex adaptive systems that would otherwise remain obscure to more distant parties (i.e., everyone other than the parties directly involved in the work). Perhaps the most well-received of these is the WAX framework, which describes the gaps between Work as Imagined, Work as

Done, and a number of other different perspectives. They also include comprehensive frameworks or theories, such as the four potentials for resilient performance (Monitor, Anticipate, Respond, Learn) and the Theory of Graceful Extensibility. They also describe more specific phenomena, including enduring patterns related to tradeoffs, governance, adaptation, governance, and coordination. This grounding includes both patterns and anti-patterns of sustained resilient performance.

5.2. Pragmatic tools grounded in RE science

RE has continuously increased the number of pragmatic, useful tools that are grounded in RE science. There are now a number of tools that are meant to be used by frontline workers (i.e., the sharp end), as well as those meant to be used by more experienced analysts with RE training whose outputs are meant to influence decision-makers and other actors to shape frontline work (i.e., the blunt end). RE concepts have integrated into systems assessment tools using more formal modeling methods, including knowledge graphs, network analysis and agent-based modeling, and have also created their own structures, such as the Resilience Analysis Grid (RAG), the Functional Resonance Analysis Method (FRAM), and Systemic Contributors and Adaptations Diagramming (SCAD). Design guidelines, computer-aided tools and serious games have been created to operationalize resilience engineering concepts into practice.

5.3. An increased training base for RE

There are now a number of universities worldwide, including The Ohio State University, Lund University, Sapienza University, Norwegian University of Science and Technology, Linköping University, Universidade Federal do Rio de Janeiro, Federal University of Rio Grande do Sul and KTH Royal Institute of Technology that have degree programs, concentrations, and courses dedicated to RE. In addition, a number of companies also offer RE training modules or courses to professionals. There are a number of online materials available, including virtually the entire [REA webinar library](#) and the Resilience Engineering 101 video series published by the [Cognitive Systems Engineering Laboratory at The Ohio State University](#).

Editor additional note (IH): Three editions of a distance graduate course on Resilience Engineering were conducted under the [STERNA project](#) involving students from Brazil, Norway and other countries. Many members from RE worldwide community contributed to the lectures. We could benefit from the recordings.

5.4. RE connections and influence

RE has forged connections and been an influencing force on a number of other disciplines and professional groups. RE concepts and methods have been adopted by a number of other safety-related disciplines and working groups. There are a number of popular RE-related podcasts whose explicit intent is to make RE and RE-related concepts more approachable to safety and systems performance professionals. RE professionals are currently serving as boundary-spanners to the disciplines of Cognitive Systems Engineering, Operational

Research, Chaos Engineering, Organizational Resilience, Societal Resilience, Information Science, High Reliability Organizing, Disaster Management, Organizational Risk, and many others.

5.5. RE community maturity

The RE community has matured and grown. There is a sense across the community that, even though it has grown, there continues to be strong interest and deep knowledge of what others in the community are doing. The interdisciplinary nature brings highly diverse viewpoints, with a common thread being that the community is hesitant to seek easy answers. There is commitment for RE theory to serve RE practice, and RE practice to directly inform and guide RE theory.

The RE community has also been successful in communicating and embedding within other channels and organizations. There have been a number of special issues across multiple highly-respected peer-reviewed journals dedicated to RE concepts or methods. There are also a number of technical groups in other organizations, including the International Ergonomics Association, that are dedicated to RE. RE also has a number of organizations dedicated more centrally to RE, including the Resilience Engineering Association, Safety II in Practice, Resilient Healthcare Society, and the FRAMily.

6. Challenges

Session moderation: Laura Maguire (TCE, USA) and Christopher P. Nemeth (ARA, USA). Report contribution from Laura Maguire, Christopher P. Nemeth

Challenges can be either obstacles or opportunities outside of the RE community, within the RE community, or within ourselves. Participants were invited to answer two questions: What are the key challenges faced in RE? What would help you incorporate RE more into your day-to-day work? Session participants' comments pointed to these themes.



Figure 6 Notes from interactive session on challenges

6.1. Narrow field needs a broader perspective

References and points of view in RE literature need to be broadened to include other fields such as biology, organizational science, sociology, and psychology. RE is understood as either a safety or a human factors “thing.” RE’s origins in safety science need to be extended to include opportunities to improve system performance through deep and well-founded insights into actual work-as-done. Reframe RE as a means to create and manage systems that are flexible enough to meet demand or seize opportunities.

Editor additional note (IH): There exists few examples on broadening RE to other fields such as ecology (Panarchy), organizational (Horizon-2020 and Horizont Europe projects related to resilience management and critical infrastructures) and sociology (when studying societal resilience ENGAGE project).

6.2. Theory needs to be translated to practice

While RE is rich in theories, there is not enough evidence that it offers substantial benefits. There are too many terms, too complicated concepts and knowledge, and few practical tools. There is little evidence of skill capturing the complexity of the application areas and then translating into finding and requirements that can then be digested by others who are not involved in the research. The audience outside of researchers has

difficulty translating concepts and cases developed from one domain to another. Managers want simple tools to make decisions. They want to analyze observational data to translate results into requirements for improved performance. Methods and models need to be developed that are easily accessible by practitioners and managers. There needs to be a link between the macro system that is trying to create a policy to fulfill a mission, and a performance outcome.

Editor additional note (IH): There exist concrete examples on translating RE language into practical applications such as workshops to study production pressure such as the STELLA report: <https://snafucatchers.github.io/>. Or using diverse perspectives to design hospitals (i.e. Saurin et al. work in Brazil).

6.3. Value needs to be made evident in contrast to current practices

Industry needs certainty to optimize performance in the short-term, which limits acceptance of buffers, slack, and adaptation that are inherent in RE. Legislators, regulators, organizations, and even individual practitioners are less inclined to take on interventions or coordination that cross organizational levels and boundaries. Some fields such as aviation, air traffic control, and civil aviation are already overwhelmed by the amount of safety tasks that have to be done. RE's advantage is not understood clearly enough to replace current work that is done to assure safety or compliance. Better expression of RE's value and processes can enable many of those who are at various levels within organizations to share information and change adaptive capacity across boundaries with minimal friction. There is a need for concise, plain language interpretation of RE theory and results, and easily adopted tools or practices.

Editor additional note (IH): European regulations such as Critical Entities Resilience (CER) Directive address the increased interconnection across critical infrastructures and cross-border nature of operations. This calls for cross organizational collaboration.

6.4. The RE community needs support

The Resilience Engineering Association needs to develop efficient ways to support the RE community through a number of methods. Develop a form that REA leaders or member(s) might use to collect information on current RE issues and practices. Build an inventory of case studies to demonstrate value and results. Serve as an agent to promote RE benefits and as a point of contact to respond to industry interest.

7. Opportunities

Session moderated by Dave Alderson (NPS, USA) and Jonas Lundberg (LiU, Sweden).

Contribution from Jonas Lundberg

Introduction: Where do the opportunities lie for advancing Resilience Engineering in the future? Three main themes finally emerged from the discussions on day two of the RE meeting, by re-arranging and grouping notes and specific topics from the meeting. The topics were **seeding the next generation**, **translation**, and **value proposition**.

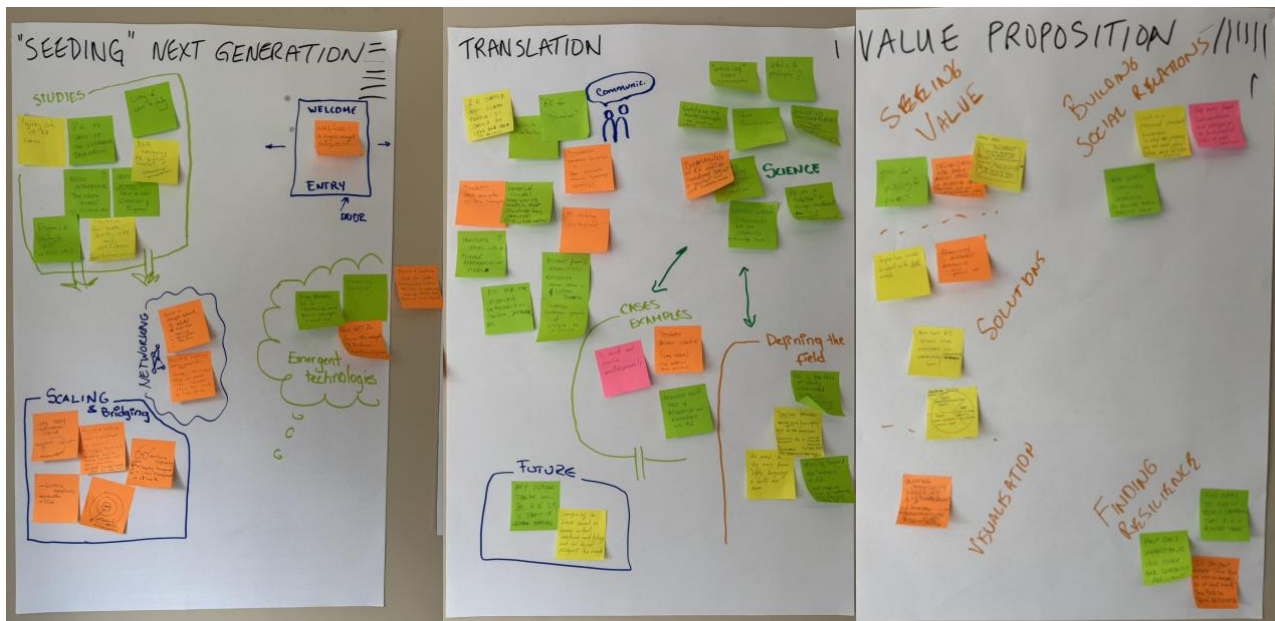


Figure 7 Results from interactions categorized and labelled according to emergent themes

7.1. Seeding the next generation

Seeding the next generation was a theme centered on how a new generation of people can grow into the field and to take it further. The *first* theme, depicted as a door, was a single theme, something that is easy to grasp, that captures the essence of resilience engineering, that can work as an **entry point** to RE in a welcoming manner. Work-as-done/work-as-imagined was proposed as such a topic. The *second* theme in this area (top left) was concerned about the opportunities for studying RE. This theme centered around an **RE “hub”**, a centralized place to find courses, study programs, and perhaps also a quality assurance of courses. It also centered around giving courses, such as summer schools, and networking opportunities. The *third* theme (middle) was an expansion on the **networking** topic, to actively look forward into fields where RE would have high value, and promote it there, through networking for training/education and practice. The fourth, bottom theme, scaling and bridging was concerned with how RE fits into longer innovation and development cycles in society, on bridging between fields where RE is important (safety, crises, climate), and the development of tools and methings as a means. Finally, **emerging technologies** right now points at developments such as large language models. For the next generation, it will be important to look for these

new fields, and see how RE can complement and expand in these new fields that open up due to emerging technologies.

7.2. Translation

Translation was a topic centered around RE for different groups. The first group, was newcomers, denoted by the **communication** label (top left). For this group, RE should be accessible and “not scare people off”. This connects to and extends the “entry point” topic in the seeding the next generation theme. It contains ideas such as “RE for dummies”, widening the audience of RE. Media that each new generation uses, such as (currently) tik-tok, instagram, and so on was seen as important for visibility. It continued on the theme of finding “canonical examples”, engineering models to illustrate basic concepts, such as saturation. Another communication issue was that of a simple representation of RE, an illustration that captures the essence of RE, preferably also in the form of a metaphor that can be the basis of an illustration. It emphasises the need to communicate both common ground with other areas (such as systems thinking) and unique RE aspects. The *second* topic (top right), **science**, goes in a somewhat different direction. It goes into fundamentals, such as underlying concepts, philosophy, and technology (tools). It was about the field, the core and its “fuzzy boundaries” to nearby fields. That was expanded on in the *third* topic **defining the field** (lower right). On the one hand it wrestled with a single definition of resilience (as the field associated with) and on the other hand resilience as a mosaic. It also was concerned with the origins in safety science, and perhaps moving away from the language of that field. The *fourth* topic, (middle) extends on communication and translation by focusing on **case and examples**, across industries, examining the application of practices, and to find patterns. Finally, the **future** topic, points at remembering that human nature is part of resilience, including emotion and feelings. This highlights that RE will perhaps need to encompass notions that are currently not in the focus, identifying these in time will be important for RE to stay relevant.

7.3. Value proposition

Value propositions was a smaller but broad topic concerned with communicating value and the actual value of RE. The first themes, **seeing values** and **visualizations**, points at representational forms such as tools for visibility for executive levels of organizations, and basic forms such as value maps (e.g. services, and their “pains and gains”), how organizations are explicit about the value of investments in adaptive capacity. The second topic, **solutions**, concerned how RE solves problems for communities, how value propositions need to start with local needs, and issues such as reconciling different interests (local/global). Finally, the *third* theme collected notes on **building social relations**. One central relation is that of academics and consultants working together. The theme also touched on the tension between individuals and social relations. On the one hand, a notion was that of emphasising the social relations rather than individuals in RE. Another note, on the other hand, emphasises the personal side, that RE as a value is also a personal value. It requires that people share this value for RE to succeed.

8. Open space

Session moderation: Arie Adriensen (TUDelf, NL), Riccardo Patriarca (UniRoma,IT), Ivonne Herrera (NO). Section editors: Arie Adriensen and Riccardo Patriarca

This section reflects the topics people committed to at the RE20 meeting. It includes an overview of the agreed topics and their descriptions below. This is just one possible organization: please note that the actual book structure and the chapters could look different. RE20 meeting attendees were encouraged to think about how they would like to form writing teams on the assembled topics, and were encouraged to invite authors that did not attend the RE20 meeting as well as those who did. These activities created a bottom-up approach, fully benefiting from the enthusiasm of RE20 event contributors and their interests. However, the editorial team will decide with a top-down approach how the book will ultimately be structured, taking full advantage of the RE20 submissions that predated the RE20 event, the contributors of the RE20 event, and by exercising their own good judgment. Hence, the results from this report are a step towards achieving our final goal, a book for an audience comparable to our author team. However, they should not be viewed as a prescription for how we will ultimately achieve that goal. The following proposed sections is the result of a mixture of researchers and practitioners enthusiastic about RE describing its progress, addressing its challenges, and unlocking its potential.

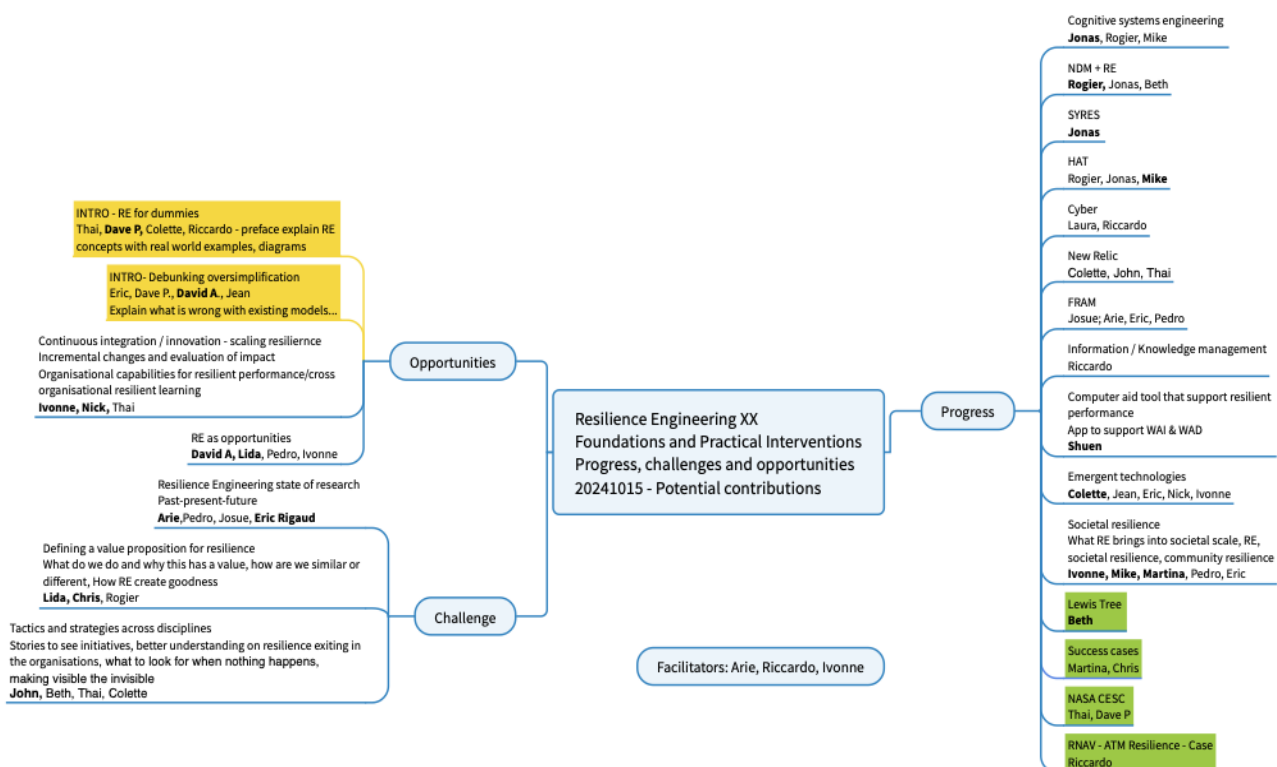


Figure 8 Mind map with RE labels for further dialogue and interaction

8.1. Introduction to Resilience Engineering (RE)

8.1.1. Debunking and RE for Dummies

From transcript 017 prepared by John Allspaw, Edited by Ivonne Herrera (participants David Provan, Thai Wood, Colette Alexander, Riccardo Patriarca)

Potentially being maybe a first chapter of the book, maybe even a preface, which would ease the reader into a book and provide an overview of resilience engineering in a very basic, approachable way. It will contain explanations of concepts using real world examples, like explaining socio-technical systems through the use examples and metaphors like road and traffic systems with cars and people and pedestrians and traffic lights and just understanding some of the things that we're going to talk about in the book through quite useful ways of thinking about them in daily life. This could be lifted out of the book and used as a 15 or 20 page pocket resource for people who have only recently been exposed to RE and are interested in learning more.

It will be important to be intentional about how we explain the different RE concepts and when to use diagrams to augment those explanations. We could include complex things like word clouds on topics such as graceful extensibility, going solid, resilient potentials, anticipation, and foresight. We agreed that these would all be oversimplifications, and would obscure the depth of scholarship behind RE, but would be valuable to make things accessible for more people.

We discussed using plain language and then eliciting stories about specific types of phenomena. For example, we could tell a story that shows the concepts of initiative and reciprocity, highlighting how they play a role in the story. These are ingredients for graceful extensibility, but that isn't explicit in this initial story. They can then make those connections themselves later on when we introduce the deeper concept of graceful extensibility. They can then clearly see the throughline from specific events in the story through more basic concepts then on through to deeper concepts.

We also talked about how to debug oversimplifications. We actually had many different notions for what this could be. On the one hand, picking up off of RE for Dummies, there are views advocating for picking some very common oversimplifications and addressing them in more of an explainer kind of way. This could be a separate thing or could be part of the RE for Dummies kind of thing.

Finally, we talked about models and what is really wrong with existing models, when do they work or fail to work? How far should we go in debunking? What is an oversimplification? And also thinking about assumptions about the world and the way in which that leads to oversimplification. We would need to lay that all out in some way, but we didn't get very far on HOW to do that!

8.1.2. Past and present of the Resilience Engineering - Perspective on the modelling challenge

Eric Rigaud (other contributors welcome) (other potential contributors David Provan, David Alderson, Jean Pariès)

The Resilience Engineering (RE) research and development community emerged at the beginning of the 21st century to help people and organizations cope with complexity under pressure to achieve success. This field has evolved along two major theoretical dimensions: First, the individual and collective dimension focuses on what Woods (2015) defines as the "ability to recognize and adapt to handle unanticipated perturbations that question the model of competence and demand a shift of processes, strategies, and coordination." Second, the organizational dimension examines the learning, monitoring, and anticipating competencies that support organizational responding capabilities, which Hollnagel (2006) characterizes as the ability "to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and/or in the presence of continuous stress."

From a constructivist epistemological perspective (Morin, 1990; Le Moigne, 1990), the modeling challenge in any scientific discipline concerns the construction of intelligible representations of perceived complex phenomena. These representations aim to understand and explain the phenomena's organization, functioning, and transformation while developing theoretical knowledge that supports understanding and action. Over the past 25 years, the RE community has developed, discussed, and experimented with various concepts, theories, models, and tools to support sociotechnical systems performance in the face of complexity. This evolution reflects a progressive understanding of system adaptation and resilience.

This paper aims to critically analyze essential RE modeling approaches and propose an integrated framework. We examine how different modeling approaches contribute to understanding and supporting system resilience. Our analysis draws on complex adaptive systems theory to examine key RE modeling approaches, including Performance variability and functional resonance (Hollnagel, 2014), System boundaries and critical thresholds (Woods, 2015), Adaptive capacity and graceful extensibility (Woods, 2018). Building on this analysis, we propose an integrated modeling framework synthesizing these approaches to support RE-based interventions. This integration combines complementary theoretical perspectives, addresses practical implementation challenges, supports system assessment and improvement, and guides resilience-focused interventions.

8.1.3. Future of Resilience Engineering

Arie Adriaensen, Pedro Ferreira (Anthony Smoker and James Burnell invited to contribute)

In addition to the past and present of resilience engineering and how this emerged through identifying patterns and the resulting theorems, this contribution will identify a number of interesting developments in the Resilience Engineering literature that have typically not found their way into our REA community. The chapter will provide a critical reflection on which elements could be added to existing Resilience Engineering theorems or challenge our theories to be pursued as interesting lines of research for the future in our own community. It is envisioned that this could be an interesting closing chapter to extend the horizon of RE research and application perspectives for the near future.

8.2. Progress

8.2.1. The Systemic Resilience Model (SYRES)

Jonas Lundberg, Björn Johansson

The notion of resilience is intuitively clear – but can be difficult to grasp when trying to understand it in-depth. This regards both classification of events and systems and understanding them in-depth to improve them. In one case, an aircraft can crash, no one was hurt, and it was seen as an accident (e.g. landing with landing gears that are not extended). In another case, an aircraft can crash, no one was hurt, but it is instead seen as resilient performance (e.g. landing an aircraft on water, after a bird strike). Is it then the physical object that is to be seen as the object of resilience, the performance of a team or person, is it the triggering event that decides what kind of event we have encountered, or is it something else? How can we analyze resilience, in order to improve it? In this chapter, we provide an answer to this through the Systemic Resilience Model (SYRES). We present the model together with cases from literature and our research projects. The model describes on the one hand, resilience as adaptive activity, and on the other hand, as adaptive structures. It describes both facets in relation to functional dependencies between core resilience functions: anticipate, monitor, respond, recover, learn, and self-monitoring. These are related to time in the form of event-based constraints (e.g. latent conditions, event onset cues, event effects, damages). We re-introduce this model with recent advances, in particular the Core Value Ladder, resource context, and the temporal dimension. With the introduction of the Core Value Ladder, resilience becomes a double adaptive process. Not only does the system shift through adaptation of structures and activities, but the goals of the system may shift as well on a core value ladder when under pressure. Regarding the resource context, we discuss the notion of resilience as competitive versus collaborative. The temporal dimension is considered through the notions of perception points, decision points, and action points. In some fast-moving domains and events these may pertain to individuals (e.g. a decision may be part of an action flow for instance in

controlling the landing of an aircraft), whereas in other slower-moving domains and events, they mainly pertain to organizations (e.g. a meeting can be a decision point). We discuss how preparedness as well as adaptations near or during response affect resilience through the organization and reorganization of these points. We relate them to observability of event-based constraints. In addition to the SYRES model as a whole to understand resilience strategies in-depth, we also present a simplified approach to determine overarching resilience strategies. Finally, we discuss future research needs, in particular the use of the full model versus the use of simplified instruments. We also outline future research needs related to the introduction of more advanced AI-systems in socio-technical systems that need to exhibit resilience. These systems may exhibit resilience as purely technical systems, as purely human systems, but also as socio-technical systems that include humans in the loop. The resilience of systems may differ depending on what boundary is chosen (technical, human socio-technical) This re-introduces a fundamental question – resilience of what, against what?

8.2.2. Functional Resonance Analysis Method (FRAM)

Arie Adriaensen, Josue Franca, Eric Rigaud, Riccardo Patriarca, Pedro Ferreira

FRAM is a well-known Resilience Engineering method that can be applied to assessing and managing non-trivial sociotechnical systems. The guidance on how FRAM leads to the identification of functions, the aggregation of performance variability, as well as the management of the so-called Functional Resonance, leaves some gaps that could lead to suboptimal results and unrealistic expectations. This contribution suggests how FRAM can be operationalized in different settings. Based on an explorative review of FRAM publications, it is suggested to specifically look at how the scope and intended purpose of the analysis can be aligned with the possibilities of data collection and processing to eventually lead to the design of interventions. This exercise has partially been done in healthcare (Sujan et al., 2023) but, to the best of our knowledge, not in other domains. It is therefore suggested to look at how the operationalization of FRAM can be characterized in relation to different domains and intervention purposes. The chapter will also align with the upcoming “Navigating the FRAM” book edited by Riccardo Patriarca and planned to be published in Q2 of 2025.

8.2.3. Joint human-autonomy activity for resilient teaming

Mike Rayo, Rogier Woltjer, Jonas Lundberg

Teams of human operators and highly automated systems, especially with automation approaching autonomous operation, are in many safety-critical and high-risk domains envisioned to mature in the near future. Each technical system can, however, not be fully autonomous, just like individual humans are not fully autonomous. A precondition for resilient human-autonomy teams is that both humans and technology

are able to jointly contribute to the envisioned automated activity, which means that they can both jointly contribute to the potential for resilient performance. How to accomplish this has been debated over the last decades, with researchers developing new joint activity architectures, while limitations of much-relied on frameworks such as Levels of Automation have been exposed. Concepts and challenges that this chapter aims to highlight include:

- What adaptive capacity could look like?
- What joint activity concepts could support them?
- How are margins, buffers, and performance boundaries managed?
- How teaming performance can be gracefully extended if necessary?
- How joint activity may match task pacing and other contextual aspects?
- How delegation of tasks may be negotiated and coordinated?

Selected conceptual, design, methodological, and assessment aspects for Resilience Engineering of human-autonomy teams are discussed.

8.2.4. New Relic

John Allspaw (other potential contributors Colette Alexander, Thai Woods)

In a 2021 article published in *Applied Ergonomics*, Richard Cook and Beth Long present a case study of resilience *engineering*. They describe in detail how an organization developed and refined an approach to better handle unexpected disruptions. This approach involved establishing a standing reserve of expertise and sharing its adaptive capacity when it's needed. This was adjusted and modified over time as the benefits became apparent.

This article is notable because, as the authors point out, there are relatively few examples of *engineering* resilience in the literature compared to other topics in the field. This case was found within the domain of online software engineering and operations, one of the many domains represented in the RE community. We might expect researchers from other domains to be aware of this unique demonstration of resilience engineering. Are they?

We might also imagine that others have explored what features of this case could be effectively “translated” to other environments, such as medicine, aviation, or others. Have they?

The multidisciplinary and multi-domain nature of the RE community is recognized as a strength, and indeed it is. But does this make it more difficult to keep aware of what progress is being made (as in this case), and

what challenges are encountered in other domains? This chapter looks at these concerns and what, if anything, might be done differently to cope with them.

8.2.5. Cyber – critical digital infrastructures

Laura Maguire, Riccardo Patriarca

Large-scale distributed software systems are, by their nature, continuously changing across many dimensions. Cross-scale interactions between individuals, automation and technical components, organizations, their users and the broader macro environmental and operational conditions require actors within the system to continually adjust performance in anticipation of, and in response to, adverse and unexpected events, including cyber-attacks. In this chapter we will explore the complexities inherent in building and maintaining critical digital infrastructure for resilient performance as well as strategies and structures to support adaptive capacity, in such socio-technical - or even better socio-cyber-physical - systems.

8.2.6. Information - Knowledge management

Riccardo Patriarca

Knowledge management plays a pivotal role in enhancing organizational resilience by fostering adaptive capacity and informed decision-making. This interplay strengthens resilience in complex socio-technical environments, leveraging both explicit and tacit knowledge. The conversion from tacit to explicit varieties of knowledge is expected to make visible weak signals, as tangible representation of knowledge orchestration. This chapter explores how organizations can leverage a quest for weak signals to make their operations safer and more efficient. Use cases in real aviation operations will offer a complementary view to theory.

8.2.7. Computer-Aided Resilience Engineering Work As-Imaged/Work-As-Done Analysis Module

Sheuwen Chuang

Work As-Imaged (WAI)/Work-As-Done (WAD) is a well-recognized concept and approach for understanding and applying resilience engineering (RE). It has been adopted to analyze the distinction between how work is ‘imagined’ or thought of and how work is actually done to reveal and develop system resilience. Computer-aided resilience engineering (CARE) systems are software that supports practitioners in utilizing RE methods. The WAI-WAD analysis is the first module of CARE. Its functions include analyzing the work system, identifying situations that disturb processes, identifying critical resources needed,

WAI, and corresponding WAD, as well as facilitating learning and redesigning processes for work improvement. Using the CARE—WAI/WAD analysis module makes the RE application efficient and effective. Moreover, the module can accumulate employees' experiences in coping with work situations. This knowledge database will add value to future on-the-job training and help improve the quality of the work system.

8.2.8. Emergent technologies

Past, Present, and Future of the Resilience Engineering perspective on the technology system

Eric Rigaud, Nick McDonald (other potential contributors Colette Alexander, Jean Paries and Ivonne Herrera)

Technology, defined as the "physical objects, tools, and equipment used in the production processes in organizations, including the techniques and knowledge used to transform inputs into outputs" (Hatch, 2018), has evolved from being one of many driving forces to become a fundamental matrix that shapes the transformation of industrial societies and organizational processes (Castells, 2010; Zuboff, 2019).

Technological systems evolve through a dual dynamic: the continuous improvement of existing technologies and the emergence of breakthrough innovations that radically transform established practices (Arthur, 2009). While some technologies gradually become obsolete and disappear, others adapt and evolve, creating layers of interconnected systems with varying degrees of maturity (Geels, 2002). This technological landscape is periodically disrupted by revolutionary innovations that fundamentally alter the game's rules, creating new possibilities while potentially rendering entire categories of existing technologies obsolete (Christensen et al., 2018). This constant interplay between evolution, extinction, and emergence creates a complex adaptive system where technological change accelerates and becomes increasingly unpredictable.

The Resilience Engineering (RE) research and development community emerged at the beginning of the 21st century to help organizations cope with complexity under pressure to achieve success (Hollnagel et al., 2006). The dynamics of technology as a complex adaptive system present challenges and opportunities: while increasing complexity and sources of pressure threaten established practices, they also create new possibilities to adapt successfully under both anticipated and unanticipated situations (Woods, 2015). Thus, resilient systems must cope with known technological variability and develop new capabilities to maintain successful operations as their technological foundations continuously evolve and transform (Dekker et al., 2016).

This contribution analyzes how Resilience Engineering has historically conceptualized technological systems critically and examines the challenges emerging from their increasingly complex and adaptive evolution (Woods & Hollnagel, 2021). By integrating insights from both complex adaptive systems theory

(Holland, 2006) and technological evolution studies (Arthur, 2009), this analysis explores how the fundamental principles of RE must evolve to address the dynamic nature of modern technological landscapes.

One of the major emerging challenges for Resilience Engineering concerns the possibility of harnessing the data from new information-rich technologies to engineer a ‘whole system’ resilience. The alternative is increasingly differentiated silos of data that may be effective on a local level but do not contribute to building a system-wide resilience. The latter is predominantly the current state of the art.

New digital technologies and information systems in principle provide the opportunity to understand and monitor the normal operational process. In safety II terms they may provide a key source of evidence about work as done and what goes right (Hollnagel, as well as systems for adaptation, learning and improvement (e.g. Woods, 2018). However, data systems are often disconnected, data is often inaccurate, while in some cases the amount of data is overwhelming, in others there is a dearth of appropriate data. Data integration and data governance are challenges.

It is possible to outline a roadmap for the increasingly integrated use of technology-generated operational data, from directly managing process inputs to managing overall process performance and outcome (enabling powerful feedback), to building a systemic knowledge base that can support evidence-driven policy and practice. Each step is difficult. It involves building an integrated digital knowledge infrastructure, with a capability to manage and to support a range of organisational functions that support system resilience. This is core to a resilient system of mindful governance and accountability (McDonald et al., 2019).

8.2.9. Societal resilience

Ivonne Herrera and Mike Rayo (other potential contributors Martina Ragosta, Matthieu Branlat, Johan Bergström)

The new scale of disruptive events surpasses traditional emergency preparation, response, and recovery measures. To address these global challenges, international policies, and directives (e.g., Sustainable Development Goals, Sendai framework for disaster risk reduction, European Union Disaster Resilience Goals (CER, NIS2), promote a multidimensional, cross-sector approach and a more inclusive, equitable, and sustainable world that “leaves no one behind” approach, known as a “whole-of-society” approach. This approach involves policymakers, practitioners (first responders, public authorities), industry (large companies and SMEs), NGOs, local communities, citizens and working together to build a more resilient and equitable world. Effectively managing and even thriving despite the new scale of events will require new and more flexible configuration, synchronisation and collaboration among all societal levels with citizens playing a crucial role in adaptation, response and shaping response to future disruptions.

There exists efforts bringing resilience engineering to the societal scale. In this context, societal resilience is understood as a potential of all societal actors (both formal, e.g. authorities, and informal, e.g. citizens) to anticipate, adjust, adapt, and change everyday life, especially in the face of adverse situations (prior, during, and after) (Horizon 2020, ENGAGE project, 2020-2023). Efforts exist on revisiting concepts and methods to scale-up knowledge to a societal scale. It includes the development and use of analogue and digital tools, practices and strategies. Current work exists around the role of citizens (individuals and groups) as a crucial contributor to deal with crises tapping into citizens' needs, tacit knowledge, and capabilities to identify how citizens can develop and synchronise locally driven adaptive responses towards disruptive events (UCPM project, Empower Citizens, 2025-2027). In addition to being focused on crisis management, these same concepts are being used in the context of community co-planning, reimagining the role of community members as more vibrant and engaged participants whose voices are more readily heard. A number of efforts are underway to develop processes, collaborative architectures and technologies (i.e., computational ethnography) that can provide rich, quality ethnographic results that reflect the lived experiences and sentiments of groupings of people so large that they are impractical with current qualitative research methods.

8.2.10. Cognitive Systems Engineering and Resilient Joint Cognitive Systems

Mike Rayo, Rogier Woltjer, Jonas Lundberg

With recent advances in technology toward systems that approach autonomous operations, systems can engage in cognitive work, such as planning, goal setting, and making trade-offs. To address issues around how to successfully team up technology with humans, Cognitive Systems Engineering (CSE) is a solid foundation, especially for systems that are required to exhibit reliable real-time control. Such systems can be found for instance in air traffic management and industrial process control. However, in a changing world and to face the unexpected and unplanned, they also need to exhibit resilience. In this chapter we argue that RE does not replace CSE, but that they are complementary approaches that are both needed. We present and discuss common foundations and bridges between the areas, and present a basic set of notions for engineering resilient joint cognitive systems.

8.2.11. Resilience Engineering and Naturalistic Decision Making

Rogier Woltjer, John Allspaw, Elizabeth Lay

The core subject of study of the Naturalistic Decision Making (NDM) research community is expertise, understanding and improving decision-making in complex contexts, dealing with uncertainty and conflicting goals under time and resource scarcity. The core subject of Resilience Engineering (RE) is the adaptive capacity of systems and organizations to cope with trade-offs, uncertainty, complexity and variability. Adaptation requires expertise, and the NDM and RE communities both study individuals, teams, and socio-

technical systems, as part of organizations, using similar and oftentimes overlapping concepts and interests. This chapter explores some of the most striking similarities, overlaps and differences, in terms of concepts, models, methods, data, and research outputs, between the NDM and RE research communities. The chapter concludes with expected synergies and ways forward for interaction between NDM and RE.

8.2.12. Implementing Resilience Engineering, a case study from line clearance industry

Elizabeth Lay

Surprise is ubiquitous yet seldom acknowledged nor prepared for in ordinary work situations. In this chapter, we explore the practical application of fundamental Resilience Engineering premises “surprise will happen” and “work is variable” to the tree industry. We help translate Resilience Engineering theories into practical actions. This is a story about steps on a journey to transform from traditional, Behavior Based Safety to Safety II-Safety Differently focused on learning from surprise and managing variable work to create safety in the high-risk jobs of removing trees near power lines.

Practical application includes tool and practices invented in collaboration with OSU safety researchers that are being introduced more broadly across industries: close call mining, writing and telling stories that help people recognize early signs of trouble, creating space to practice with real work variability through “drill day”, using After Action Reviews to better understand the shape of surprise, changing leadership safety conversations by asking questions that explore trade-offs and everyday work, and reframing risk in terms of uncertainty (Press Pause, Uncertainty Gauge).

8.3. Opportunities

8.3.1. Evolving organisational capabilities to ensure resilient performance

Nick McDonald, Ivonne Herrera

The ever-changing landscape of our society characterised by an unstable political context, extreme weather events affecting critical infrastructures, and digital and green transformations are constant reminders of the need to revise and update the way of working to continued operations. This results in an exponentially increased demand for effective theories, methods and practices for resilient performance.

Resilience Engineering cannot deliver a specific set of capabilities to address diverse scales and growing complexity within and across organisations. It must deliver an overarching framework of evolving concepts and methods enabling us to understand complex interactions incorporating diverse dimensions of sustainability. Resilience is not just a spontaneous adaptation cycle, nor is it just an alternative grounded approach to safety management. It must critically address a range of systemic processes of proactive

adaptation. This includes adjustment at operational level within local processes, design for operations; management of risk and quality; organisational change, learning and improvement; emergency response and crisis management; short and long term innovation cycles; organisational and governance aspects. Understanding each of these processes involves dealing with organisational (and inter-organisational) systems, trade-offs, structures and processes, physical and technical infrastructures, as well as data, information and knowledge. While some of these aspects are general across a range of industries and services, other are specific to particular contexts. We need to understand both general principles and specific aspects.

So far RE has (for example):

- Delivered a critique to safety management proposing complementary ways to to safety management (Safety-II, address the gap between WAD-WAI)
- Highlighted the importance of complexity, emergence and non-linearity
- Addressed the challenge of limited resources (management of trade-offs and production pressure)
- Emphasized the certainty of limited resources and continuous change
- Delivered a set of potentials (monitor, anticipate, respond, learn)
- Produced systemic models and principles
- Mapped local adaptation in the context of crises

The range of concepts and methods in RE discourse must match the scale and complexity of challenges and opportunities we face adopting a dynamic ‘whole-systems’ and “whole-of-society” perspectives in context. We need to become more genuinely inter- and trans-disciplinary in our theoretical approaches. RE needs to adapt its own concepts and methods to assessing its own performance. It is important to understand in depth the long journey from theory and research to practice and building the capability for mature systemic practice. There are many open questions such as governance: how to legislate for, regulate and institutionalise the next generation of resilient capabilities?; implementation: how to move from body of knowledge into practice?, what is the impact on both theory and practice?

8.3.2. Resilience Engineering and opportunities

Participants: David Alderson, Pedro Ferreira and Lida Z. David. Edited from AI transcript and potential contributor Ivonne Herrera

There are some basic principles and processes that resilience engineering follows. One aspect of this is from the perspective of handling surprise. Equally important, though, is the perspective of seeking opportunity. We are considering the notion that the processes that guide us through challenges are basically the same as those at work in everyday situations and also for seizing opportunities. Being able to sustain operations during

change requires using enablers like critical thinking, taking initiatives and other processes. We can view these not only through the perspective towards not risk aversion, but also in seeking opportunities.

8.4. Challenges

8.4.1 What is the value proposition of Resilience Engineering?

Christopher P. Nemeth, Lida Z. David, Rogier Woltjer

What do we accomplish with RE, and why is it valuable? Clear answers can define RE's progress, challenges, and open the way for future opportunities. A concise description of RE's value can demonstrate how it can complement and enhance, rather than conflict with, traditional approaches to performance and safety improvement. Understanding RE can make it easier for organisations and practitioners to understand, promote, and use it.

8.4.1. Tactics and strategies across disciplines

John Allspaw (many participants are interested in this topic)

At the 20-year mark, it seems reasonable to take stock of Resilience Engineering and reflect on what progress has been made thus far and what challenges we can anticipate ahead. But what does progress look like? Would we recognize progress if we saw it?

If the number of practitioners in an organization clearly understands fundamental RE concepts increases, is that progress? If specific and concrete changes are made to work practices or environments that — in the eyes of RE researchers — demonstrate genuine positive support for *adaptive capacity*, is that progress?

In this chapter, we explore how various domains (like construction and software services) within the RE community perceive and acknowledge progress being made (in their local environments) in distinct ways.

In a 2021 article published in *Applied Ergonomics*, Richard Cook and Beth Long present a case study of resilience engineering (Building and revising adaptive capacity sharing for technical incident response: A case of resilience engineering, doi:10.1016/j.apergo.2020.103240). They describe in detail how an organization developed and refined an approach to better handle unexpected disruptions. This approach involved establishing a standing reserve of expertise and sharing its adaptive capacity when it's needed. This was adjusted and modified over time as the benefits became apparent.

This article is notable because, as the authors point out, there are relatively few examples of *engineering* resilience in the literature compared to other topics in the field. This case was found within the domain of online software engineering and operations, one of the many domains represented in the RE community.

We might expect researchers from other domains to be aware of this unique demonstration of resilience engineering. Are they? We might also imagine that others have explored what features of this case could be effectively “translated” to other environments, such as medicine, aviation, or others. Have they?

The multidisciplinary and multi-domain nature of the RE community is recognized as a strength, and indeed it is. But does this make it more difficult to keep aware of what progress is being made (as in this case), and what challenges are encountered in other domains? This chapter looks at these concerns and what, if anything, might be done differently to cope with them.

9. Resilience Engineering Association

9.1. Introduction

Elizabeth Lay and Pedro Ferreira

Editor's note (MR & IH): In addition to identifying topics for the RE20 book and reflecting on RE progress, the Resilience Engineering Association leadership took the opportunity provided by the assembling of these RE practitioners and academics to talk more about REA, its current structure, where the leadership wanted to take it, and how those attendees could play a role in its future.

The Resilience Engineering Association (REA) is an international community of practice which acts as a conduit between knowledge, theory, and resilient performance. REA includes a network of scientists, researchers, and practitioners who bridge theory and evidence-based practice, which is gathered from the eyes of people working in diverse industries.

REA Leadership Team is composed of the Executive Committee, Communications Team, Membership Team and the Young Talent Program.

9.2. REA overall strategy

Session moderated by Elizabeth Lay, Eric Rigaud and Mike Rayo

Strategic purpose of REA:

- Provide a path to learning about what a system is and what is required for resilient performance.
- Foster cross-disciplinary collaboration, uniting experts to tackle system resilience challenges.
- Connect science and industry through turning theories into practical solutions for resilient performance.

One of the most important events is our Biennial symposiums; the next symposium will be held jointly with the Resilient Health Care Society in Brazil <https://www.ufrgs.br/resilience/>

9.3. REA Communications

Session moderated by Lida Z. David

REA accomplishes our purpose through communication activities, enhancing engagement and visibility across various channels ([website](#), [webinars](#), [LinkedIn](#), [Newsletter](#)/Magazine). During the Porto meeting, the REA communications strategy 2024-2025 was discussed, as summarised here: Overall, we aim to better understand the background and interests of our community members, and tailor our content accordingly. The **REA website** will be redesigned to serve as a comprehensive portal, both for academia and practitioners. **Webinars** will emphasise relevance of RE to current issues (e.g. disasters, breakdowns e.g. Crowdstrike outages 2024, etc). We aim to develop panel discussions followed by open cafes. We further aim to release a **REA Magazine** to provide diverse, accessible content on REA topics. To enable quick dissemination, possible tactics to achieve this include releasing individual contributions on LinkedIn and combine into one Magazine. With respect to **Social media**, particularly LinkedIn, we will drive active discussions, featuring bi-weekly posts from our REA leadership team. Posts may include creative contributions, and a dynamic idea corner to connect users to the website and magazine. These initiatives aim to create a vibrant, interconnected platform that reflects and amplifies the interests of the REA community. Main channels and events to join in 2025:



Figure 9 RE Communications activities with link

9.4. REA Young Talent Programme

Session moderated by Arie Adriaensen

Our current REA Young Talents organizing team reflects the gender- and geographical diversity of our RE community (Chair: Arie Adriaensen | the Netherlands; co-chairs: Tanno Karo | Japan, Ellke Ketelaers | Switzerland).



Figure 10 Young Talents workshop 2023 – France (in the company of Ivonne Herrera and Erik Hollnagel)

The mission of the Young Talents Program of the Resilience Engineering Association is to empower, inspire, and nurture the next generation of resilience engineers with the aim to equip future leaders with the skills, insights, and networks necessary to drive new theoretical contributions and resilient solutions across diverse industries and communities with a special focus on connecting the academic and the applied perspective.

The Young Talents program creates value by providing young researchers with unique, real-world learning experiences, access to a global network of resilience engineering experts, and platforms for professional growth. The highlight of our Young Talents program is a bi-annual workshop organized to coincide with the REA symposium. During this workshop, Masters' and Ph.D. students within the fields of RE will have the opportunity to present their work to and exchange with prominent researchers in these fields. During several online activities, Young Talents are prepared for this workshop and get the opportunity to bond before meeting each other in person. As the Young Talents program has typically been driven by previous program participants, it ensures the safeguarding of Resilience Engineering across generations.

The Young Talents program has been the entry point for many actively engaged in the REA organization. Recently, the Young Talents program has also focused on greater diversity within the RE community by focusing on participation from and initiatives for participants from Asia. Expanding RE's graphical diversity is an important objective.

The [call for proposals](#) for the next Young Talents workshop is now launched and will be organized in conjunction with the [11th Symposium on Resilience Engineering](#) in Canela, Brazil.

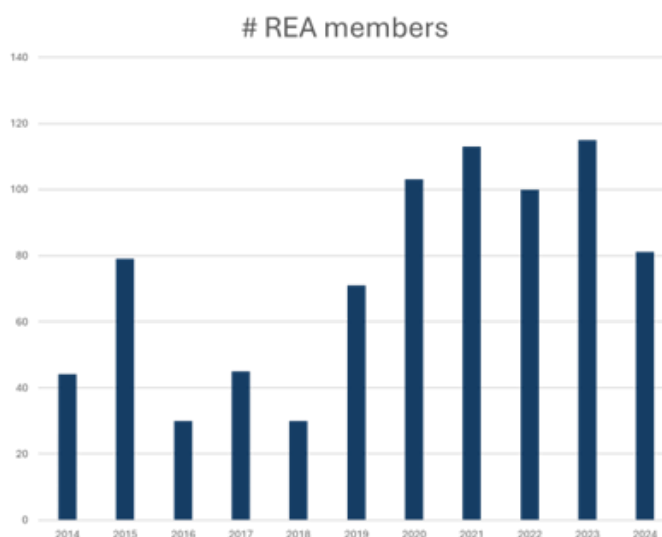
The Young Talents participation history and distribution can be tracked by infographics through this [link](#).

9.5. REA membership

Contribution from Elizabeth Lay

REA is currently seeking a leader for the membership team. REA membership numbers increase during symposia years and have been slightly declining. The purposes of the Membership Team are:

- To understand who members are and what they need and want
- Create value for members (e.g., networking activities)



10. Concluding remarks – the way forward

The material collected and this report provide a basis for knowledge sharing, investigating further lines of inquiry, furthering practice and joining new partnerships. Different initiatives will follow, including the next REA symposium, new young talents joining the community, strengthening relations with other communities and the preparing a book to reflect more in detail on progress, challenges and opportunities.

We thank the organisers and participants of the RE20 Porto meeting for embarking on this journey of discovery with us. Now we call on them, and you, to join us in continuing on that journey. The RE20 meeting much like previous meetings, produced themes and topics that could only emerge from diverse perspectives coming together. We see this meeting as a landmark moment that further clarified the three interlinked areas of progress, challenges and opportunities.

What is unique to Resilience Engineering as a transdisciplinary discipline for research and practice and the Resilience Engineering Association as a community is our people. We're passionate to contribute to address complexity. Our community is one of interacting, discussing and learning together across multiple diverse domains as well as multiple systems scales, from intraorganizational units to large-scale societies.

We have made progress both in theory and practice! However, by the end of the meeting, it was also clear that these two areas require further attention. Resilience Engineering is grounded in foundational concepts, and further work is required to make these concepts and pragmatic tools available to wider and diverse audiences. While Resilience Engineering started from safety toward the end of the meeting there is consensus that Resilience Engineering is not solely about safety.

This report reflects specific developments and intends to serve as source of inspiration to learn, agree, disagree and grow. We welcome you to be a part of all of the above!

Appendix A. Agenda

Day 1	Activity
15:00 – 15:45	Working lunch: welcome, purpose, plan & goals and introduction activity
15:45 – 18:15	<p>Charrette Round 1, 2, & 3: 3 questions – 3 groups (45 min per question)</p> <p>Reflecting on your own experiences and work:</p> <ul style="list-style-type: none"> – Progress: How has RE advanced in recent years, and what key developments or innovations have been achieved? (What is unique to RE?) – Challenges: What are the key challenges faced in RE? – Opportunities: Where do the opportunities lie for advancing RE in the future?
18:15 – 18:45	Debrief: what worked well, what can be improved, what is next & pose questions for reflection
18:45 – 19:15	Facilitators organize Day 1 work and plan for Day 2
Day2	
8:00 – 9:00	Summarize initial picture from day 1.
8:30 – 12:30	<p>Go deeper on exploration of progress, challenges, and opportunities using Charrette process: Look for connections, patterns, commonalities. Seek opportunities to collaborate.</p> <ul style="list-style-type: none"> · Revisit question 1 – 1 hr. · Revisit question 2 – 1 hr. · Revisit question 3 – 1 hr.
12:30 – 13:30	Working lunch
13:30 – 16:30	<ul style="list-style-type: none"> – Debrief morning session. – Open space for creation of book topics <ul style="list-style-type: none"> – Part 1 - 1 hr. Groups self-organize according to themes. – 15 min check-in: Come back together. – What else do we need to work on? Gaps? – Part 2 – 1 hr. 45 min – Produce rough topics/titles/outline for book. – Self-organize again. As a group, work on the book. Collectively decide what is most important. What do you want to write about?
16:30 - 17:00	Debrief: what worked well, what can be improved, what is next & pose questions for reflection
Day 3	
8:30 – 12:30	<p>Design for our future: REA strategy, tactics (actions going forward) 2024 REA strategy (brief).</p> <p>Membership, scholarship, communications, support for practitioners, support for academics, funding, next symposium. Feedback how is REA supporting these things? + and – Gaps? How can people contribute? Share out.</p> <p>12:00 – 12:30</p> <p>Closure What worked well? What could be improved? Next steps?</p>

Appendix B. Acronyms and abbreviations

Acronym	Explanation
CI	Critical Infrastructure
DRS	Disaster Resilient Societies
RE	Resilience Engineering
REA	Resilience Engineering Associatiom

Appendix C. Individual submissions overview



Join the Resilience Engineering community



www.resilience-engineering-association.org



RESILIENCE ENGINEERING ASSOCIATION