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DESIGN FOR RESILIENT PERFORMANCE: PRINCIPLES, PRACTICES, AND ASSESSMENT

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Tese submetida ao Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul como requisito parcial à obtenção do título de Doutora em Engenharia, na área de concentração em Sistemas de Qualidade.

Orientador: Professor Orientador Tarcisio Saurin, Dr.

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Esta tese foi julgada adequada para a obtenção do título de Doutora em Engenharia e aprovada em sua forma final pelo Orientador e pela Banca Examinadora designada pelo Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul.

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Dedico esta tese ao meu pai Arno de Oliveira
Disconzi (in memoriam), que sonhava em me
ver doutora. Sei que te fiz orgulhoso.

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RESUMO

A resiliência é a propriedade dos sistemas sociotécnicos complexos (SSCs) de manterem as suas funcionalidades frente a mudanças e eventos esperados e inesperados. O desempenho resiliente (DR) resulta tanto da auto-organização informal das pessoas quanto de recursos projetados. Esta tese enfatiza a DR apoiado por ações projetuais, tendo por objetivo desenvolver um método para avaliar o uso dos princípios e práticas de *Design for Resilient Performance (DfRP*) nos sistemas sociotécnicos. A estratégia de pesquisa adotada foi a *Design Science Research (DSR),* desenvolvida em três fases: compreensão do problema, desenvolvimento da solução e avaliação da solução. Inicialmente, uma revisão da literatura foi conduzida para identificar princípios de projeto de SSC na área de fatores humanos. Posteriormente, três rodadas do método Delphi foram conduzidas com especialistas, resultando na proposta do conceito e de sete princípios de *DfRP*. Tendo em vista compreender como os princípios se manifestam na realidade, bem como avaliar a sua validade externa, estudos de caso foram conduzidos em hospitais, construção civil e manufatura. Nesses estudos, foram analisadas as seguintes práticas de DfRP: os times de resposta rápidas e os *huddles* em hospitais, a cadeia de ajuda em uma planta de manufatura e os diálogos diários de segurança em um canteiro de obras. Por fim, o método de avaliação dos princípios e práticas de DfRP foi desenvolvido e testado em um hospital, no qual os *huddles* eram a prática central de *DfRP*. O método permite a avaliação de 24 atributos dos princípios, a análise de suas relações (um modelo foi desenvolvido com base em uma pesquisa com especialistas) e a investigação de práticas que operacionalizam os princípios. Um sistema de pontuação ilumina a intensidade de uso dos princípios. Este estudo contribui para a teoria de *DfRP* e oferece uma nova abordagem para avaliação da resiliência.

Palavras-chave: desempenho resiliente; projeto de sistemas de trabalho; times de resposta rápida, huddles; cadeia de ajuda; toolbox talks.

ABSTRACT

esilience is the property of complex sociotechnical systems (SSCs) to maintain their functionalities in the face of expected and unexpected changes and events. Resilient performance (RP) results from both the informal self-organization of people and designed resources. This thesis emphasizes RP supported by design actions, aiming to develop a method to assess the use of principles and practices of Design for Resilient Performance (DfRP) in sociotechnical systems. The adopted research strategy was Design Science Research (DSR), developed in three phases: problem understanding, solution development, and solution evaluation. Initially, a literature review was conducted to identify SSC design principles in the human factors domain. Subsequently, three rounds of the Delphi method were carried out with experts, resulting in the proposal of the concept and seven DfRP principles. In order to understand how the principles manifest in reality and to assess their external validity, case studies were conducted in hospitals, construction, and manufacturing. In these studies, the following DfRP practices were analyzed: rapid response teams and huddles in hospitals, the help chain in a manufacturing plant, and daily safety dialogues on a construction site. Finally, the evaluation method for DfRP principles and practices was developed and tested in a hospital, where huddles were the central DfRP practice. The method allows the assessment of 24 attributes of the principles, the analysis of their relationships (a model was developed based on expert research), and the investigation of practices that operationalize the principles. A scoring system illuminates the intensity of principle usage. This study contributes to the theory of DfRP and offers a new approach to resilience assessment.

Keywords: resilient performance, work systems design, rapid response teams, huddles, help chain, toolbox talks.

SUMÁRIO

1 INTRODUÇÃO

1.1 Contexto

A teoria dos sistemas sócio-técnicos (STS) descreve o funcionamento de sistemas que envolvem interações entre seres humanos, tecnologias, organização do trabalho e o ambiente externo (Baxter; Sommerville, 2011; Dekker, 2014). A complexidade dessas interações tem aumentado ao longo das últimas décadas, devido a fatores como cadeias de suprimentos compostas por muitos atores, ambiente externo turbulento, uso crescente de tecnologias digitais e diversidade de metas, por vezes conflitantes, que as organizações devem atingir (Luther et al., 2023).

A literatura salienta alguns atributos típicos de sistemas sócio-técnicos complexos (SSCs), tais como grande número e diversidade de elementos, interações dinâmicas não-lineares, feedback *loops*, incertezas, interação com o ambiente externo, entre outras (Perrow, 1984; Cilliers, 2002; Braithwaite, 2018; Jensen; Aven, 2018). Consequentemente, em SSCs, as operações exibem alguma forma de variabilidade, definida como a falta de uniformidade de uma classe de entidades; essa variabilidade pode ser projetada em um sistema (por exemplo, a variedade de produtos) ou ser aleatória (por exemplo, a auto-organização das pessoas para lidar com variações na demanda ou uma falha técnica) (Hopp; Spearman, 2008). Sendo assim, a variabilidade no dia-a-dia do trabalho é inevitável, gerando a necessidade de ajustes de desempenho (Stevens et al., 2021). No entanto, esses ajustes muitas vezes são imperfeitos, contribuindo tanto para resultados esperados quanto para os inesperados (Hollnagel; Woods; Leveson, 2006; Hollnagel, 2021).

Embora seja provável que todos os STS tenham pelo menos algumas características de complexidade, alguns sistemas, como por exemplo, plantas petroquímicas, infraestruturas de transporte, geração e distribuição de energia, hospitais, são considerados fortemente complexos (Perrow, 1984). No entanto, mesmo dentre esses sistemas, as características de complexidade podem estar presentes em diferentes níveis (Perrow, 1984).

Considerando tais características, existe a necessidade de uma gestão que se adeque à natureza dos SSCs (Hollnagel et al., 2017). A Engenharia de Resiliência (ER) apresenta princípios e práticas de gestão compatíveis com as características dos SSCs, visando auxiliar os sistemas, e as pessoas que fazem parte deles, a lidarem com a complexidade (Hollnagel et al., 2017; Ham, 2021).

Resiliência é definida por Leveson (2006) como a habilidade do sistema se adaptar às circunstâncias, com o objetivo de manter o controle. Para Wreathall (2006), resiliência é a capacidade organizacional de manter um estado estável, ou recuperá-lo, permitindo a continuação das operações após a ocorrência de variabilidades significativas. Conforme Hollnagel e Nemeth (2022), resiliência é *"a habilidade de obter sucesso sob condições variadas, de modo que o número de resultados esperados e aceitáveis (em outras palavras, atividades do cotidiano), seja o mais alto possível"*. Como principal aspecto em comum, essas definições de resiliência enfatizam a capacidade adaptativa em nível organizacional. Por sua vez, a ER tem por objetivo desenvolver teorias, métodos e ferramentas que auxiliem na gestão da resiliência, visando um funcionamento eficiente e com segurança (Nemeth; Herrera, 2015; Patriarca et al., 2018).

Hollnagel (2017) afirma que para um sistema ser resiliente, quatro potenciais são essenciais: responder, monitorar, antecipar e aprender. A importância relativa desses quatro potenciais depende do contexto, embora todos sejam necessários. Responder consiste na habilidade das organizações em responder às questões usuais e distúrbios incomuns do sistema. O potencial de monitorar envolve observar o que pode acontecer em um futuro a curto prazo. Para isso, deve-se saber o que procurar no intuito de monitorar tudo aquilo que pode afetar o funcionamento do sistema de forma positiva ou negativa, no horizonte de tempo imediato. O potencial de antecipar implica em saber o que esperar, ou seja, consiste em descobrir possíveis eventos futuros, que possam ocorrer a longo prazo, e que podem afetar a organização de uma maneira positiva ou negativa. Assim, o sistema deve se preparar para esses eventos, através de ações planejadas. Por fim, tem-se o potencial de aprender, no qual a organização aprende com o passado através de suas experiências de sucesso e insucesso (Hollnagel, 2017).

A ER vem sendo estudada e praticada em diversos setores, tais como aviação, saúde, construção, químico, marítimo, petróleo, rodoviário, dentre outros (Patriarca et al., 2018; Cantelmi et al., 2022). Através de uma revisão sistemática da literatura, Righi et al. (2015) identificaram seis áreas de pesquisa envolvendo ER, sendo elas: teoria de ER, identificação e classificação da resiliência, ferramentas de gestão de segurança, análise de acidentes, avaliação de risco e treinamento. Neste mesmo trabalho, sugestões de estudos futuros são apresentadas, tendo por foco refinar constructos chave, posicionar a ER em relação a outras teorias, investigar barreiras na implementação da ER, e dar ênfase à resiliência no projeto de sistemas.

Conforme Wachs et al., (2016), o desempenho resiliente (DR) decorre, em parte, da auto-organização das pessoas que buscam preencher lacunas nos padrões de trabalho. Contudo, os autores apontam que o desempenho resiliente também decorre de recursos projetados com antecedência para esse propósito. De acordo com Hollnagel e Nemeth (2022), a maioria dos sistemas sócio-técnicos apresenta algum grau de resiliência projetada, embora isso seja geralmente uma consequência não intencional de decisões relacionadas com as dimensões tradicionais de desempenho como qualidade, produtividade, confiabilidade e segurança.

1.2 Problema de pesquisa

A crescente complexidade dos sistemas sócio-técnicos tornou mais evidente a necessidade de considerar a resiliência como uma dimensão de desempenho organizacional que precisa de recursos e planejamento (Galaitsi et al., 2021), começando na fase de concepção do sistema. A pandemia de coronavírus tornou essa necessidade ainda mais clara para os SSCs de diversas naturezas, como saúde, construção, educação, aviação, serviço público e cadeias produtivas (Carayon; Perry, 2021; Drăgoicea et al., 2020).

Conforme Rankin et al. (2014), os projetos dos sistemas devem permitir e apoiar que as pessoas tenham um desempenho resiliente. Algumas pesquisas fazem referência à resiliência projetada (*Design for Resilience*), com destaque para estudos nas áreas de cadeias de suprimentos na indústria da manufatura, projeto de produtos, projeto de edificações e desenvolvimento de *software* (Chatterjee; Layton; 2020; Borsci et al.; 2018; Ali et al., 2021; Croce et al., 2021).

O estudo de Kusiak (2020), por exemplo, discute o projeto para resiliência no contexto de produtos manufaturados, apresentando a modularidade e a diferenciação tardia do produto como princípios projetuais relevantes. Por sua vez, Borsci et al. (2017) exploraram o projeto de tecnologias médicas resilientes, propondo o uso de protótipos e testes em distintos cenários, principalmente envolvendo riscos.

Apesar desses estudos e outros similares se enquadrarem na temática de projeto para a resiliência, há ênfase na dimensão técnica dos sistemas estudados, dando atenção secundária às dimensões sociais e organizacionais, bem como à interação dessas com a dimensão técnica.

Muitos desses estudos (por exemplo, Borsci et al.,2017; Dragoicea et al., 2020) também possuem ênfase em variabilidades extremas e relativamente raras (por exemplo, desastres naturais) ao invés das variabilidades usuais no dia-a-dia, tais como escassez de recursos e pressões por eficiência. Contudo, a ER também possui interesse na dimensão sócio-técnica e nas variabilidades diárias (Hollnagel, 2017).

Embora existam muitas abordagens "*design for X*", como *Design for Manufacturing, Design for Assembly* e *Design for Quality* (Sassanelli et al., 2020), o conceito de *Design for Resilient Performance (DfRP*), no contexto dos SSCs e considerando a lente teórica da ER, ainda não foi explorado na academia e na prática. A presente tese trata dessa lacuna, tendo por foco estudar a porção projetada de resiliência, a qual dá suporte a resiliência decorrente da auto-organização informal das pessoas. Ainda que não existam estudos que explicitamente se refiram ao *DfRP* e seus princípios, os SSCs normalmente possuem algum grau de resiliência projetada (Wachs et al., 2016), conforme já mencionado.

Como um recorte adicional, esta tese possui ênfase no uso do *DfRP* no dia-a-dia dos SSCs, visando compreender como o desempenho resiliente é apoiado por práticas organizacionais. Um pressuposto subjacente a essa ênfase é o de que o *DfRP* é implícito e contínuo, ocorrendo por meio de práticas gerenciais que, embora não explicitamente focadas no desempenho resiliente, acabam por influenciá-lo. Neste estudo, assume-se que práticas são ferramentas e processos gerenciais projetados que operacionalizam princípios mais abstratos, incluindo necessariamente um componente humano. Um componente técnico é útil, mas não fundamental para uma prática de *DfRP*. Essa definição é baseada na premissa de que o desempenho humano continua sendo essencial para a adaptação, apesar dos avanços tecnológicos (Hollnagel, 2021; Xu et al., 2021).

Essas práticas podem envolver pessoas de vários níveis hierárquicos, como por exemplo no método *Resilient Performance Enhancement Toolkit (RPET).* Esse método propõe a reflexão sobre o trabalho diário desempenhado pelas equipes hospitalares frente às variabilidades. A proposta central é uma reunião diária dos trabalhadores e supervisores para uma discussão rápida (não mais de 20 minutos) sobre o dia de trabalho enfrentado (Hollnagel, 2019). Também no contexto hospitalar, ocorre a prática dos *huddles* pelas equipes assistenciais (Dutka, 2016). Os *huddles* são reuniões breves, em torno de 10 minutos, que ocorrem diariamente em ambiente clínico (Schatz; Bergen, 2021). O foco é planejar, comunicar e discutir tarefas e funções diárias de maneira coletiva, considerando principalmente as demandas relacionadas ao tratamento dos pacientes e ao fluxo de trabalho (Rodriguez et al., 2015). Inspirado no RPET e nos *huddles*, Wahl et al. (2022) relatam a implementação da *Green Line tool* em um hospital Sueco. O objetivo desta ferramenta foi promover o aprendizado e melhorias com base no que acontece em um dia usual de trabalho (Wahl et al., 2022). Os autores propuseram uma adaptação dos *huddles* já realizados na unidade neonatal do hospital, encorajando a discussão e o aprendizado a partir de resultados positivos, em complemento ao tradicional foco de aprendizagem baseado em situações indesejadas. Os autores destacam que houve dificuldade por parte dos participantes em descrever e aprender a partir de sucessos ao invés de fracassos.

No âmbito da construção civil, uma prática potencialmente relacionada ao *DfRP* são as *toolbox talks*, também chamadas de Diálogos de Segurança (DDS), nas quais trabalhadores e seus líderes se reúnem no começo da jornada de trabalho para conversar sobre assuntos relacionados principalmente à segurança no trabalho (Stray et al., 2017). Outras ações similares, principalmente envolvendo gestão de projetos, são as reuniões para *briefing* e *debriefing*. Nessas reuniões as equipes se reúnem para entendimento e discussão de um conjunto de informações e dados para desenvolvimento de um trabalho ou documento (Halamek et al., 2019).

Além das rotinas citadas, com formatos que envolvem reuniões para reflexão e aprendizagem sobre o trabalho, há outros tipos de rotinas gerenciais em que os recursos estão em espera e podem ser acionados para lidar com a variabilidade apenas quando necessário. Esse é o caso da prática conhecida como *Help Chain*, ou Cadeia de Ajuda (CA). A cadeia de ajuda corresponde a uma padronização do processo de resposta imediata a anormalidades identificadas nos processos (Tortorella; Fettermann, 2018). Consiste em uma rede formada por áreas de suporte ao processo produtivo, com gatilhos de pedido de ajuda pré-definidos (Flinchbaugh, 2007; Pelizzon et al., 2019).

Nos hospitais, os Times de Resposta Rápida (TRRs) têm papel similar ao da cadeia de ajuda. Os TRRs são formados por profissionais da saúde com o objetivo de identificar e agir preventivamente frente a quadros de deterioração de condições clínicas, a fim de impedir mortes intra-hospitalares evitáveis (Devita; Hillman; Bellomo, 2017). O TRR é ativado através de gatilhos baseados nos sinais vitais do paciente, podendo ser no formato dicotômico ou via escore agregado (Davies et al., 2014).

Percebe-se que as rotinas mencionadas, seja no formato de reuniões ou de recursos em espera podem contribuir para o desempenho resiliente, em termos dos potenciais de monitorar, antecipar, responder e aprender frente às variabilidades. Entretanto, essas contribuições são implícitas, o que sugere que os seus benefícios para o *DfRP* podem não estar sendo completamente explorados. Dessa forma, esta tese analisa práticas com contribuição potencial para o *DfRP*, verificando seus pontos em comum, diferenças e possibilidades de aperfeiçoamento.

Ainda, o *DfRP* geralmente implica no redesenho de um sistema sociotécnico existente, em vez de projetar um novo sistema do zero. Esse redesenho pode se beneficiar da avaliação do grau em que o sistema já contempla a *DfRP*. Para isso, a utilização de ferramentas como o *Resilience Assessment Grid* (Hollnagel, 2017) e indicadores de resiliência (Peñaloza et al., 2021) oferecem informações úteis. Como desvantagem, nenhuma dessas abordagens é enquadrada em termos de *DfRP*, o que se deve em parte à falta de uma teoria de *DfRP* abrangente e empiricamente testada. Assim, as avaliações de resiliência não são explicitamente orientadas para o projeto, e a transformação das descrições de desempenho resiliente em intervenções tende a depender excessivamente de projetistas experientes e familiarizados com a ER. Além disso, as ferramentas de avaliação de resiliência não abordam explicitamente questões centrais da gestão da resiliência, uma aproximação da *DfRP*, propostas por Wiig et al. (2020), nomeadamente resiliência para quê (os objetivos apoiados pela DR), de quê (quais materiais e recursos sustentam a resiliência), para quê (o que desencadeia e ativa a resiliência) e através de quê (mecanismos, atividades e interações que suportam a resiliência). Conforme Hermelin et al. (2020), a literatura sobre resiliência e seus benefícios carece de estudos sobre como reconhecer, operacionalizar e implementar práticas resilientes de acordo com a realidade das operações.

1.3 Questões e objetivos de pesquisa

1.3.1 Questões de pesquisa

Considerando a problemática apresentada, esta tese busca responder a seguinte questão principal de pesquisa: Como avaliar o uso dos princípios e práticas de *Design for Resilient Performance (DfRP)* nos sistemas sócio-técnicos?

Com base nisso, as seguintes questões secundárias são propostas:

(a) Qual o conceito e os princípios de *DfRP*?

(b) Como as práticas relacionadas a reuniões reflexivas e equipes em espera consideram os princípios de *DfRP*?

1.3.2 Objetivos

No intuito de responder à questão de pesquisa, esta tese tem por objetivo geral desenvolver um método para avaliar o uso dos princípios e práticas de *Design for Resilient Performance (DfRP*) nos sistemas sócio-técnicos.

A partir do desdobramento do objetivo geral desta tese, dois objetivos específicos foram elaborados:

a) Propor um conceito e princípios de *DfRP*;
b) Avaliar o uso dos princípios de *DfRP* por práticas de reuniões reflexivas e equipes em espera.

1.4 Estratégia de pesquisa

A estratégia de pesquisa adotada nesta tese é a *Design Science Research (DSR),* a qual trata da solução de problemas práticos e com relevância teórica através da proposta de artefatos projetados (Van Aken, 2004). Esses artefatos geralmente são modelos, métodos, frameworks, projetos e princípios, teorias de design, dentre outros (Hevner et al., 2004). Para Lukka (2003), a *DSR* permite aproximar a teoria da prática e vice-versa.

Tendo em vista essas características da *DSR*, verifica-se que se trata de uma estratégia de pesquisa adequada, considerando que o objetivo geral proposto neste trabalho envolve a elaboração de um método para avaliação do uso dos princípios e práticas de *DfRP*. Para a solução do problema, esta tese divide-se em três fases, as quais são apresentadas na Figura 1. A primeira fase consiste na *(i)* compreensão do problema, envolvendo a elaboração do conceito de *DfRP* e de seus princípios, como também o entendimento de como esses princípios se manifestam no dia-a-dia dos SSC através de práticas formais adotadas pelas organizações. Esta fase abrange os objetivos específicos a e b propostos. As fases *(ii)* desenvolvimento da solução e *(iii)* avaliação do artefato compreendem o objetivo geral da tese, que é o de elaboração um método para avaliar os princípios e práticas de *DfRP*, testado e validado na prática.

No intuito de compreender o problema sob diferentes perspectivas, os setores hospitalar, da construção civil, e da manufatura foram selecionados para os estudos empíricos. As atividades nesses setores exigem e manifestam desempenho resiliente (Soliman; Saurin, 2017; Austin et al., 2022; Bhattacharjee et al., 2024), bem como apresentam práticas formais que, com base em indicações preliminares da literatura, aparentam usar os princípios de *DfRP*. Também se optou por diversificar os tipos de práticas a serem observadas no decorrer da tese de acordo com seu formato e foco. Foram selecionadas para investigação duas práticas em formato de reuniões de reflexão, os *huddles* e as *toolbox talks*, e duas que disparam pedidos de ajuda com recursos em espera, o TRR e a cadeia de ajuda. A escolha dessas práticas justifica-se pois elas são relativamente disseminadas em vários países e em muitas organizações (Scofield et al., 2022; Al-Shabbani et al., 2020; Davies et al., 2014; Pelizzon et al., 2019), o que aumenta a validade externa do artefato proposto.

Um misto de abordagens dedutivas e indutivas é aplicado nesta tese. A abordagem dedutiva baseia-se em uma teoria pré-existente, ou seja, parte do entendimento da regra geral para compreensão e conclusão de casos específicos. Enquanto isso o método indutivo consiste em comparar casos específicos visando resultar em uma regra geral (Gephart, 2004; Gale et al., 2013).

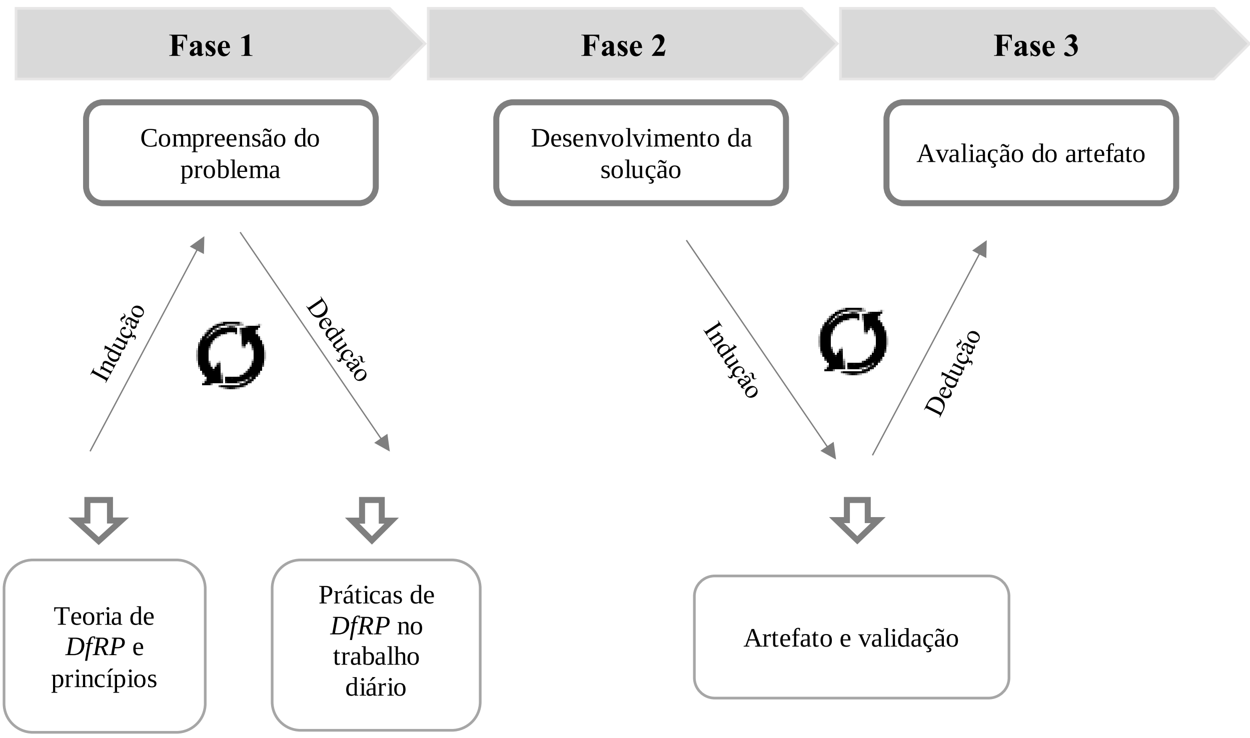

Figura 1 – Fases da pesquisa

Fonte: elaboração própria.

Sendo assim, considerando o objetivo geral desta tese, verificou-se a possibilidade de desenvolver dois ciclos de indução-dedução, como demonstrado na Figura 1. A primeira etapa de indução parte de uma revisão bibliográfica e rodadas do método Delphi com especialistas para a construção do conceito de *DfRP* e de seus princípios. Posteriormente, na seguinte etapa de dedução, confronta-se a teoria proposta com a prática, buscando a validade externa dos princípios em diferentes contextos através dos estudos de caso já mencionados. Esse primeiro ciclo de indução-dedução compõe a fase 1, de compreensão do problema.

A fase 2 de desenvolvimento da solução é indutiva, pois tem por foco o desenvolvimento do artefato, de acordo com as observações realizadas e as proposições resultantes da fase anterior de dedução. O segundo ciclo indutivo-dedutivo encerra-se com a fase 3, de dedução. Para cumprimento desta fase de avaliação do artefato, apresenta-se a aplicação prática do framework através de um estudo de caso em um hospital, com destaque para a prática dos *huddles* no setor de emergência adulta de um hospital público.

1.5 Estrutura da tese

A estrutura desta tese divide-se em três fases, as quais já foram apresentadas anteriormente. Quatro artigos contribuem para o atendimento aos objetivos apresentados, conforme demonstra a Figura 2.

O artigo 1 intitulado "*Design for resilient performance: Concept and principles*" visa responder ao primeiro objetivo específico exposto nesta tese e tem por foco propor o conceito de *Design for Resilient Performance (DfRP)* e uma lista de princípios fundamentais. Para construir o conceito e definir os princípios, foi conduzida uma revisão bibliográfica, um estudo Delphi com especialistas composto por três rodadas e um estudo de caso em um hospital. Este artigo consta em sua íntegra publicado na revista *Applied Ergonomics* sob DOI: https://doi.org/10.1016/j.apergo.2022.103707.

O artigo 2 tem por título *"Design for Resilient Performance: a study of toolbox talks in construction"*, e juntamente com o artigo 3, o qual intitula-se "*Practices for Design for Resilient Performance: the role of huddles in emergency departments and help chain in manufacturing plants"* respondem ao segundo objetivo específico da tese, tendo por foco a análise de práticas rotineiras de gestão organizacional que fornecem suporte implícito aos princípios de *DfRP,* através de estudos de casos que abordam as *toolbox talks*, os *huddles* e a cadeia de ajuda. O artigo 2 foi publicado no *10th Symposium on Resilience Engineering*, organizado pela *REA (Resilience Engineering Association),* disponível no endereço: https://www.resilience-engineering-association.org/blog/2023/12/15/10th-symposium-proceedings-preliminary-version/ .O artigo 3 foi publicado em uma versão simplificada, em português, no XXIII Congresso de Brasileiro de Ergonomia, organizado pela Associação Brasileira de Ergonomia (ABERGO) em 2023, disponível no endereço: www.even3.com.br/Anais/abergo2023/688414-PROJETO-PARA-DESEMPENHO-RESILIENTE--O-PAPEL-DAS-REUNIOES-REFLEXIVAS-E-DAS-EQUIPES-EM-ESPERA.

O artigo 4 tem por título *"Principles and practices of designing for resilient performance: an assessment framework"*. Sua proposta consiste em apresentar um framework para avaliar em que medida um sistema utiliza práticas e princípios de *DfRP*, inclusive desdobrando os princípios em atributos observáveis e auditáveis. Além disso, o framework permite a análise das relações entre os princípios, e a análise aprofundada das práticas que os operacionalizam. Tal protocolo foi validado por meio de um estudo de caso através da avaliação dos *huddles* do setor de emergência de um hospital público. O framework apresentado neste artigo atende ao objetivo geral proposto nesta tese e encontra-se publicado em sua íntegra na revista *Applied Ergonomics* sob DOI: https://doi.org/10.1016/j.apergo.2023.104141.

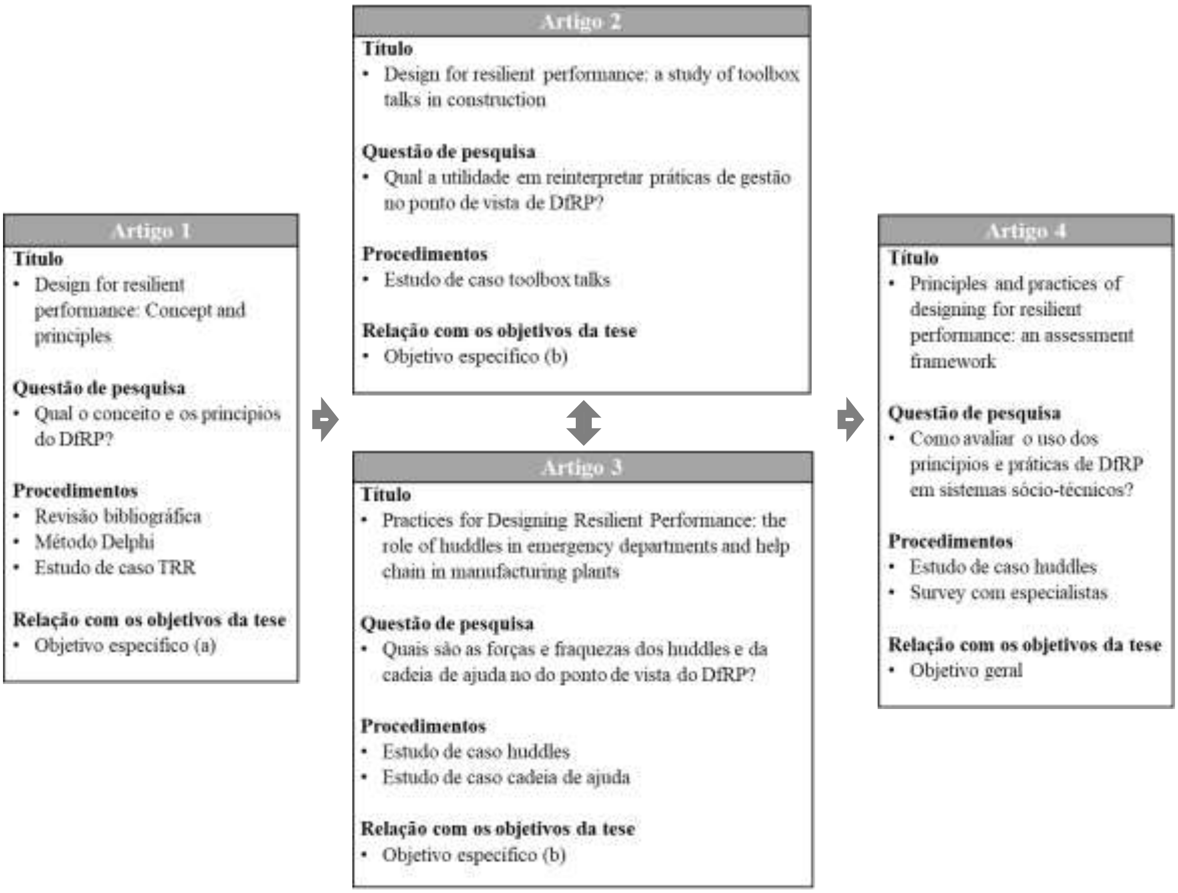

Figura 2 – Estrutura da pesquisa
Fonte: elaboração própria.

1.6 Delimitações da tese

O escopo de pesquisa adotado nesta tese apresenta algumas delimitações, tais como: *(i)* o conceito de resiliência abordado adota a perspectiva da engenharia de resiliência no contexto dos sistemas sócio-técnicos complexos; *(ii)* os dados empíricos são resultantes de quatro estudos de caso, cada qual considerando uma prática gerencial, sendo elas TRR, *huddles*, *toolbox talks* e cadeia de ajuda. Contudo, existem outras formas de colocar o *DfRP* em prática, bem como também há necessidade de análise em uma gama mais variada de SSCs; *(iii)* foram identificados e estudados dois grupos de práticas de *DfRP*, o que não significa que não possam haver outros; *(iv)* os princípios são resultantes de um estudo Delphi envolvendo um painel de especialistas selecionados, bem como o desenvolvimento do modelo de relacionamento entre os princípios foi resultante de uma survey com especialistas. Apesar de terem sido cuidadosamente escolhidos, uma composição diferente poderia ter gerado resultados distintos;

(v) os princípios de *DfRP* foram analisados em sistemas já existentes, ou seja, não serão testados na fase de projeto de um novo sistema; *(vi)* os estudos de casos realizados foram transversais, portanto não foi possível analisar como a adoção dos princípios e práticas de *DfRP* mudaram ao longo do tempo.

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2 ARTIGO 1 – *Design for resilient performance: Concept and principles*

Abstract

Resilient performance in socio-technical systems is usually described as stemming from people's self-organization and spur-of-the-moment actions and decisions. However, this is not exclusive with work system design ahead of time, with the deliberate intention of influencing resilient performance. This paper proposes a concept and principles of Design for Resilient Performance (DfRP), making explicit contributions that had been concealed and fragmented in the literature. Based on a literature review of influential human factors studies, 23 design principles were initially identified and set a basis for a Delphi study with 27 experts from nine countries. After three Delphi rounds, consensus was obtained and the DfRP concept was defined as well as seven design principles, namely: (*i*) there must be functional models of the system; (*ii*) make variations in performance visible; (*iii*) use the type of standardization that best fits the nature of the function; (*iv*) design slack resources and strategies; (*v*) design for acceptable performance even under degraded conditions; (*vi*) design must involve leveraging diverse perspectives; and (*vii*) design to support continuous learning at the individual and organisational level. The applicability of the principles is demonstrated through an exploratory case study of the rapid response team in a hospital. The principles of DfRP are contributions of prescriptive nature, which might give rise to more resilient socio-technical systems.

Keywords: resilient performance, Delphi method, design, complexity, rapid response teams.

1 Introduction

Resilient performance (RP) is a key functional property of complex socio-technical systems (CSSs), preventing them from breaking down in face of both expected and unexpected changes and disturbances (Hollnagel, 2017). RP is emergent, partly arising from the self-organization of people who fill out gaps in work system design and partly from resources designed ahead of time (Wachs et al., 2016).

This study focuses on the designed portion of resilience, which supports resilience from self-organization. Although most CSSs have some degree of designed resilience, this is often an unintended consequence of decisions concerned with traditional performance dimensions such as quality, productivity, reliability, and safety (Hollnagel, 2020). Further, previous studies that refer to the concept of design for resilience (DfR) neglect the role of human agency (Uday and Marais, 2015), taking an overly technical perspective (Matelli and Goebel, 2018; Kusiak, 2020). Possibly due to this technical emphasis, these earlier studies use the term DfR instead of DfRP – the former conveys resilience as a static property, while the latter acknowledges it as a dynamic and functional property of CSSs (Hollnagel and Nemeth, 2022). Woods (2018) makes this point by framing resilience as a verb instead of a noun.

The need for DfRP arises from the growing complexity of socio-technical systems, which have been more and more large and interconnected (Hulme et al., 2019; Mazhar et al., 2019). The disruptions caused by the coronavirus pandemic have made that need even clearer to systems of several natures such as healthcare, education, and manufacturing supply chains (Drăgoicea et al., 2020; Stevens et al., 2021).

Although the theory of DfRP still needs articulation, the human factors discipline has a history of developing principles for work system design. These principles have been set out, for example, in socio-technical systems theory (Trist, 1981), high-reliability organizations theory (Weick and Sutcliffe, 2011), joint cognitive systems theory (Hollnagel and Woods, 2005), macroergonomics (Hendrick and Kleiner, 2011), systems thinking applied to human factors Wilson (2014), and resilience engineering (RE) (Patriarca et al., 2018). However, even RE has not yet defined the DfRP concept, which can be due to the descriptive rather than prescriptive emphasis of most studies (Righi et al., 2015; Patriarca et al., 2018).

Although it is possible that several principles set out by these earlier contributions are useful, or at least not in conflict with RP, the concept of DfRP and its corresponding design principles still need definition and testing based on primary empirical data, which is the research gap addressed by this study. Against this background, the objective of this paper is to propose a concept and principles of DfRP. Both concepts and principles were devised in light of RE, which is the human factors approach most closely connected to the proposal of this study. The research method was based on a literature review and a Delphi study with RE experts. This method differs from some of the earlier human factors contributions on work system design principles, which are presented in books that do not offer a verifiable research method.

The applicability of the principles is demonstrated through an exploratory case study of the Rapid Response Team (RRT) in a hospital. RRTs were chosen as they are relatively small organisational structures that apparently fit the notion of DfRP. In addition, health services are widely acknowledged as CSSs (Salehi et al., 2021; Braithwaite, 2018), making them natural candidates for the investigation of RP.

2 Design for resilience in the literature

A literature review was conducted to identify how design for resilience has been approached in the literature. In December 2021, a literature search was carried out using the terms "resilien* design" OR "design for resilien*" OR "design principles for resilien*" in the title, abstract, and keywords. The Scopus database was considered without any limitations regarding the year of the publication. As for the type of publication, we included journal articles, either conceptual or empirical, excluding conference papers, books, thesis, industry reports, and magazines. The search produced 399 results. After adding the filters of only documents in English with open access, 114 papers remained. These papers were read in full, and 47 studies were removed as they did not address the topic of interest, despite citing the search terms in the title, abstract, or keyword.

As a result of this process, 67 papers were selected – the complete list is available in the supplementary material. Thirty-two publications (48%) date from 2021, 2020, and 2019, indicating the current relevance of the theme. Most papers (73%) involve empirical work, while 27% are only theoretical. The topic is studied in several areas such as software development (12 papers), built environment and building construction (8), supply chain (7), water supply systems (4), and ecosystems (2), among others. Only Zhang and Lin (2010) refer to the design of resilient systems using the RE lens. However, they focus on engineered systems, discussing applications to "resilient machines" and objects like desks. In comparison to socio-technical systems, engineered systems tend to be more amenable to mathematical modelling, simulation of expected performance, and the consequent comparison between alternative resilient designs (MacKenzie and Hu, 2019).

Indeed, although several papers are explicitly framed as "design for resilience", they neither emphasize the role played by humans in the studied systems (i.e., a human factors concern) nor are they concerned with RP to cope with everyday variabilities (e.g., scarcity of resources, efficiency pressures), which is a RE concern, according to Hollnagel (2014). In fact, even when explicitly accounting for human factors, design for resilience approaches are applied to technological artefacts. This use of human factors can be illustrated by Borsci et al. (2018), who discuss resilient design implications of medical devices as used in practice by healthcare professionals, in contrast to the imagined use by designers.

In turn, as example of technical emphasis, Kusiak (2020) discusses design for resilience in the context of manufactured products, presenting modularity and delayed product differentiation as relevant design principles. The focus on significant threats rather than everyday variability is exemplified by Chatterjee and Layton (2020), which address design for resilience in the context of supply chain capacity to cope with extreme weather events. These authors also argue that the design of resilient supply chains might benefit from architecting principles of biological ecosystems.

Overall, the characterization of earlier studies indicates that socio-technical systems and human factors theories have received scant attention from the general design for resilience literature. Of course, there are limitations inherent to this type of review as some relevant studies can have been neglected due to the adopted criteria for selecting the publications. In spite of this, the technical emphasis of the reviewed literature is clear, which further justifies the previously mentioned research gap. It is worth noting that the findings from the general design for resilience literature might be relevant for DfRP. However, as suggested by the substantial number of relevant papers found in our review, the full consideration of that literature would imply a scope too large for the present study.

3 Research method

3.1 Research design

This study involved three main stages: a literature review of principles for work system design, Delphi study, and case study (Figure 1). An initial list of principles for work system design was developed based on a review of influential human factors publications, mostly written by leading academics on the topics as follows: socio-technical systems theory, open socio-technical systems, high-reliability organizations, complex socio-technical systems, joint cognitive systems, macroergonomics, systems ergonomics, systems thinking, theory of guided adaptability, systems-of-systems, and resilience engineering.

These topics cover principles developed over decades of human factors research, ranging from the early studies on socio-technical systems to resilience engineering. In total, these studies presented 113 work system design principles (Appendix A). These principles were narrowed down based on four rounds of revisions involving the two authors of this study, considering three criteria: unification of redundant principles; elimination of principles unrelated to DfRP; and elimination of unclear principles, which occasionally occurred as some publications only cited the principles as bullet points, without further explanation. In each round, one of the authors made an initial application of the criteria and then submitted the revised list to the other author, which offered their comments and returned the list. This process resulted in 60 principles after the first round, 34 after the second, 30 after the third, and finally, 23 principles.

These 23 principles provided a starting point for the Delphi study, which further refined the list of principles as well as the concept of DfRP. Then, an exploratory case study of RRTs was carried out to demonstrate the applicability of the principles. The data collection and analysis procedures for the Delphi study and the case study are described next.

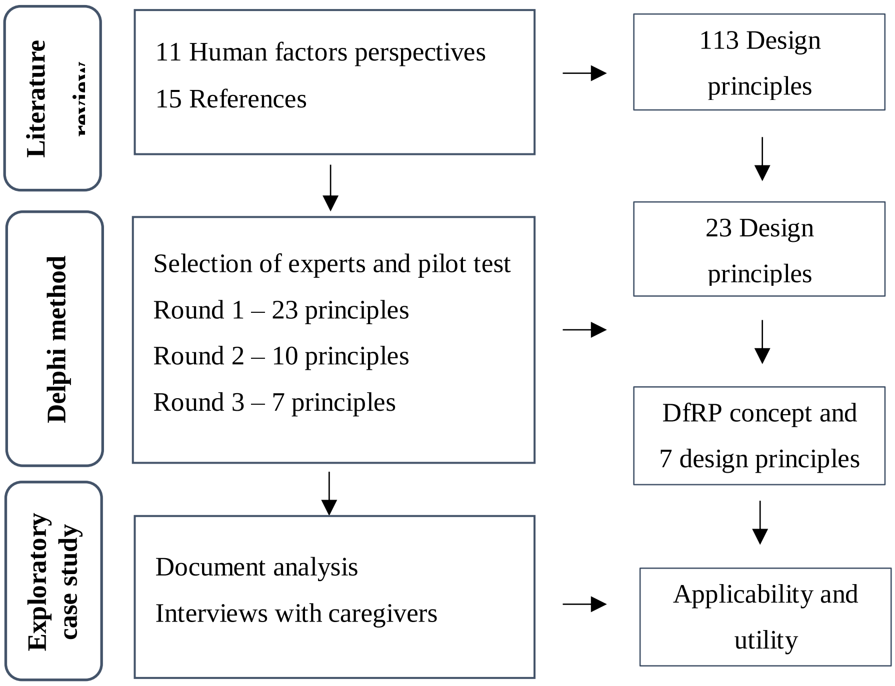

Figure 1. Research design

3.2 Delphi study

Despite some variations, the core characteristics of the Delphi method are consensual, involving anonymity among experts, controlled feedback, and repeated interactions (Geerts et al., 2021). Usually, two to four rounds are necessary to reach a consensus (De Loë et al., 2016). Figure 2 presents an overview of the Delphi method in this study.

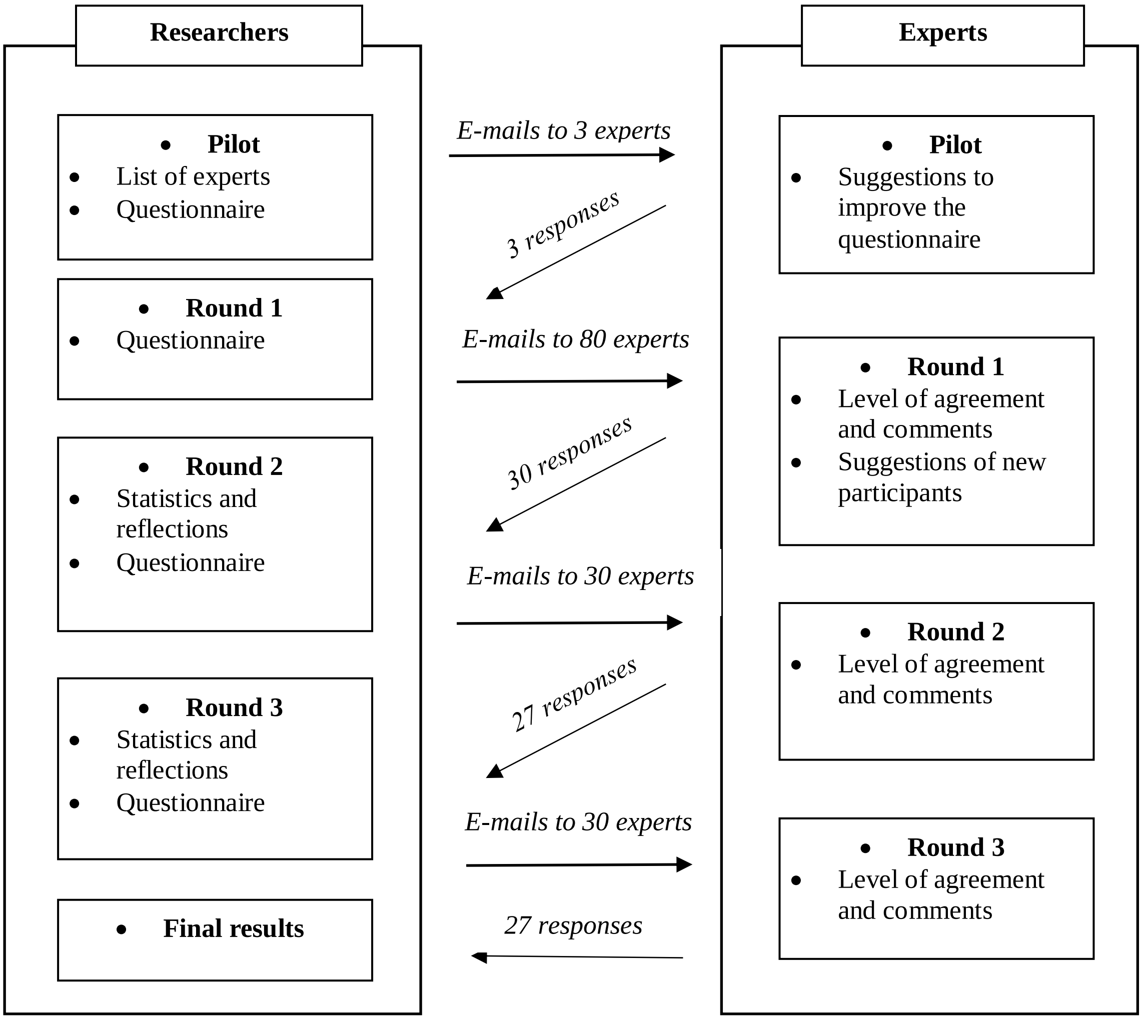

Figure 2. Stages for the application of the Delphi method

In the Delphi method, the experts must have knowledge and experience, be willing to participate in all rounds, and have communication skills to express their viewpoints (Giannarou and Zervas, 2014). Following these premises, we invited experts considering two criteria: *(i)* academics who co-authored at least one paper explicitly mentioning RE in title or abstract, published in respected human factors or safety science journals; and *(ii)* practitioners who co-authored at least one paper explicitly mentioning RE in the title or abstract, published in reputable international conferences. Years of RE experience, while relevant, was not a criterion for the inclusion/exclusion of experts. By contrast, we defined that all experts should have at least five years of experience in general, either as researchers or practitioners. Despite low RE experience, some participants could have a long experience on proxy topics such as safety or operations management. Thus, they could offer interesting viewpoints by confronting their past acquired experience on the proxy topics with their more recent involvement with RE.

Based on these criteria, an initial list of 80 experts was developed. The experts were identified from their published papers, our personal contacts in the RE community, and from snowballing – i.e., indications of the respondents during the first round. The first version of the survey instrument, containing the 23 principles devised from the literature review, was piloted with three contacts from the list of 80 experts. There were minor suggestions for improvement, involving the wording of some sentences. As such, the three responses from the pilot could be used in the final data analysis.

Next, an invitation was sent by e-mail to the whole panel of experts, asking for responses in no more than seven days. After this period, a reminder was sent out, offering an additional week for the reply. The same protocol was used in the following rounds. The results were compiled and sent back to each participant in the new questionnaire at each round.

Three rounds were conducted between May and August 2021. During the first round, the snowballing process gave rise to nine additional respondents – we contacted them before ending the first round. Of the 89 contacts (i.e., original 80 + 9), 30 submitted their responses in the first round – all of them fulfilled the aforementioned selection criteria. This is a satisfactory number for a Delphi study, within the recommended range from 10 to 30 experts (Mullen, 2003). However, three experts did not return their responses in rounds 2 and 3. Therefore, 27 respondents participated in the three rounds (Table 1). There were representatives from nine countries (Australia, Brazil, Denmark, Italy, Norway, Spain, Sweden, USA, and UK), including 19 academics, three practitioners, and five classified as both. The average RE experience was high (9.4 years), especially if considering that RE as a scientific community was born around 17 years ago, in the 1st RE symposium in Sweden. The information available from the experts' publications and practical experience indicates that they are acquainted with a variety of domains such as healthcare, aviation, construction, manufacturing, software development, manufacturing, and power generation. Thus, a reliable panel was formed, capable of offering rich and diverse contributions.

Table 1. Participants involved in all rounds of the Delphi study. Notes: (1) all academics and academics/practitioners, except for two, have a Ph.D. degree – these two have a MSc degree; (2) two out of the three practitioners have a Ph.D.; the other has a BSc but attended several outreach courses on RE.

Expert	Background	RE experience (years)	Professional experience (years)
E1	Academic	8	10
E2	Academic	14	22

E3	Academic	13	12
E4	Academic	5	25
E5	Academic	15	40
E6	Academic	10	17
E7	Academic	2	22
E8	Academic	10	37
E9	Academic	5	14
E10	Academic and practitioner	7	10
E11	Academic	15	19
E12	Academic and practitioner	17	50
E13	Academic	7	8
E14	Academic	5	5
E15	Academic	6	19
E16	Academic	11	15
E17	Academic	10	27
E18	Academic and practitioner	5	20
E19	Academic	10	25
E20	Academic	15	35
E21	Academic	14	14
E22	Academic and practitioner	4	23
E23	Practitioner	5	22
E24	Practitioner	17	25
E25	Academic and practitioner	10	30
E26	Academic	10	23
E27	Practitioner	3	15

The questionnaire applied in round 1 was comprised of three sections. The first section addressed the respondent profile and introduced our preliminary concept, asking the experts' opinions on it. In the second section, experts should indicate their level of agreement with each of the 23 design principles (an excerpt of this section is presented in Table 2) using a 5-point Likert-type scale: I totally agree with the inclusion of this principle (5); I partially agree with the inclusion of this principle (4); I have no opinion on this principle (3); I partially disagree with the inclusion of this principle (2); and I totally disagree with the inclusion of this principle (1).

In addition, experts were invited to justify their level of agreement and, if necessary, provide alternative definitions to the principles. In the third and final section of the questionnaire, the expert could suggest principles not included in the list, indicate additional respondents, and provide general feedback on the research proposal.

Table 2. Excerpt of the questionnaire used in the first round of the Delphi study

Principle	Definition
1. System components should be compatible with each other and with the environment	The notion of compatibility is central to a systems perspective. A design involves a set of working arrangements, and these need to be compatible with surrounding systems and practices, including, for example, systems for payment, selection, work measurement, performance assessment, and so on.
Please, indicate your level of agreement with this principle: 1( ) 2( ) 3( ) 4( ) 5( )	
Comments:	

In the second Delphi round, a revised concept and a revised list of 10 principles were presented. Following the initial section with the respondent characterization, experts' comments on the new concept were requested. Additionally, we asked whether the experts preferred either the term DfR or DfRP – they could also indicate that they would feel comfortable with either option. In the first round, we had used the term DfR. However, after feedback from two experts, we made the decision to hear the whole panel on that issue. In the second section of the questionnaire, the revised list of 10 principles was set out, and experts should point out their agreement level using the same 5-point Likert scale used on the previous round. The final questionnaire section was left again for general comments and suggestions of new principles.

In the third and last Delphi round, another revised concept was presented, followed by a list of seven revised principles. Again, experts assigned scores to their level of agreement and offered comments. The study stopped at the third round as the responses were mostly convergent, and consensus building from the first to the third round was clear. We assessed consensus based on a mixed qualitative and quantitative approach, as recommended by Mullen (2003). From a quantitative standpoint, we relied mostly on the coefficient of variation (CV). Similar to other Delphi studies (Shah and Kalaian, 2009; Giannarou and Zervas, 2014), we considered three ranges of CV: 0% to 15% as an indication of strong consensus; >15% to 30% as an indication of moderate consensus; and > 30% as an indication of weak consensus. When the number of experts is close to the recommended upper limit of 30 participants, which is our case, a moderate consensus is good enough (English and Kernan 1976; Shah and Kalaian, 2009; Giannarou and Zervas, 2014). In fact, the consensus in Delphi studies is context-dependent (Shah and Kalaian, 2009), and CVs as high as 50% or 60% have been found to be acceptable in some cases (Seagle and Iverson, 2001; Henning and Jordan, 2016).

Further, these ranges of CVs were not blindly followed for the assessment of consensus. We took advantage of the rich comments offered by the experts and identified the most salient convergent and divergent viewpoints. As a piece of evidence of the experts' qualitative contributions (and of how their viewpoints evolved towards consensus), their comments totalled 5,942, 2,793, and 1,461 words, respectively, in the first, second, and third rounds. We also relied on our own judgment: in particular, one of the authors of this paper is himself a leading RE academic with 13 years of experience on the topic. Therefore, the final DfRP concept and associated principles were a social construction involving both the experts and us, rather than the result of a mechanistic application of questionnaires and calculation of CVs. After completing round 3, the results were compiled and emailed to the participants.

3.2 Case study of Rapid Response Teams

In order to demonstrate the applicability of the DfRP principles, an exploratory case study of RRTs was conducted in a public teaching hospital in Brazil. We have conducted several resilience engineering studies in that hospital in recent years, making it easier to access the data sources. The hospital has about 6,000 employees, 850 in-patient beds, and 150 intensive care unit (ICU) beds. The facilities encompass approximately 223,000 square meters spread over two main buildings, with 13 and eight floors.

The data collection was mostly based on semi-structured individual interviews. The interview script consisted of two sections (Appendix B), addressing information about the respondent and the hospital, followed by questions on the team functioning. Given the exploratory nature of this case study, the questions were not explicitly and strictly connected to the DfRP principles. Two professionals representing the afferent arm (i.e., those who monitor the patients and call the RRT) and two professionals from the efferent arm (e.g., those who respond to the call; the RRT itself) were interviewed online. The interviewees from the afferent arm worked at the largest surgical ward of the hospital, which offered plenty of opportunities for RRTs. The interviews lasted on average one hour, were audio-recorded, and fully transcribed (23,155 words). Table 3 presents the profile of the interviewees.

Table 3. Profile of the interviewees

Interviewee	Occupation	RRT position	Time working at the hospital	Period in the RRT	Interview duration
N1	Nurse	Afferent arm	8 years	2014-2021	30 min
N2	Nurse	Afferent arm	25 years	2014-2021	73 min
P1	Physician	Efferent arm	8 years	2014-2017	52 min
P2	Physician	Efferent arm	12 years	2014-2021	80 min

As complementary data sources, we consulted the standardized operating procedure that described the functioning of the RRT and posters that displayed the calling criteria. We judged the data obtained from the four interviews and documents as good enough for the exploratory purpose of this case study, thus implying theoretical saturation (Fusch and Ness, 2015). The data collection procedures were approved by the ethics committee of the hospital, and the informed consent of the interviewees was obtained.

A content analysis of the interviews´ transcripts was carried out (Pope et al., 2000). Initially, in the familiarization stage, we read the transcripts several times in order to gain an understanding of the recurring themes. Next, the seven DfRP principles were imposed on the data as heuristic device. In the coding stage, we identified excerpts of text related to the principles, highlighting both instances of using them and when their lack was a drawback. These latter instances were interpreted as improvement opportunities for the re-design of work systems supportive to resilient performance. Thus, these opportunities were logical consequences of not using the principles and were sometimes spontaneously mentioned by the interviewees, facilitating the coding process. The content analysis was primarily conducted by the first author, and then all codifications were thoroughly revised by the second author, who also read all of the transcripts.

4. Results

4.1 The concept of DfRP

The concept presented in the first round of the Delphi study was based on the resilience definition proposed by Hollnagel et al. (2011). It was as follows*: "DfR involves the design, carried out in advance of its implementation, of measures of any nature, at the micro, meso,* *and macro levels, that support the ability of socio-technical systems to adjust their performance before, during, or after changes and disturbances, so that they can produce the required outputs in expected and unexpected conditions".*

The experts offered several comments regarding that concept, such as: *"I can see how you have derived the definition from resilience engineering, and it makes sense, but it is also very long and complicated (E1)", "DfR must also consider the dimension of human skills (E22)", "one aspect of resilience that isn't explicitly captured in this definition is the idea of building up capacity that you can deploy during an incident (E27)*". The comments on the concept totalled 1,786 words in the first round.

Based on the received feedback, the concept was revised in the second Delphi round: "*DfR involves the functional modelling of systems and the use of design principles as a basis for the deliberate support to integrated human, technical, and organisational adaptive capacities aiming at the preservation of high-importance goals and functions in face of variabilities. DfR implies that resilient performance might be supported through designs that are inevitably underspecified. Therefore, unanticipated self-organization and chance are expected to fill out gaps in design – this portion of performance corresponds to emergent resilience, which is complementary to designed resilience".* Again, the experts´ comments (924 words) made clear that the concept was not yet good enough. Two exemplar comments are transcribed next: *"this definition is too long and complex (E18)", "I would say that only the first sentence is a definition. The rest are implications and limitations…(E21)".*

In the second round, the experts also gave their opinions on whether the term DfR or DfRP should be used: 50% preferred DfR, 23% DfRP, and 27 % were comfortable with either option. We opted for accuracy, in line with half of the panellists. The term DfRP implies a functional perspective of resilience, which is consistent with the use of this concept in socio-technical systems. In the third round, a concise definition was proposed and then adopted as consensus emerged. The definition is presented below:

"DfRP is the use of design principles to support integrated human, technical, and organisational adaptive capabilities".

Comments were much shorter (214 words) in this round and mostly convergent: *"the definition is now short and precise (E7)", "nice and concise! (E17)", "I agree with this definition (E5)",* and *"this definition is adequate, and I liked DfRP better than DfR (E3)".* Despite being concise, the definition has three main assumptions. First, DfRP implies the use of design principles, which need to be explicitly stated and based on reliable sources. Second, DfRP is socio-technical as it addresses human, technical, and organisational capabilities. Third, DfRP aims at supporting adaptation through design, which implies providing resources to cope with uncertainty.

It is worth noting that the definitions presented in the first and second rounds are not technically wrong: experts´ comments were mostly targeted at the length of the definitions, on the use of terms that were not self-explanatory (e.g., socio-technical system), and on terms that restricted the concept too much (e.g., functional modelling). A concise concept proved to be important to reach consensus as it left less room for diverse interpretations.

4.2 DfRP principles adopted in the first round of the Delphi study

Table 4 presents 15 human factor studies that proposed work system design principles potentially useful to DfRP. These studies are related to 11 theoretical backgrounds, all of them systems-oriented. In fact, the word "system" appears on seven out of the 11 titles of the backgrounds.

Table 4. Main literature sources for the initial identification of DfRP principles

References/Background	1	2	3	4	5	6	7	8	9	10	11	Number of principles	Number of citations (Scopus)
Hollnagel and Woods (2005)				X								3	724
Clegg (2000)	X											19	402
Cherns (1987)	X											10	345
Woods (2015)										X		4	303
Braithwaite (2018)			X									20	263
Wilson (2014)							X					6	234
Hendrick and Kleiner (2001)					X							3	139
Sutcliffe (2011)		X										5	119
Badham et al. (2001)						X						5	88
Uday and Marais (2015)											X	10	86
Hollnagel (2017)										X		4	68
Saurin et al. (2013)			X									6	58
Provan et al. (2020)									X			4	36
Yu et al. (2020)										X		8	8
McNab et al. (2020)								X				6	6

	Total	**113**

(1) Sociotechnical systems; (2) High-reliability organizations; (3) Complex socio-technical systems; (4) Joint cognitive systems; (5) Macroergonomics; (6) Open sociotechnical system; (7) Systems ergonomics; (8) Systems thinking; (9) Guided adaptability; (10) Resilience engineering; (11) Systems-of-systems.

The number of principles varies substantially, from three (Hendrick and Kleiner, 2001; Hollnagel and Woods, 2005) to 20 (Braithwaite, 2018). Their level of detail also differs widely. For example, Clegg (2000) discusses each of his 19 principles and categorizes them into three groups, namely meta, content, and process principles. By contrast, Braithwaite (2018) lists his 20 principles as bullet points without detailed explanation.

As a commonality, 14 out of the 15 studies are conceptual, which means that they do not demonstrate the applicability of the principles based on primary empirical data. In addition, most publications do not present verifiable methods for their proposals – e.g., systematic literature reviews, case studies for theory building, or consultation with experts. The exception is McNab et al. (2020), which present six systems thinking-based design principles developed from workshops with healthcare professionals. Cross-references between the publications are also uncommon. Despite these drawbacks, these studies have been influential, supporting theoretical and empirical investigations in a wide variety of industry domains.

However, by listing all of the 113 principles side-by-side, it quickly becomes clear that some of them are either overlapping or not relevant for DfRP. Regarding overlaps, it is common that the same principle is worded slightly differently. For example, Saurin et al. (2013) state a principle named "encourage diversity of perspectives when making decisions", while McNab et al. (2020) refer to "seek multiple perspectives". Similarly, "anticipation" or "predictability" appears on several theories, such as sociotechnical systems, joint cognitive systems, macroergonomics, complex systems, and guided adaptability.

Besides, some principles are not clearly relevant from the resilience viewpoint – e.g., "design practice is itself a socio-technical system" (Clegg, 2000); "work with, not against trends" (Braithwaite, 2018). As a result of considering these shortcomings, it was possible to narrow down the initial list from 113 to 23 principles (Table 5), which set a starting point for the Delphi study.

In the first round, only five out of the 23 principles had CV equal to or lower than 15%, corresponding to strong consensus. Principle 13, related to the use of multiple perspectives, was the most consensual (Mean = 4.8; CV=10%). The experts´ remarks shed light on this result: *"this is actually needed for complex systems… the challenge is how to combine the different* *views (E15)"; "quite possibly the most important principle! (E25)";* and *"the more diverse the perspective the better the decision making (E23)".*

In turn, four principles had CVs equal to or higher than 30%, suggesting weak consensus. Principle 8, stating that problems should be controlled at the source, had the highest CV (39%) and a low agreement level (Mean = 3.3). The following experts´ remarks offer insight into this result: *"this assumes that all problems have a well-defined source...that may not be the case, as many of them are emergent… (E12)"; "here I do not agree with the idea of 'source'…I believe that it is more meaningful to understand the full orchestration…(E13)"*.

Table 5. Design principles used in the first round of the Delphi study

Principles and exemplar references	Mean	CV
1. System components should be compatible with each other and with the environment (Clegg, 2000)	3.9	30%
2. Performance depends on jointly optimizing the technical and social sub-systems (Badham et al., 2001)	4.2	26%
3. Interactions between system elements should be explicitly modelled and influenced through design (Wilson, 2014)	4.4	24%
4. Systems should look simple to their users (Clegg, 2000)	3.8	33%
5. Give visibility to processes and outcomes (Saurin et al., 2013)	4.7	14%
6. Support real-time information sharing (Uday and Marais, 2015)	4.3	21%
7. Balance standardisation and variety (Braithwaite, 2018)	4.3	24%
8. Problems should be controlled at source (Clegg, 2000)	3.3	39%
9. There should be minimum necessary specification in the means of undertaking tasks (Clegg, 2000)	3.9	30%
10. Support the use of the informal system, not just the formal system (Braithwaite, 2018)	4.1	25%
11. Provide slack resources to cope with variability (Saurin et al., 2013)	4.6	18%
12. Deference to expertise (Sutcliffe, 2011)	4.4	22%
13. Seek multiple perspectives (McNab et al., 2020)	4.8	10%
14. Power and authority (Cherns, 1987)	3.9	29%
15. Ability to respond, drift correction and rebound (Hollnagel, 2017)	4.6	16%
16. Ability to monitor (Hollnagel, 2017)	4.7	13%
17. Ability to anticipate the impact of changes, threats and opportunities (Hollnagel, 2017)	4.7	15%
18. Ability to learn (Hollnagel, 2017)	4.6	15%
19. Monitor and understand the gap between work-as-imagined (WAI) and work-as-done (WAD) (Hollnagel, 2014)	4.4	21%

20. Foster social capital (Yu et al., 2020)	4.3	20%
21. Embrace polycentric control/decentralization (Yu et al., 2020)	4.2	22%
22. Support graceful degradability (Woods, 2015)	4.4	23%
23. Support sustained adaptability (Woods, 2015)	4.5	18%

4.3 Final version of the DfRP principles

Table 6 presents the final list of the principles obtained in the last Delphi round. The agreement level was high (means ranged from 4.3 to 4.7) and the CVs were fairly low, ranging from 11% to 20%. On the one hand, the experts′ remarks indicated consensus: "*the basis for design should be a model, in the sense of an articulated understanding, of how the system functions"* (E12 on principle 1); "*the last sentence really nails it"* (E14 on principle 4); and "*thank you for exploiting the two phases of applicability of this principle"* (E23 on principle 6).

On the other hand, the experts still raised questions in this round: "*it is very difficult, if not impossible to include all non-routine conditions. In the definition you included the word "certain" which is not deterministic. What are the inclusion criteria?"* (E20 on principle 1); "*I would be stronger in the second sentence: "gathering and sharing this information in real-time is vital to understanding complex systems, which change quickly"* (E15 on principle 2). Thus, even though the quantitative results suggested consensus, there was still room for improvement, and therefore some of the comments received in this round were used in our final proposal – e.g., the aforementioned comment of E15 regarding the definition of the principle on visibility. In fact, as conveyed by the comments from the experts in the last round, the refinement of the wording and definition of the principles can be an endless process. Thus, future changes in this regard should be expected as academics and practitioners make their own re-interpretation of the principles when using them.

The order of presentation in Table 6 does not imply a strict implementation sequence. In fact, any strict sequencing would be contradictory with the complexity of the design process itself (Clegg, 2000). However, as emphasized by E12 (see their comment above), principle 1 takes precedence over the others as it demands a deep understanding of the system's functioning before making any design decisions. This makes sense as the other principles imply changes in the system functioning, and the models stemming from principle 1 support the understanding of the implications of the changes.

Two principles are socially oriented: diverse perspectives (principle 6) and learning (principle 7) essentially refer to the contribution of people to resilient performance. In turn, principles 2, 3, 4, and 5 are social-technical in the sense that their implementation tends to involve interactions between people and technologies – e.g., making variations in performance visible (principle 2) may benefit from visual management devices such as warning lights while requiring people capable of interpreting and responding to the signals.

Table 6. Final version of the DfRP principles

Principle	Definition	Mean	CV
1. There must be functional models of the system	The system's functioning, both under normal and degraded conditions, must be explicitly modelled, in the sense of an articulated understanding. Models must include the main interactions with the external environment. A description of the system's functioning should be available for those who play a role in the design team.	4.6	16%
2. Make variations in performance visible	In complex systems, variations in performance are inevitable. Gathering and sharing this information in real-time is vital to understanding performance.	4.8	11%
3. Use the type of standardization that best fits the nature of the function	Standardisation can range from strictly defined process steps to the definition of goals that leave completely open the means for their achievement. A variety of standards, in terms of their level of detail and action or decision-taking specification, might co-exist for different functions in the same system.	4.3	20%
4. Design slack resources and strategies	Slack resources (e.g., equipment, time, money) slow down the propagation of variability and support adaptation. However, some types of slack resources add elements and interactions to the system, increasing complexity and posing their own threats. Slack resources are deployed through slack strategies (i.e., how to use the resource) such as redundancies and reciprocity – e.g., one unit helps another whose adaptive capacity is saturated.	4.7	12%
5. Design for acceptable performance even under degraded conditions	Design should support the maintenance of acceptable performance, which involves the preservation of higher-order goals, even under degraded conditions. This principle can benefit from the slow (or graceful) system degradation, which allows time for action-taking.	4.5	18%
6. Design must involve leveraging diverse perspectives	This principle is applicable both to the design process (i.e., designers should account for diverse perspectives in their decision-making) and to the system resulting from design (i.e., the system should have mechanisms for giving a voice to people from different hierarchical ranks, suppliers, clients, etc.). There can be a tension between the number of perspectives to be considered and the coordination costs of accounting for them. Designers should have the ability, and be given the proper organizational support, to cope with this tension.	4.6	17%
7. Design to support continuous learning at	Complex systems offer learning opportunities ranging from everyday work to accidents. Learning in complex systems is	4.6	17%

the individual and organisational level	harder because impactful events are unlikely to reoccur at the same way. Design can play a major role in supporting continuous individual and organisational learning (e.g., training programs, after-action reviews, incident investigations). Learning should occur from all operations rather than from a specific subset.

4.4 Rapid Response Teams: the applicability of DfRP

4.4.1 Characterization of the RRT

RRTs are based on the identification of hospital-ward patients whose condition is deteriorating, early notification of a predefined set of responders, rapid intervention and ongoing evaluation of the processes of care – RRTs have been put in place because of evidence of "failure to rescue" with available clinical services (Jones et al., 2011). The studied RRT was set up in 2014 and, according to data provided by the team coordinator, in 2020 there were 130 activations per 1,000 hospital admissions. Interviewee P1, who was a member of the committee responsible for implementing the RRT, shed light on their rationale: "*the decision to install a RRT was made by top management, with the objectives of reducing admissions from wards to ICUs as well as alleviating the workload of the emergency department, which was responsible for attending to critically-ill patients in the wards".*

Although the use of multidisciplinary RRTs (e.g., doctors, nurses, nurse technicians, and physiotherapists) is recommended as best practice (Moreira et al., 2018), at the studied hospital the RRT is composed of one physician at each shift. Eight physicians are members of the RRT and they take turns across shifts – one of them is also the RRT general coordinator. They are specialized either in internal medicine or critical care medicine, having at least two years of experience in the care of critically-ill patients.

In fact, these eight physicians form the efferent arm of the RRT, which corresponds to those that are called into action by the afferent arm, which involves ward nurses and nurse technicians who monitor the vital signs of patients "*usually 3 or 4 times a day, if the patient is stable* (interviewee N1)*"*. The communication between both arms is made by telephone and the efferent arm is expected to be at the bedside in no more than five minutes after being called. In the case study, the RRT must be called whenever any of the triggers indicated in Table 7 is activated. The following report from interviewee N2 illustrates the activation process: "*we* *monitor the patient's vital signs and call the RRT by telephone when any of the triggers is observed. We explain what is happening and what is the trigger that justifies the call. Then, the doctor comes and provides patient care, which can include, for example, requests for exams and prescription of medications".* The impact of the RRT was highlighted by interviewee P2: "*The RRT is usually called several hours before a possible cardiac arrest…that is why there was a 40% reduction in cardiac arrests at the hospital*".

Table 7. Triggers for calling the RRT.

Clinical conditions		Triggers
	Airway	Need for intubation
	Breathing	Respiratory frequency < 8 or > 35 movements per minute
		Oxygen saturation < 90%
	Blood circulation	Heart rate < 40 or > 140 beats per minute
		Systolic blood pressure < 80mmHg
		Systolic blood pressure between 80 and 90 mmHg and deterioration of the clinical condition
	State of consciousness	Decrease in Glasgow coma scale > 2 points
		Repeated or prolonged seizure (> 5 minutes)

4.4.2 DfRP concept and principles in the case study

The studied RRT is fully aligned with the proposed concept of DfRP. It is a designed structure composed of integrated human (i.e., afferent and efferent arms), technical (e.g., equipment for monitoring vital signs), and organisational elements (e.g., procedures for calling the RRT). It dampens variability propagation and supports performance adjustment, such as changing the plan of care, before the occurrence of undesired outcomes. RRTs are based on technical design principles, which involve, for example, the choice of relevant triggers and the specification of required qualifications for team members.

Table 8 presents the RRT evaluation in light of the DfRP principles. This evaluation suggests that all of the principles are adopted to some extent, which is sometimes intrinsic to the nature of the system – e.g., RRT is itself as a slack resource (principle 4) and the visibility of variations (principle 2) occurs due to the electronic monitoring of vital signs. This suggests that certain types of systems might be naturally prone to DfRP. The evaluation also sheds light on how contextual factors pose limits to DfRP. For example, according to P1 and P2, the use of diverse perspectives (principle 6), represented by multidisciplinary efferent arms, was compromised by the scarcity of human and financial resources. Organizational culture is another contextual factor that may have played a role in the learning from using the system (principle 7), as the lack of follow-up meetings involving nurses and physicians may be due to strict hierarchical barriers between both groups of professionals.

Further, the improvement opportunities listed in Table 8 provide piece of evidence of the practical utility of the principles for assessing existing systems. These opportunities suggest that resilient features might be added to existing systems instead of being completely determined by the original system design. As such, the extent to which a system is consistent with DfRP seems to be a dynamic property, which changes over the system life-cycle.

Table 8. Evaluation of the DfRP principles in the case study of RRTs

Principle	Applicability	Improvement opportunities
1. There must be functional models of the system	The main functional model of the RRT is the standardized operating procedure (SOP) that describes the purpose of the team, responsibilities of both arms, activation triggers, activation process, and response time. Information on the triggers is also displayed on posters distributed in the wards and on the back of the identification badges of staff. The SOP accounts for some variabilities such as patients whose vital signs are constantly within the range of the triggers (e.g., hypertensive patients) – the RRT does not need to be called in this situation.	Additional variabilities that frequently occur, such as simultaneous calls, could be included in the SOP.
2. Make variations in performance visible	The uptake of this principle is intrinsic to RRTs as they imply the real-time monitoring of vital signs of patients through sophisticated equipment. Variations in these vital signs are shown on displays that have a public interface. The afferent arm checks the vital signs at the bedside once per shift for stable patients. Patients with more sensitive conditions can be monitored continuously through telemetry.	Despite the visibility of vital signs, they need to be recorded by staff on the electronic patient chart. The afferent and efferent arms make their own records and do not have access to each other database, which makes communication difficult. There could be a database shared by both arms.
3. Use the type of standardization that best fits the nature of the function	The SOP resembles the concept of process-oriented procedure, proposed by Hale and Borys (2013). This type of procedure is midway between action-oriented and goal-oriented procedures (Hale and Borys, 2013). It does not strictly specify time and motion sequences but rather indicates who should make decisions, when, and based on what criteria. It fits the nature of the RRT functions (e.g., monitor vital signs, call RRT), which, despite having a regular sequencing and steps, are subject to variations depending on the patient unique condition and physician preferences.	Despite the standardized triggers, interviewees N1 and N2 (afferent arm) reported that tacit knowledge plays a role in the decision to call the RRT – i.e., sometimes, even in the absence of the triggers, they feel they must call the RRT. This could be made explicit in the SOP. A flexible SOP could also be useful as a formal protection for the afferent arm, which otherwise might be afraid of being criticized for calling the RRT when this is unnecessary, from the viewpoint of the efferent arm.

4. Design slack resources and strategies	The RRT is a form of standby slack resource. Also, the RRT activation creates slack in terms of time as it implies action-taking well before an undesired outcome. Thus, exams and changes in the treatment can be made under less time pressure in comparison to what would have occurred without the RRT. It also creates financial slack as cardiac arrests imply longer length of stay at the hospital.	As it occurs with slack resources in general, the RRT is subject to efficiency pressures as it can be interpreted as waste, especially if unused for long periods. It can be an easy target to cost-cutting initiatives. It is important to make it explicit to management the RRT benefits based on avoided costs of treatment – currently, there is no such type of analysis at the hospital.
5. Design for acceptable performance even under degraded conditions	Although the patient (as a person) is not designed, they can perform acceptably even under degraded conditions (i.e., when sick). Thus, principle 5 is acknowledged as the RRT assumes that adverse outcomes do not occur suddenly but rather gradually evolve, often subtly, during hours. The pandemic tested the limits of this principle. At the peak, the intensivists left their RRT positions to work full-time in the care of COVID patients. They were replaced by physicians from other specialties. No data was available regarding whether their performance was acceptable under this degraded condition.	No opportunity related to this principle was identified.
6. Design must involve leveraging diverse perspectives	On the one hand, this principle is observed as patient care is carried out jointly by the afferent and efferent arms. On the other hand, the efferent arm is composed only by physicians.	The interviewees acknowledge that the efferent arm should be multidisciplinary. However, the interviewees argued that this multidisciplinary composition would imply higher costs, which are currently not affordable by the hospital.
7. Design to support continuous learning at the individual and organisational level	The RRT design foresees monthly meetings to discuss the performance of the team and improvement opportunities. The four interviewees also reported that there can be quick meetings, especially during shift handovers. However, the meetings are separate for the afferent and for the efferent arms. Another learning mechanism is in place when the risk	There could be regular meetings involving both arms, in order to discuss the RRT performance and improvement opportunities.

management department, at the hospital level, discusses adverse events in which the RRT played a role.

An example of learning, reported by all interviewees, refers to the revision of the triggers: in order to reduce the number of unnecessary calls, the range of some triggers was narrowed. This change was seen as positive by the afferent arm, which was uncomfortable for calling the RRT too often.

5. Discussion

In this section, a discussion is made of the validity of the DfRP concept and principles. Validity is the extent to which a concept, conclusion, or measurement is well-founded and likely corresponds accurately to the real world (Brians, 2016). Content validity is concerned with whether the concept and principles cover the conceptual space, capturing all facets of the studied construct (Pennington, 2018). This validity type was ensured by the review of key human factor publications on principles for work system design. This review provided a wide coverage of the conceptual space, which was further verified by the experts in the Delphi study – some of the experts were themselves the authors of the reviewed papers. In this respect, the experts also assessed the face validity of the concept and principles, which means that they "appeared to be" a good translation of the content domain (Lawshe, 1975).

In turn, construct validity refers to the degree to which inferences can legitimately be made from the research proposal to the theoretical constructs on which it is based (Trochim, 2006). For this study, construct validity concerns the question of whether the DfRP concept and principles are grounded on resilience engineering (RE) and offer insights into its use in socio-technical systems. Construct validity benefited from the profile of the experts, all of them experienced academics or practitioners. This validity type is reflected in the wording and definition of the principles, which use traditional RE vocabulary and ideas. For example, principle 1 (there must be functional models of the system) is associated with the Functional Resonance Analysis Method (FRAM), which has been the main modelling tool in RE studies (Patriarca et al., 2020; Hollnagel, 2012). Similarly, principle 5 (design for acceptable performance even under degraded conditions) resembles the concept of graceful extensibility, which is the ability of a system to extend its capacity to adapt when surprise events challenge its boundaries (Woods, 2015). The same applies to principles 2 (make variations in performance visible) and 7 (design to support continuous learning at the individual and organisational level), which resemble Hollnagel´s (2017) resilience potentials of monitoring and learning, respectively. At the same time, these and the other principles are not exactly the same as those stated by earlier RE studies, which suggests divergent validity, that is, the extent to which a research proposal differs from others (Trochim, 2006). The concept and principles are different because they are explicitly stated and underpinned by the notion of *design*, which is not a commitment made by prior studies. Furthermore, the process for developing the concept and principles necessarily implied in the refinement of previous contributions, stressing what was most clearly connected to DfRP.

Construct validity was reinforced by the exploratory case study, which shed light on the resilience of RRTs. What is more, that study offered insight into the principles in use, highlighting the role of context. For example, it made clear that the individual parts of complex systems (e.g., physiological attributes of people) cannot always be designed, which poses limits to DfRP. In the same vein, the use of the principles seems to be intrinsic to certain activities (e.g., real-time monitoring and display of vital signs).

Regarding predictive validity, it assesses the ability of the research proposal to predict something it should theoretically be able to predict (Trochim, 2006). For the present study, predictive validity refers to whether the uptake of the principles predicts RP, which begs the question of how to assess it. Although this is still a matter of debate, the assessment of RP is usually informed by resilience-based indicators (e.g., Penaloza et al., 2020; Chuang et al., 2020), which can derive, for example, from the resilience assessment grid (Hollnagel, 2017). The expectation is that the more the system uses the DfRP principles the better its resilience-based indicators. In this respect, the case study suggests that the use of the principles is not binary but rather is a matter of degree. For example, although there was a functional model for the RRT (i.e., the SOP, principle 1), it had drawbacks such as the neglect of common variabilities. The case study also revealed that the use of the principles changes over time (e.g., the chosen triggers, principle 7), which poses additional challenges for assessing their predictive validity.

As such, insight into predictive validity might involve measuring the extent to which the DfPR principles are adopted, and checking the results against resilience-based indicators. These indicators might stem from resilience-oriented goals defined at the outset of the design process. For example, an important design goal might be the minimization of the human cost of RP, defined as the extra effort of practitioners to achieve their goals, playing out in terms of high workload and burnout (Terra et al., 2021). Thus, a resilient design should be consistent with the law of fluency, which states that “well adapted cognitive work occurs with a facility that belies the difficulty of the demands resolved and the dilemmas balanced” (Hoffman and Woods, 2011). In other words, people´s self-sacrifice must not be normalized as normal work (Smaggus, 2019) in light of DfRP. In the case study, the human cost of RP was possibly high during the pandemic, which highlights the limits of DfRP in face of extreme events.

Finally, it is worth mentioning that the scientific investigation of DfRP is particularly consistent with the design science research (DSR) approach, which is arguably useful (Righi et al., 2015) for resilience engineering. DSR is a type of case-based research, which differs from the traditional case study research strategy as its main contribution is prescriptive (i.e., solution-oriented) rather than descriptive (i.e., problem-oriented) (Holmström et al., 2009). The contribution of DSR is a generic design to be used as a "design model by well-trained and experienced designers to make their own context specific design" (Van Aken et al., 2016). The use of DfRP can give rise to new or revised practices for the management of resilience, which would be themselves outputs of DSR. This is a necessary type of contribution as the DfRP concept and principles are presented in a high level of abstraction and therefore need to be translated into viable practices for researchers and practitioners. Besides, our proposal offers an opportunity to check whether prior applications of DSR to resilience engineering (e.g., Rosso and Saurin, 2018) are consistent with DfRP.

6. Conclusions

Although resilient performance might be supported by work system design in socio-technical systems, there is no articulated theory of DfRP, from the viewpoint of resilience engineering. We offer an initial contribution to address that research gap by proposing a concept of DfRP and seven design principles. The validity of the concept and principles benefited from a literature review of work system design principles, a Delphi study, and an exploratory case study of RRTs. While the literature review and the Delphi study indicated that the principles made sense in theory, the RRT study demonstrated their applicability and utility for the identification of improvement opportunities. The principles are contributions of prescriptive nature, which means that their use is expected to contribute to more resilient socio-technical systems. However, the first principle (i.e., there must be functional models of the system) is a prescription that makes clear the need for a thorough description of the system before changing it through the other principles.

Some limitations of this study must be mentioned. First, a different composition of the panel of experts could have produced different results. Nevertheless, the panel was highly qualified and carefully selected, suggesting reliable findings. Second, despite the RRT study, there is a need for assessing a broader range of socio-technical systems. Third, we did not investigate how the principles should be integrated with design principles related to other performance dimensions such as those related to quality, productivity, safety, and reliability. Fourth, our literature review for selecting the initial list of principles did not include the general design for resilience literature that addresses systems other than socio-technical.

There are several opportunities for future research stemming from this work such as: *(i)* to review the principles presented in the general design for resilience literature, verifying their similarities and differences in relation to the principles proposed in this study; (*ii*) to test the concept and principles in the real design of socio-technical systems, rather than only as a tool for retrospective assessments; (*iii*) to explore how DfRP interacts with other Design for X approaches, investigating synergies, trade-offs, and new design principles emerging from these interactions; (*iv*) to develop a tool for the assessment of the use of the DfRP principles, possibly with performance levels, which could be useful for the comparison between alternative designs; (*v*) to assess whether the level of adoption of the principles is correlated with performance outcomes such as safety; (*vi*) to investigate the use of the principles in a wide variety of socio-technical systems, identifying good practices and lessons learned that might be transformed in knowledge to practitioners; (*vii*) to identify or adapt existing practices that might operationalize the principles of DfRP (e.g., FRAM, causal-loop diagrams, and agent-based-modelling can support principle 1); and *(viii)* to devise new practices conceived from the outset with DfRP in mind. Regarding *(vii)* and *(viii),* it might be useful to develop practices that integrate DfRP to everyday management routines. This is important as DfRP is not a one-off activity and needs to be continuously revisited in face of a dynamic context during the system life-cycle.

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APPENDIX A – List of the 113 work system design principles used as initial basis.

References	Principles
McNab et al. (2020)	Foundation concept
	Seek multiples perspectives
	Consider work conditions
	Analyse interactions and flow
	Understand why decisions make sense at the time
	Explore performance variability
Provan et al. (2020)	Anticipation
	Readiness to respond
	Synchronization
	Proactive learning
Yu et al. (2020)	Recognize that system context matters
	Foster social capital
	Maintain diversity
	Manage connectivity
	Encourage learning-by-doing
	Embrace polycentric control
	Address the problem of fit or match the scale of a problem to that of governance and collaborative networks
	Manage for complexity
Braithwaite (2018)	Take multiple evaluations of what's going on
	Use system tools to uncover the system's features
	Customise change to local contexts
	Work with, not against, trends
	Balance standardisation and variety
	Use the informal system, not just the formal system
	Take every opportunity to bolster communication, trust, and interpersonal relations
	Model the system's properties
	Use multimethod research and improvement techniques
	Appreciate less is more in interventions
	Leverage complexity thinking
	Focus less on the individual and more on the system
	Develop and apply feedback to people involved at every opportunity
	Look for things going right as well as those going wrong
	Adopt a new problem solving focus based on systems thinking rather than obsessing with finding "a" way forward
	Look for behavioural patterns in the system and listen to the language people use
	Beware excessively causal logic
	Trade-off between constant turmoil and implementing changes before they are ready
	Understand that adaptation is almost always micro and granular
Hollnagel (2017)	Ability to respond
	Ability to monitor

	Ability to anticipate
	Ability to learn
Uday and Marais (2015)	Physical redundancy
	Functional redundancy
	System-level properties
	Repairability
	Internode interaction
	Localized capacity
	Human-in-the-loop
	Drift correction
	Improved communication
	Layered defence
Woods (2015)	Resilience as rebound
	Resilience as robustness
	Resilience as graceful extensibility
	Resilience as sustained adaptability
Wilson (2014)	Systems focus
	Context
	Interactions
	Holism
	Emergence
	Embedding
Saurin et al. (2013)	Give visibility to processes and outcomes
	Encourage diversity of perspectives when making decisions
	Anticipate and monitor the impact of small changes
	Design slack
	Monitor and understand the gap between prescription and practice
	Create an environment that supports resilience
Sutcliffe (2011)	Preoccupation with failure
	Reluctance to simplify
	Commitment to resilience
	Sensitivity to operations
	Deference to expertise
Hollnagel and Woods (2005)	Support for coping
	Time
	Predictability
Badham et al. (2001)	Systems with interdependent parts
	Open systems adapting to and pursuing goals in external environments
	Open socio-technical systems possessing an internal environment made up of separate but interdependent technical and social sub-systems
	Open socio-technical systems with equifinality
	Open socio-technical systems in which performance depends on jointly optimizing the technical and social sub-systems
Hendrick and Kleiner (2001)	Joint design
	Humanized task approach

	Consider the organization socio-technical characteristics
Clegg (2000)	Design is systemic.
	Values and mindsets are central to design
	Design involves making choices
	Design should reflect the needs of the business, its users and their managers
	Design is an extended social process
	Design is socially shaped
	Design is contingent
	Core processes should be integrated
	Design entails multiple task allocations between and amongst humans and machines
	System components should be congruent
	Systems should be simple in design and make problems visible
	Problems should be controlled at source
	The means of undertaking tasks should be flexibly specified
	Design practice is itself a socio-technical system
	Systems and their design should be owned by their managers and users
	Evaluation is an essential aspect of design
	Design involves multidisciplinary education
	Resources and support are required for design
	System design involves political processes
Cherns (1987)	Compatibility
	Minimal critical specification
	Variance control
	Boundary control
	Information flow
	Power and authority
	The multifunctional principle
	Support congruence
	Transitional organization
	Incompletion

APPENDIX B - Interview script for the case study of Rapid Response Team (RRT).

Section	Questions
Introduction	What are your activities and experience at the hospital and at the RRT?
	Characterization of the hospital: number of in-patient beds, ICU beds, public or private, number of employees.
	For how long the RRT has been in place? Why was it implemented?
	Who was involved in the RRT design? Have the opinions of all interested parties been heard?
	Who was responsible for the care of ward patients in deteriorating health conditions prior to the RRT?
	Where the RRT is physically located in the hospital building?
RRT functioning	Could you describe the functioning of the RRT? Is there any form of visual management to display the teams' performance (e.g., whiteboard, posters)? How long does the RRT have to reach the bedside after being called?
	How are patients monitored to know when the RRT should be called? Are records made after RRT care provision?
	What are the triggers for calling the RRT? Are the triggers always strictly observed?
	What are the difficulties and variabilities in the everyday use of the RRT (e.g., related to demand, equipment, human resources?)
	What is the composition of the RRT and the required qualification for members? Is the team composition adequate both in terms of size and profile?
	How is the performance of the RRT measured? Is there any routine (e.g., meetings) for discussing the RRT performance? Could you give examples of unintended consequences, positive or negative, arising from the RRT?

3 ARTIGO 2 – *Design for Resilient Performance: a study of toolbox talks in construction*

Abstract

Although resilient performance is intrinsic to complex socio-technical systems, it might also be deliberately supported and engineered through design. This idea is referred to in this paper as designing for resilient performance (DfRP), encompassing design principles developed in an earlier study. There are several engineered practices in organizations that give rise to design decisions that affect resilient performance. However, performing in a resilient manner is not the main purpose of any organization, and therefore DfRP tends to be concealed. This paper explores the utility of re-interpreting existing management practices from the viewpoint of DfRP. For this purpose, a case study of toolbox talks in a construction site was carried out, based on interviews, observations, and documents. Results indicated that the toolbox talks were strongly aligned to the principles of DfRP, suggesting that they were valuable investments of the participants´ time, probably being regarded as cost-effective by managers. This finding also sheds light on why the toolbox talks, which have a long history of application in the construction industry of several countries, are regarded by prior studies as a best practice.

Keywords: resilient performance, toolbox talks, design.

1 Introduction

Resilient performance (RP) is a functional property of complex socio-technical systems, playing a role in their safe and efficient functioning under expected and unexpected conditions (Hollnagel, 2014). RP emerges from both deliberate design decisions and the self-organization of people without reliance on centralized controls. The portion stemming from deliberate design is referred to in this paper as designing for resilient performance (DfRP), defined as "the use of design principles to support integrated human, technical, and organisational adaptive capabilities" (Disconzi and Saurin, 2022). For instance, DfRP can involve the provision of human (e.g., workers on standby), technical (e.g., extra inventories), or organizational (e.g., redundant quality checks) slack resources that can be called on times of need (Fireman et al., 2022).

DfRP creates conditions conducive to self-organization and is often implicit in organizational routines, not being a one-off activity but rather occurring continuously as the socio-technical system evolves (Disconzi and Saurin, 2022). In the realm of practices that contribute to DfRP, this paper explores the role of toolbox talks (also known as toolbox meetings) in a construction site. The toolbox talks usually occur daily, mainly at the beginning of the work shift or during breaks (Jeschke et al., 2017). These meetings typically last from five to ten minutes, involve workers and supervisors (these normally lead the meetings), and address workplace safety, occupational hygiene, ergonomics, and work procedures (Olson et al., 2016). All workers involved in the construction site attend the meetings (Kaskutas et al., 2013). As such, toolbox talks are deliberately designed, even though their everyday occurrence is always unique, displaying social interactions that reflect the local circumstances.

Furthermore, toolbox talks are one of the so-called best practices of safety management in construction sites, being correlated with low accident rates (Bridi et al., 2021). However, it is necessary to understand how these best practices are implemented and under what conditions they are effective, rather than only identifying what the best practices are (Bridi et al., 2021). It is also worth noting that the toolbox talks are representative of a broader family of reflective meetings concerned with making sense of systems performance, being either prospective or retrospective (or both, occasionally). Other examples of reflective meetings are the daily safety huddles in hospitals, the morbidity and mortality meetings in hospitals, ward rounds, briefings and debriefings in project management, and the resilient performance enhancement toolkit. This last practice is the only explicitly discussed from a resilience engineering perspective, by Wahl et al. (2022) in a healthcare context, and by Martins et al. (2022) in construction sites.

2 Principles of DfRP

Table 1 presents the principles of DfRP adopted as a basis for this study. These principles were developed by Disconzi and Saurin (2022) based on a Delphi study with 27 experts from nine countries. The purpose of developing these principles was twofold: supporting work system designers interested in strengthening the RP of the (re)designed systems; and serving as a basis for the evaluation of existing systems, shedding light on their strengths and weaknesses from the resilience engineering perspective.

The principles recognize RP as a dynamic and functional property of socio-technical systems, besides acknowledging technical, social, and organizational factors that support RP.

This contrasts with the narrower perspective of design for resilience in the context of technical infrastructures (e.g., Chatterjee and Layton, 2020).

Table 1 – Principles of DfRP (Disconzi and Saurin, 2022)

Principle	**Definition**
1. There must be functional models of the system	The system's functioning, both under normal and degraded conditions, must be explicitly modelled, in the sense of an articulated understanding. Models must include the main interactions with the external environment. A description of the system's functioning should be available for those who play a role in the design team.
2. Make variations in performance visible	In complex systems, variations in performance are inevitable. Gathering and sharing this information in real-time is vital to understanding performance.
3. Use the type of standardization that best fits the nature of the function	Standardization can range from strictly defined process steps to the definition of goals that leave completely open the means for their achievement. A variety of standards, in terms of their level of detail and action or decision-taking specification, might co-exist for different functions in the same system.
4. Design slack resources and strategies	Slack resources (e.g., equipment, time, money) slow down the propagation of variability and support adaptation. However, some types of slack resources add elements and interactions to the system, increasing complexity and posing their own threats. Slack resources are deployed through slack strategies (i.e., how to use the resource) such as redundancies and reciprocity – e.g., one unit helps another whose adaptive capacity is saturated.
5. Design for acceptable performance even under degraded conditions	Design should support the maintenance of acceptable performance, which involves the preservation of higher-order goals, even under degraded conditions. This principle can benefit from the slow (or graceful) system degradation, which allows time for action-taking.
6. Design must involve leveraging diverse perspectives	This principle is applicable both to the design process (i.e., designers should account for diverse perspectives in their decision-making) and to the system resulting from design (i.e., the system should have mechanisms for giving a voice to people from different hierarchical ranks, suppliers, clients, etc.). There can be a tension between the number of perspectives to be considered and the coordination costs of accounting for them. Designers should have the ability, and be given the proper organizational support, to cope with this tension.

7. Design to support continuous learning at the individual and organizational level	Complex systems offer learning opportunities ranging from everyday work to accidents. Learning in complex systems is harder because impactful events are unlikely to reoccur at the same way. Design can play a major role in supporting continuous individual and organizational learning (e.g., training programs, after-action reviews, incident investigations). Learning should occur from all operations rather than from a specific subset.

3 Method

The studied toolbox talks were carried out in the construction of a school in Norway. The project includes the construction of two buildings, a school building of 14,800 m² and a rehabilitation center with approximately 10,000 m². The construction activities started in April 2021 and are expected to end in April 2023. The project workforce includes a project manager, a site manager, ten administrative workers, and 130 operatives, who work on-site from Monday to Friday from 7 am to 3 pm. The construction company has over 30,000 employees in 11 countries and develops several types of projects, such as highways, airports, hospitals, buildings, homes, schools, shopping centers, and tunnels.

Data collection involved: (i) non-participant observations of 15 meetings, totalling 7 hours; (ii) documentary analysis of project schedules, standardized operating procedures, and written records of the decisions made in the toolbox talks; and (iii) semi-structured interviews, totalling three hours, with the site manager and two workers. The interviews were based on an interview guide that addressed the description of the interviewees' everyday activities and how the toolbox talks contributed to these activities. Data collection stopped when the researchers perceived that data saturation had been achieved. Data from all sources were subjected to a template analysis (Cassel and Symon, 2004), using the seven principles of DfRP as a starting point to the identification of relevant excerpts of text. The template analysis was conducted by the first author, and her codifications were subsequently reviewed by the other authors.

4 Results

The toolbox meetings occured daily, starting at 7 am in the lunchroom and counting on 60 participants approximately (Figure 1). The site supervisor guided the discussions, and the leaders and workers of the different crews were present such as diggers, electricians, plumbers, and concrete. The observed meetings lasted on average 13 minutes, ranging from 9 to 15 minutes. The meetings were divided into two major parts. Initially, there was an overall toolbox talk with workers from all construction zones (Figure 1, on the left), and then there were meetings specific for each work zone, called after-meetings. These subsequent meetings included only the workers related to the discussed construction activities and they could occur in places other than the lunchroom. Figure 1, on the right, shows workers from the concreting production crew who remained in the lunchroom for the after meeting, while the electricians went to the locker room to hold their own after meeting.

Figure 1. Views of the toolbox talks in the lunchroom.

Table 2 presents the main results from the evaluation of the principles of DfRP in the toolbox talks. Findings revealed that the principles are also applied in processes that interact with the toolbox talks. For example, the meetings do not produce any functional model (principle 1) of the construction activities but rather use, update, and put into context functional models developed in other processes such as production planning. The same was true for principle 2: records of deviations from the project schedule, displayed on performance measurement dashboards, made variations in performance visible and were sometimes discussed in the toolbox talks.

Based on these insights, a proposition for empirical testing is set out as follows: the effectiveness of DfRP practices depends on the use of DfRP principles in the broader socio-technical system. This proposition is complementary, rather than exclusive, to the need for using the principles at the practice itself. In the case study, this can be illustrated by the tailored format of the meetings for sub-groups of workers (application of principle 3), and the multidisciplinary composition of the team that attends the meetings (principle 6).

Table 2. Evaluation of the DfRP principles in the toolbox talks

Principles	Evaluation
1. There must be functional models of the system	The project schedules, which are presented in several formats and adopt different time horizons, are functional models of the construction site and are used during the meetings. The supervisor guides the conversations with the long-term project schedule in hand. The supervisor and crew leaders also bring with them a schedule of activities for the month and the week ahead. During the meeting, the supervisor takes notes on these documents, as indicated by his remark as follows*: "I write down the discussed activities that I need to remember and prioritize, such as checking if a safety procedure of a complicated task is being followed or the need for borrowing equipment from another site, for example ".* Standardized operating procedures (SOPs) are also functional models. Although these documents are not always explicitly mentioned in the meeting, they bound decision-making. For example, in one of the meetings, there was a discussion on the fact that some workers were not wearing safety glasses during the concreting activities, a rule specified in the concreting SOP. The employees explained that they could not see using the glasses on a rainy day. The leader accepted this justification. Thus, the SOP seemed to be used as a generic procedure put into context during the meeting.
2. Make variations in performance visible	The toolbox talks are a major opportunity for face-to-face information sharing on performance variations related to the progress of works, delays from suppliers, safety issues, as well as discussion of daily production problems. Information on these variations is usually obtained from performance metrics that are part of the construction project management system. The reasons underlying the variations and their consequences are often clarified during the toolbox meeting.
3. Use the type of standardization that best fits the nature of the function	This principle stands out in the different types of toolbox meetings that take place in the morning: the general meeting and the after meeting focused on each work zone meeting. The first meeting is relevant to all work zones (e.g., it addresses the progress of the works on the site as a whole as well as occupational hygiene habits). The second meeting addresses the construction activities in the main work zone (e.g., how deep the soil will be excavated and the corresponding safety controls). The meeting leaders used different types of production schedules (i.e., the overall schedule for the site and the detailed schedule for each work zone) to guide the conversation. The after-meeting arose from the need to discuss some of the

	construction activities more deeply. According to the site manager, *"it came as a consequence of the success of the first meeting* ".
4. Design slack resources and strategies	The talks play a role in managing capacity slack as they imply decision-making related to the production flow. The different work zones and production crews serve as slack to each other. They frequently borrow workers, machines, and materials from each other. For example, during one of the toolbox talks, members of the concreting crew reported that they were late on schedule because the cleaning crew had not completed their predecessor activities. A decision was made to transfer workers from another crew to help the cleaning crew. Further, the first and second meetings are partly redundant. Information that had already been checked in the first meeting is often rechecked during the second meeting.
5. Design for acceptable performance even under degraded conditions	Bad weather is a degraded condition, and it happens frequently depending on the season. Therefore, the talks often need to address safety and production issues stemming, for example, from heavy rain, snow, and icy surfaces. Moreover, fewer people attend the meetings on rainy or snowy days, and others are late. In these cases, whenever possible, the key information is presented again in the after-meeting.
6. Design must involve leveraging diverse perspectives	This principle is intrinsic to the toolbox talks as they are multidisciplinary. There are representatives from different hierarchical levels, including supervisors, crew leaders, and workers from different trades, such as plumbers, electricians, diggers, cleaning, and scaffolding. Occasionally, the supervisor invites participants on an ad-hoc basis – e.g., those responsible for purchasing materials to bring updates on the scheduled deliveries.
7. Design to support continuous learning at the individual and organizational level	The toolbox meetings offer plenty of learning opportunities, in part due to their multidisciplinary nature. There are opportunities for problem identification and discussion of possible solutions, including the revision of safety procedures for risky activities such as those involving explosives. The interviews revealed that the meetings have contributed to changes in the SOPs, creation of new SOPs, changes in the safety checklists, and the creation of the after-meetings.

5 Conclusion

This study revealed the utility of the seven principles of DfRP for understanding daily toolbox talks in a construction site. Findings indicate that those talks are strongly consistent with the DfRP principles, providing piece of evidence that they are valuable investments of the participants´ time, probably being regarded as cost-effective by managers. Indeed, the after meetings were introduced as a result of the perceived success of the overall meeting that addressed all construction activities, and also because this meeting did not allow the necessary time for discussing details of each work zone. As such, the alignment of the toolbox talks to the DfRP principles sheds light on why they are regarded as a best practice in the construction industry.

As a limitation, the present study did not investigate how the decisions made in the toolbox talks were actually implemented in the construction site, and what the implications were for performance dimensions such as cost, quality, safety, and productivity. It is possible that this further investigation reveals shortcomings in the toolbox talks that were not captured by this study.

In the sequel of this research project, other practices supportive of DfRP will be investigated, comprising not only other types of reflective meetings but also practices involving teams that are activated in case of need – e.g., rapid response teams in hospitals and help chains, a standardized routine for coping with abnormalities in manufacturing plants. Results from this expanded investigation will explore the general utility of the principles and set a basis for the development of a protocol for assessing the use of the DfRP principles in socio-technical systems of different domains. This unit of analysis targeted by this protocol will be the socio-technical system rather than the DfRP practices. The assumption is that, in a given system, there will be several DfRP practices that interact with each other, along with interactions with other, designed or not, social and technical artefacts. The protocol will include maturity levels of adopting the principles, consisting of a new approach for resilience assessment. The protocol application is expected to shed light on how existing safety and production management practices can be improved in order to explicitly and systematically support RP through work system design.

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4 ARTIGO 3 - *Practices of designing for resilient performance: the role of huddles in emergency departments and help chain in manufacturing plants*

Abstract

Although resilient performance is intrinsic to complex sociotechnical systems, it might also be engineered through design. This idea is referred to as designing for resilient performance (DfRP), encompassing design principles developed in a prior study. There are several engineered management practices in organizations, in which work system design decisions that affect resilient performance are made. However, supporting resilience is not usually an explicit objective of using these practices. This paper assesses two practices (daily huddles in an emergency department, and the problem-solving lean practice called help chain, in a manufacturing plant) from the viewpoint of the principles DfRP. Data collection and analysis for the assessment of both practices was similar, involving interviews, observations, and documents. Results shed light on the practices´ strengths, weaknesses, and interactions with the broader sociotechnical system. Moreover, insights into the cost-effectiveness of these practices, using financial and non-financial metrics, were obtained. Key differences and commonalities between both practices were identified.

Keywords: resilient performance, work system design, practices, huddles, help chain.

5 ARTIGO 4 - *Principles and practices of designing for resilient performance: an assessment framework*

Abstract

Although resilient performance is intrinsic to socio-technical systems it might be supported by design, an idea known as Design for Resilient Performance (DfRP). Considering that such design is usually a re-design, learning from existing systems is crucial. This article introduces a framework for assessing the extent to which a system uses practices and principles of DfRP. The framework allows for the assessment of 24 attributes of the principles, the analysis of their relationships (a model was devised based on a survey with experts), and the investigation of practices that operationalize the principles. A scoring system sheds light on the effectiveness of using the principles. The framework application is exemplified based on the study of an emergency department in which daily huddles stood out as a practice of DfRP. This study involved interviews, observations, and documentary analysis. Based on this, a knowledge structure of DfRP is presented, comprised of concepts, principles, and practices. Six propositions to guide the framework application are set out, addressing themes such as the need for cost-effective DfRP, short control cycles, and customized designs that meet preferences of designers. The study contributes to DfRP theory and offers a new approach for resilience assessment.

Keywords: resilient performance, design, complexity, assessment, huddles.

1 Introduction

Resilient performance (RP) is a socio-technical system's ability to adjust its functioning prior to, during, or following changes and disturbances, thereby sustaining operations under both expected and unexpected conditions (Hollnagel, 2014). Resilient systems withstand shocks small and large, rebound from them, and might display an enhanced performance in the post-recovery phase (Grøtan et al., 2022). Although RP is, to some extent, intrinsic to the self-organization of socio-technical systems, relying solely on this source of resilience is too risky and unethical (Bergström et al., 2015). This reliance implies in RP playing out mostly at the individual level and at the expense of people's self-sacrifice such as burnout and high workload (Terra et al., 2023; Nyssen and Bérastégui, 2017).

By contrast, the work system design perspective favoured by human factors and ergonomics (Wilson, 2014) argues for the design of resources to support people at work. This is consonant with designing for RP (DfRP), defined as "the use of design principles to support integrated human, technical, and organisational adaptive capabilities" (Disconzi and Saurin, 2022). This concept is supportive to RP from self-organization on the spot by skilled workers, which is crucial under unexpected conditions (Wahl et al., 2020).

DfRP usually implies re-designing an existing socio-technical system rather than designing a new system from scratch. This re-design can benefit from the assessment of the extent to which the system already accounts for DfRP. For this purpose, the use of assessment tools such as the resilience assessment grid (Hollnagel, 2017) and resilience indicators (Peñaloza et al., 2021) offer useful information. As a drawback, none of these approaches is framed in terms of DfRP, which is partly due to the lack of a comprehensive and empirically tested DfRP theory. Thus, resilience assessments are not explicitly design-oriented, and the translation of descriptions of RP into design interventions tends to be overly dependent on experienced RE professionals. Further, resilience assessment tools do not explicitly address core questions of resilience management, a proxy of DfRP, posed by Wiig et al. (2020), namely resilience *for what* (the goals supported by RP), *of what* (what materials and resources underpin resilience), *to what* (what triggers and activates resilience), and *through what* (mechanisms, activities, and interactions that support resilience).

In this context, the research question investigated in this article is stated as follows: how can the use of principles and practices of DfRP be assessed in socio-technical systems? The terms principles and practices refer to different levels of abstraction. Principles are more abstract and related to high-level guidance to designers. Practices are designed managerial processes and tools that operationalize the principles, necessarily including a human component. A technical component is useful but not fundamental for a practice of DfRP. This definition is based on the premise that human performance remains essential to adaptation, despite technological advances (Hollnagel, 2021; Xu et al., 2021). Both principles and practices address the question of resilience *through what* set out by Wiig et al. (2020).

In order to answer the research question, a framework for the assessment of the principles and practices of DfRP is presented. Seven principles of DfRP developed by Disconzi and Saurin (2022) are adopted as a basis. They were chosen due to the verifiable approach used in their development, which involved an extensive literature review of seminal human factors publications followed by a Delphi study with 27 experts from nine countries. Moreover, the principles have been tested empirically for the assessment of practices such as rapid response teams in hospitals (Disconzi and Saurin, 2022) and toolbox safety meetings in construction sites (Disconzi et al., 2023). The present work expands the method used in these prior studies in three ways: (*i*) by considering the socio-technical system, rather than the practice, as the unit of analysis; (*ii*) by including a tool for assessing the relationships between the principles; this is relevant in complex systems as elements interact with each other (Dekker et al., 2011); and (*iii*) by assigning scores to the maturity levels of using the principles, broken-down into auditable attributes. This paper illustrates the framework's applicability to an emergency department, in which daily huddles stood out as a practice of DfRP.

2 Background

2.1 Design for resilient performance

Table 1 presents the principles of DfRP. They include social (e.g., diverse perspectives) and technical (e.g., standardization) dimensions of work system design, which should be jointly optimized as recommended by socio-technical systems theory (Clegg, 2000). The principles are concerned with RP both under every day work and degraded conditions, recognizing that the same variabilities underpin both normal work and accidents (Hollnagel, 2014). The principles are consistent with the four potentials of resilient systems proposed by Hollnagel (2017), namely monitoring (e.g., relates to visibility), anticipating (e.g., relates to all principles as design implies the anticipation of future conditions or performance), responding (e.g., relates to slack), and learning. The development of a comprehensive theory of DfRP is a work-in-progress by the human factors and resilience engineering communities, and therefore the principles are subject to continuous revision and improvement. As an illustration of this point, Haraldseid-Driftland et al. (2023) present eight principles of organizational learning from a resilience lens – e.g., create space for reflection and create awareness of adaptive capacities. These principles further develop and expand the learning principle in Table 1.

The definitions of the principles imply that they can be broken-down into auditable attributes. For example, the principle of functional modelling conveys that models should be easily available for those who operate the system, which is an auditable attribute. Furthermore, the studies by Disconzi et al. (2023) and Disconzi and Saurin (2022) indicated that the principles and practices interact with many other elements of the socio-technical system. Thus, the socio-technical system tends to be a more relevant unit of analysis than isolated practices.

Table 1. DfRP principles (Disconzi and Saurin, 2022).

Principles	Definition
There must be functional models of the system **(FUN)**	The system's functioning, both under normal and degraded conditions, must be modelled, in the sense of an articulated understanding. Models must include the main interactions with the environment. A description of the system's functioning should be available for those who play a role in the design team.
Make variations in performance visible **(VIS)**	In complex systems, variations in performance are inevitable. Gathering and sharing this information in real-time is vital to understanding performance.
Use the type of standardization that best fits the nature of the function **(STD)**	Standardization can range from strictly defined process steps to the definition of goals that leave completely open the means for their achievement. A variety of standards, in terms of their level of detail and action or decision-taking specification, might co-exist for different functions.
Design slack resources and strategies **(SLA)**	Slack resources (e.g., time, money) slow down the propagation of variability and support adaptation. However, some slack resources add elements and interactions to the system, increasing complexity and posing their own threats. Slack resources are deployed through slack strategies (i.e., how to use the resource) such as redundancies and reciprocity – e.g., one unit helps another whose adaptive capacity is saturated.
Design for acceptable performance even under degraded conditions **(DEG)**	Design should support the maintenance of acceptable performance, preserving higher order goals under degraded conditions. This principle can benefit from the slow (or graceful) system degradation, which allows time for action-taking.
Design must involve leveraging diverse perspectives **(DIP)**	This principle is applicable both to the design process (i.e., designers should account for diverse perspectives in their decisions) and to the system resulting from design (i. e., the system should have mechanisms for giving a voice to people from different ranks). There is a tension between the number of perspectives to be considered and the coordination costs.
Design to support continuous learning at the individual and organizational level **(LEA)**	Learning opportunities range from everyday work to accidents. Learning in complex systems is hard because impactful events are unlikely to reoccur at the same way. Design can support continuous individual and organizational learning (e.g., training programs, after-action reviews, incident investigations).

2.2 Resilience assessment methods

Resilience engineering usually focuses on describing what resilience *is*. This emphasis stems from the assumption that DfRP must be preceded by a deep understanding of work-as-done in reality (Nemeth and Herrera, 2015). Thus, there are several studies that report manifestations of RP and categorize them according to dimensions such as goals of resilience, reactive versus proactive, and enabling conditions (Righi et al., 2015). For systems other than organizations, such as cities (Meerow et al., 2016), the methods for resilience assessment range widely, from interviews to mathematical and computational models (Chen et al., 2023).

Regarding resilience engineering for organizations, qualitative and semi-quantitative methods are predominant (Patriarca et al., 2018). The resilience assessment grid (RAG) proposed by Hollnagel (2015) stands out with applications in sectors such as healthcare (Chuang et al., 2020), construction (Peñaloza et al., 2020a), and oil and gas (Ose et al., 2013). RAG consists of questions that should be adapted to each context, related to the potentials of resilient systems (Hollnagel, 2011). RAG provides a snapshot of the organization's current performance, setting a basis for improvement (Hollnagel, 2015).

The DARWIN resilience management guidelines are similar to RAG as they include auditable guidelines in the context of crisis management (DARWIN, 2015). This method has been applied in sectors such as the oil and gas industry (Steen et al., 2023) and shipping (Förster et al., 2019). The Functional Resonance Analysis Method (FRAM) is also used in resilience engineering for assessment purposes (Hollnagel, 2012). Bueno et al. (2021) proposed additional steps to the original FRAM to make it explicit the role of resilience – e.g., understanding the reason for desired outcomes. In the realm of safety performance measurement, the review carried out by Peñaloza et al. (2020b) concluded that some metrics commonly adopted by organizations are implicitly aligned with resilience engineering, and thus useful for resilience assessments. Overall, despite the contributions of prior resilience assessment studies, they do not have a design (i.e., prescriptive) commitment, reinforcing the research gap addressed in this article.

3 Research method

3.1 Research design

Design Science was the chosen methodological approach. Simon (1996) frames design science as a science of the artificial concerned with the development of man-made artefacts or designs. These artefacts are usually models, frameworks, methods, or constructs regarded as generic designs to be used by well-trained and experienced designers to make their own context-specific design (Van Aken et al., 2016). Although design science has a descriptive stage aimed at understanding the problem, its end goal is to develop prescriptive knowledge to solve practical problems that have theoretical relevance (Holmström et al., 2014). These characteristics fit this study, which offers a prescriptive contribution to assessing the use of principles and practices of DfRP. The descriptive stage occurred in the studies by Disconzi et al. (2023) and Disconzi and Saurin (2022). Based on these studies, some premises were adopted for devising the framework: the unit of analysis should be a system with one or more practices that operationalized the principles; the relationships between the principles should be explored; the principles should be broken down into auditable attributes; and the assessment should give rise to re-design recommendations. As usual in design science, creativity played a role, and the framework development process had several cycles of design and re-design (Van Aken et al., 2016).

Next, the framework was tested in the emergency department (ED) of a large hospital in Brazil. EDs are complex socio-technical systems owing to characteristics such as uncertainty in demand, tightly-coupled processes, and collaborative work between a wide diversity of professionals and technologies (Austin et al., 2022). Further, the hospital has been using daily clinical huddles for over five years in the context of a nationwide project led by the Ministry of Health called Lean Emergencies, inspired by lean production principles. This project aimed to reducing overcrowding and shortening waiting times. Informal staff reports indicated that they had a positive perception of the huddles, which at a cursory view were adherent to the principles of DfRP. There were two other practices that resembled DfRP: the clinical rounds and the shift handovers. However, these practices were more limited than the huddles. Clinical rounds focused on medical issues related to patient treatment and did not involve a multidisciplinary team. Shift handovers were carried out by pairs of workers from the same professional group (e.g., nurse coming in and nursing leaving the ED), and used to be limited to updates regarding documentation and condition of patients. The huddles, as detailed in section 4.2.2, were multidisciplinary and enhanced coordination between professional groups, played a role for managing ED capacity, and were carried out in a standardized way, therefore being more promising as a practice of DfRP. The hospital's ethics committee approved this study, and all participants signed a form of informed consent.

3.2 Data collection

The framework application was based on multiple sources of evidence. Semi-structured interviews were the main sources of data, including 14 professionals from the ED: physicians (4), nurses (3), nurse technicians (3), nutritionists (2), and social workers (2). They were chosen due to their regular participation in the huddles as well as their ED experience (> 5 years). An interview guide was used, containing: a question on the description of the respondent's daily activities; seven questions related to the contribution of the huddles to each of the DfRP principles (e.g., how do huddles contribute to make variations in the ED performance visible?); a question on the benefits of the huddles; and a question on the drawbacks of the huddles. Although the questions focused on the huddles, respondents were encouraged to discuss other practices or elements of the system regarded as relevant to the principles.

A group interview was conducted at the end of the study to present the main findings to staff and obtain feedback. A group interview was suitable as the results were of interest to all professionals, and this would be a cost-effective approach for all parties. The participants of this interview were physicians (2), medical residents (2), nurses (2), and nurse technicians (2). They regularly attended the huddles and voluntarily accepted an invitation made by the medical-chief to all ED staff. The interview took approximately one hour. The researcher presented the findings and posed two questions to the participants: how accurate are the findings? Can results give insights into improvement opportunities? All interviews occurred at the ED premises in a room that allowed privacy for the conversation, were audio-recorded, and produced approximately 6,000 words of transcripts.

Non-participant observations were also sources of evidence as the main researcher attended 25 huddles over different days of the week, totalling approximately 40 hours. These observations focused on the attributes associated with each principle (see Appendix), allowing for records of the length of the meetings, the number and profile of the participants, as well as their comments and decisions related to the principles. The researcher also observed everyday clinical work in all ED units, paying special attention to practices and working conditions related to DfRP. Notes from observations, corresponding to approximately 2,000 words, were recorded on a diary. Interviews and observations were discontinued after data saturation was perceived to be obtained, meaning that findings started being repetitive and sufficient for the study's purpose (Fugard and Potts, 2015). The number of interviews (14) closely matches the number (12) pointed out as a common threshold for data saturation in qualitative research in organizations (Guest et al., 2006).

Additionally, documentary analysis encompassed standardized operating procedures, notes made by professionals of their participation in the huddles, patient charts, and boards displaying metrics such as patient length of stay and occupancy rate. Documents were mostly helpful for assessing the principles related to functional modelling, visibility of performance variations, and standardization.

A separate data collection was necessary for developing a model of the relationships between the principles. These relationships were identified from a survey with 12 out of the 27 experts who had participated in the Delphi panel that resulted in the DfRP principles (see Disconzi and Saurin, 2022) – 15 experts declined the invitation to answer the survey. Thus, the respondents were familiar with the ideas underlying this study. Their academic or practical experience with resilience engineering was on average 9.5 years, and they all had either a MSc or PhD degree. The survey had seven questions, one for each principle, as follows: *to what extent does principle X support the implementation of principle Y? Assign your scores using the following scale: no support (zero), weak support (1), moderate support (2), and strong support (3).* As there were seven principles, n.(n-1) or 42 answers were required. The resulting model conveyed generic relationships that could be used for analysing specific case studies. This same approach for developing the model, with the same scale, was used by Bridi et al. (2021) and Saurin et al. (2011), respectively, for the development of relationship models between construction safety best practices and between lean production practices in manufacturing cells.

3.3 Data analysis

Transcripts of interviews, notes from observations, and documents were subjected to thematic analysis, according to the procedures proposed by Pope et al. (2000). It started by reading the notes and transcripts in order to obtain familiarity with the data. Then, excerpts of text associated with the main themes (i.e., the principles of DfRP) were identified. The first author performed an initial coding and then submitted it to the appraisal of the second author, who also read all transcripts and notes; both were experienced human factors and resilience engineering researchers. Such coding involved the triangulation of excerpts of text from all data capture approaches that were related to the same themes, embellishing one another. The feedback from the second author triggered another round of coding by the first author until an agreement was reached. Similar cycles of consensus-building occurred for the assignment of scores to the attributes of DfRP in the ED study (see scoring system described in section 4.1) – i.e., the first author made an initial assignment of scores, and the second author reviewed these.

Regarding data from the survey, a model was built considering the relationships with an average result higher or equal to 2.22 as a cut-off point. This value, in comparison with other tested thresholds (e.g., 2.5, 2.0), produced a model that was at the same time visually understandable and preserved relevant relationships. Representations based on other thresholds were either cluttered or missed crucial relationships. The final model was developed after several rounds of refinement, with principles grouped into three categories: end principles depend on others at least twice as frequently as they support other principles; intermediate principles depend as much on other principles as other principles depend on them; and basic principles support other principles at least twice as frequently as they depend on others.

The lessons learned from applying the framework, as well as extant theory, produced insight into propositions that support the framework application. The propositions offer additional guidance on where and how the generic design is to be used in the field (Van Aken et al., 2016). The proposition development is bottom-up, involving the search for patterns in data and the creative development of explanations – theories – for those patterns (Woo et al., 2017).

4 Results

4.1 Framework for assessing the use of the principles and practices of DfRP

Figure 1 presents the five-stage framework. In **stage 1**, the socio-technical system is described according to the four subsystems proposed by Hendrick and Kleiner (2001): social, technical, work organization, and the external environment. This holistic description is important as the four subsystems can be influenced through DfRP, although their joint optimization is challenging (Clegg, 2000). This stage also requires responses to the questions set out by Wiig et al. (2020): resilience for what? To what? Of what? Through what? Responses provide a rationale for applying the framework and a scope for the assessment.

In **stage 2**, practices of DfRP must be identified as they operationalize the principles and can be targeted for re-design. DfRP practices are likely to be part of the work organization subsystem described in the prior stage, contributing to decision-making that influences RP. The understanding of these practices is expanded in stage 2, obtaining information on why they are used, who is involved, how frequently the practice is deployed, where it takes place physically or virtually, how it is deployed, how it interacts with the socio-technical system, and the benefits and drawbacks of using the practice.

Data collection for stages 1 and 2 sets a solid basis for **stage 3**, focused on the assessment of the principles. They are broken down into 24 attributes (Appendix) that should be individually assessed and scored based on the scoring system proposed in Table 2. The score for each principle is the ratio between the total points obtained by the attributes and the total possible points for the principle. The overall score is the average of the scores obtained by the principles.

Table 2. Scoring system for assessing the attributes of the principles of DfRP

Level	Descriptor
Very high use (1.0 point)	The attribute is a result of design and is present in all or most of the subsystems, consistently used regardless of different people, time, and place. Informal manifestations of the attribute are at least partly supported and/or benefit from its formal manifestations.
High use (0.75 point)	The attribute is a result of design and is present in all or most of the subsystems, consistently used regardless of different people, time, and place. Informal manifestations of the attribute are entirely reliant on people's self-organization, without support from design.
Moderate use (0.5 point)	The attribute is a result of design and is present in few subsystems, being used to varying degrees, depending on the involved people, time, and place. Informal manifestations of the attribute are entirely reliant on people's self-organization, without support from design.
Low use (0.25 point)	There are no designed manifestations of the attribute. It is used only as a result of people's self-organization in case of need.
No use (0.0 point)	The attribute is not present in the system, neither as result of design nor from informal manifestations.
Not applicable	The attribute is either not applicable or not relevant to the system, owing to reasons such as process type and regulatory requirements.

Stage 4 involves the use of the relationship model, offering insight into how the principles interact with each other. This model was built based on the procedures described in section 3.3, displaying relationships pointed out by the experts surveyed. There are four main analytical possibilities: (*i*) the use of a certain principle is high, and the principles that support it are also highly used – this is an ideal condition demanding actions to sustain this performance; (*ii*) the use of a certain principle is low, and the principles that support it are also used poorly – this is the most undesired condition, demanding actions to increase the use of the supportive principles; (*iii*) the use of a certain principle is low, despite the high use of the supportive principles – this suggests that important conditions for use are in place and higher use might be a matter of taking advantage of existing opportunities; and (*iv*) the use of a certain principle is

high, despite the low use of the supportive principles –the highly used principle is in a precarious position, possibly demanding too much effort.

The application is concluded in **stage 5** with recommendations for re-design. These should be grounded on data from the prior stages, ranging from strategic (e.g., acknowledging RP as a key performance dimension and deliberately managing it) to operational issues (e.g., improving the implementation of the practices). The uptake of recommendations changes the system, setting a basis for a new cycle of applying the framework. The appendix presents the forms for applying the framework.

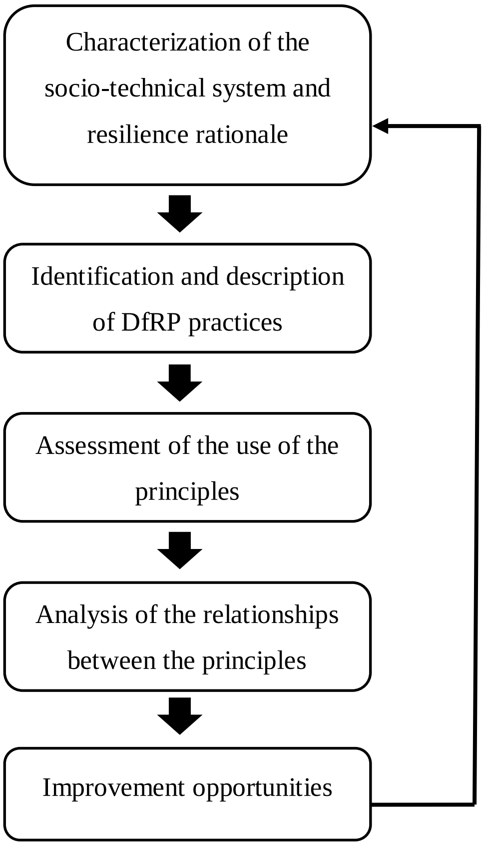

Figure 1. Framework for assessing the use of the principles and practices of DfRP.

4.2 Application of the framework to the ED study

4.2.1 Characterization of the socio-technical system and resilience rationale

Table 3 presents the characteristics of the ED according to the socio-technical subsystems (stage 1 of the framework). The ED is located in a 1.5 million capital city in

Southern Brazil. It provides care to adult patients and is part of a public, tertiary, and teaching hospital that counts on approximately 6,000 employees. The hospital is a reference for several medical specialties, with 800 in-patient beds and 150 intensive care unit beds. The main ED goal is the provision of safe and effective care to patients, addressing the question of resilience *for what*. The achievement of this goal demands human (e.g., caregivers) and material resources (e.g., built environment, technologies for treating patients), accounting for the resilience *of what* question. These resources interact with each other and play out in a coherent way in practices such as huddles, patient triage, and shift handovers, corresponding to the resilience *through what* question. However, there are barriers to RP, such as overcrowding, demand variation, patients with multiple morbidities, and a high turnover of residents and students. These factors activate RP, corresponding to the resilience *to what* question.

Table 3. Characterization of the emergency department.

Subsystems	Description
Work organization	Official capacity of 59 beds; open 24/7 Triage system for prioritizing patients Six treatment units, divided according to patient acuity Average length of stay for patients is 48 hours, but there is wide variation Doctors are responsible for treatment decision-making. Nurses are team leaders and supervise nurse technicians who provide direct patient care. Work shifts change three times a day: 8 am, 2 pm, and 8 pm Two types of daily clinical huddles, for critical and for non-critical patients
Social	50 doctors, 36 nurses, and 116 nursing technicians Multidisciplinary care team composed of physicians, psychologists, physiotherapists, social workers, residents and undergraduate students Doctors from other hospital units are called on to the ED for specialized support
Technical	Sophisticated equipment for patient care (e.g., monitor of vital signs, mechanical ventilation) Electronic medical records used side-by-side with paper-based charts. Different access levels to electronic documents, according to professional category and hierarchical level Communication between team members frequently occurs via WhatsApp The ED has its own pharmacy and X-ray room

External environment	Patients admitted via ambulance or walk-in Patients in condition of social vulnerability such as poverty and lack of social networks Admission of walk-in patients can be refused if the unit is overcrowded. Then, patients are referred to primary care units. Substantial number of patients from other cities in the region Surges in demand are common and depend on day/time/season of the year ED leadership is in close communication with the ward's bed manager (who attends the huddles of non-critical patients) and the ICU bed manager (who attends the huddles of critical patients). This is important for decision-making on patient flow.

4.2.2 Identification and description of DfRP practices

The emphasized DfRP practice, daily huddles, is further described in stage 2. There are two types of huddles (Table 4): for non-critical and for critical patients. The former patients are expected to be either discharged or transferred to in-patient wards. The latter are those expected to be transferred to the ICU.

Table 4. Main characteristics of the huddles.

	Critical patients	**Non-critical patients**
Start time	10:40 am	11:00 am and 3:30 pm
Location	Bedside	Hallway and doctors' prescription room
Frequency	Monday to Friday	Monday to Friday
Duration	20 minutes	60 minutes (morning) and 20 minutes (afternoon)
Number of beds	13	46
Time per patient on average	2 minutes	78 seconds (morning), 26 seconds (afternoon)
N. of participants on average	10	16 (morning) and 8 (afternoon)
Participants	Doctors, nursing, nutritionist, psychology, ICU bed manager. Additional participants (e.g., doctors from certain specialties) as needed.	Doctors, nursing, nutritionist, psychology, bed manager of hospital wards, social worker. Additional participants as needed.

In both types of huddles, the condition of each patient is briefly reviewed, and the expected destination of the patient (e.g., ICU) is discussed. This planning speeds up the preparation for patient handover and shortened ED stay. This aim is important as the ED is often in a condition referred to by managers as the Full Capacity Plan, meaning that the number of hospitalized patients is greater than the official number of beds (59). At the most critical level, more than 89 patients, only those at risk of death are admitted. A piece of evidence of improvements in patient flow was obtained from the hospital records, indicating that, at the time of this study, approximately 70% of the patients were discharged within 48 hours, in contrast to 55% prior to the introduction of the huddles.

Participants of the huddles carry with them a list of hospitalized patients containing information such as name, age, and updates on treatment and clinical status. There are minor differences in the lists used by the medical and nursing teams – e.g., lists used by nurses highlight care activities they are responsible for, such as "keep patient hydrated"; lists used by doctors emphasize information for treatment decisions such as results of exams. During and after the huddles, participants take notes of tasks they should do – e.g., the nutritionist wrote down that the feeding tube should be removed.

The huddles imply a commitment of resources. Based on the observations, the estimated average daily number of man-hours spent in these meetings is: 36 for critical patients; 30 for non-critical patients in the morning shift; and 18 for non-critical patients in the afternoon shift. Despite this cost, huddles have been in place for several years, suggesting that they are regarded by managers as cost-effective.

4.2.3 Assessment of the DfRP principles

Figure 2 shows the scores obtained by each principle and the overall ED score. The scores for each attribute are in the Appendix. These scores are estimates of the uptake of each principle rather than exact performance metrics. The highest score (0.87) was obtained by the principle related to standardization that fits the nature of the function (STD). The use of this principle stands out in the two types of huddles, which are more complex (i.e., longer, more interactive) for critical patients. Moreover, the triage of patients plays a role in STD. Processes that follow the triage are customized to fit the patient's acuity level, growing in complexity as acuity increases. A price paid for this customization is the complexity of the triage itself: this process uses the Manchester protocol, composed of 56 flowcharts with five possible outcomes: emergency, very urgent, urgent, slightly urgent, and not urgent. Despite these flowcharts, professional's tacit knowledge is necessary, as illustrated by the following remark from a triage nurse: "*it is not enough to consider the responses given by the patient… for example, I ask her* *to rate her pain from 0 to 10* [10 is the worst pain]. *The patient says 10, but I see her walking and talking…so I know it's at most a 5*!"

In turn, motor tasks such as hand washing had procedures that specified step-by-step how they should be conducted. On the other hand, complex care tasks such as treating sepsis had procedures organized as algorithms that posed questions for the professional and offered courses of action depending on the response. Thus, these algorithms recognized that flexibility and judgment were necessary, in line with STD.

The principle related to functional modelling (FUN) was the second best-scoring (0.85), due to the large number of standardized operating procedures, SOPs, (e.g., administering medication), and care protocols (e.g., treating strokes). However, access to these documents occurs mostly through computers, can be time-consuming, and varies according to professional group and hierarchical rank – e.g., nurses do not have access to certain documents that are only available to doctors. The patient chart plays the role of functional model of the patient, displaying information about their clinical condition in textual and graphical format. According to the observations and interviewees' reports, charts and care protocols were used more frequently than SOPs, whose existence was unknown by some employees. Thus, certain types of functional models are more relevant than others in supporting RP. Furthermore, some employees customized the models to meet their needs and preferences – e.g., one doctor created her own list of patients, containing information she regarded as relevant; in her view, the standard format provided by the computerized system was not satisfactory.

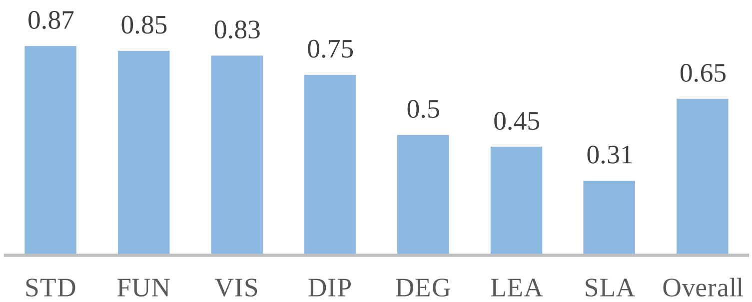

Figure 2. Scores obtained by the principles of DfRP

The principle related to the visibility of variations (VIS) also obtained a high score (0.83), which is positive in a dynamic system such as the ED. The most salient example of applying this principle concerns the monitors of vital signs at the bedside. For critical patients, an automated system connects vital sign monitors to the electronic patient chart, which is updated in real-time. For non-critical patients, charts are manually updated at shift change. Another example of using technology for VIS is the use of message apps to share information on the occupancy rate and the status of the full capacity plan (e.g., whether walk-in patients should be admitted). Furthermore, the ED receptionist accesses an electronic dashboard that presents the real-time occupancy of all EDs in the city. This is useful for advising patients diverted to other hospitals. It is also worth noting that the huddles offer opportunities for information sharing and therefore for giving visibility to variations.

Next, the principle that promotes diverse perspectives (DIP) obtained a fairly good score (0.75). The huddles were a prime example of using this principle as they counted on staff from several professional groups in addition to students, and occasionally even the active participation of the patient. Although all participants could speak up, we observed that those who did use to be the medical head of the ED, the heads of the ICU and wards, and the doctor responsible for each patient. The others used to intervene only when requested by the doctors. Patients' and families' perspectives were taken into account for decisions involving treatment and the patient's destination. Social workers connected patients, families, and the hospital team. An example of this role refers to the case of a man hospitalized for a drug overdose. His health was stable, allowing for discharge. However, during the huddle, the social worker informed that the patient's family was not ready to receive him at home. The discharge was postponed to the next day, when the social worker informed that the family had agreed to shelter the patient.

The principle related to the design for acceptable performance even under degraded conditions (DEG) scored 0.50. The importance of this principle is clear as surges in demand, along with the associated performance degradation, are normal in EDs. The main designed measure to operate under overcrowding is the full capacity plan, which consists of several responses depending on the number of patients – e.g., referral of patients to other health services, redistribution of tasks, and repurposing of spaces. Information on the ED status regarding the full capacity plan is disseminated through message apps and signs displayed at the reception.

A situation observed in a huddle illustrates the role of this practice in using DEG. A terminally-ill cancer patient had been admitted to the ED but was stable. In the huddle, participants raised the possibility of discharging this patient to free up her bed and to allow her extra time with family, on the condition that she would return a few days later for follow-up. The social worker presented this option to the family, who agreed. Thus, measures to address this patient were designed in the huddle, coping with the degraded condition of both the overcrowded ED and the patient. This example also highlights the co-design involving patient and family.

The principle of learning (LEA) scored 0.45. Again, huddles and other similar practices, such as shift changes, allowed for the operationalization of the principle. In common, these practices foster learning through information exchange, and problem-solving on the spot. This last point was exemplified in a huddle when the participants realized that the wrong medication had been delivered to a patient discharged on the day before. During the huddle, participants decided to contact the patient's family to communicate the error immediately and request the return of the pills. There was an investigation of this incident led by staff from the risk management department. In addition, ED indicators and patient charts are sources of data for learning.

The principle that promotes the use of slack resources and strategies (SLA) had the lowest score (0.31). This stemmed from the nature of slack resources to cope with overcrowding, which allows for the accommodation of extra patients but under precarious conditions. Some examples of this are as follows: use of stretchers as regular beds; placing two beds or stretchers in spaces designed for one bed; and use of armchairs as beds. The observation of one huddle illustrates these examples: participants discussed the situation of a 77 years-old patient who was in an armchair waiting for a bed in the hospital ward for five days. During the huddle, the decision was made to transfer the patient to a stretcher in another ED unit. Not only space but also people from different ED units help each other when necessary – e.g., there was a cardiac arrest in the unit for critical patients, and the doctor obtained prompt support from a colleague from another unit. According to the interviewees, inter-unit support is frequent, especially during the night shift and on weekends when the staff is reduced. The only unit that does not serve as slack to others is the stabilization unit, where initial urgent care is provided to incoming patients from ambulances. In addition to these slack resources of space and people, the morning and afternoon huddles offered partly redundant information as the patients were reviewed in every meeting.

4.2.4 Relationships between the DfRP principles

Figure 3 depicts the relationships between the principles, whereas the values in the boxes are the scores obtained by each principle. Principles FUN and DIP appear as basic, which makes sense as the former is the basis for understanding the system's functioning, and the latter is valuable for any decision. VIS was regarded as intermediate, suggesting that effective visual management is difficult to sustain while impactful. STD, SLA, DEG, and LEA were end principles associated with concrete actions, decisions, and resources that materialize DfRP.

Three end principles (SLA, DEG, and LEA) had low scores (equal to or lower than 0.5) despite the high scores of their supportive principles (0.85; 0.83; and 0.75). Two non-exclusive interpretations are proposed: (*i*) the benefits from the supportive principles have not been fully exploited (e.g., functional models could be used to determine where to place slack resources and how much; lessons from huddles could be recorded and disseminated through visual management); and (*ii*) there are factors other than the principles hindering the performance of the end principles – e.g., chronic overcrowding limits the effectiveness of any designed slack resource, and time pressures make the documentation of lessons learned a low priority.

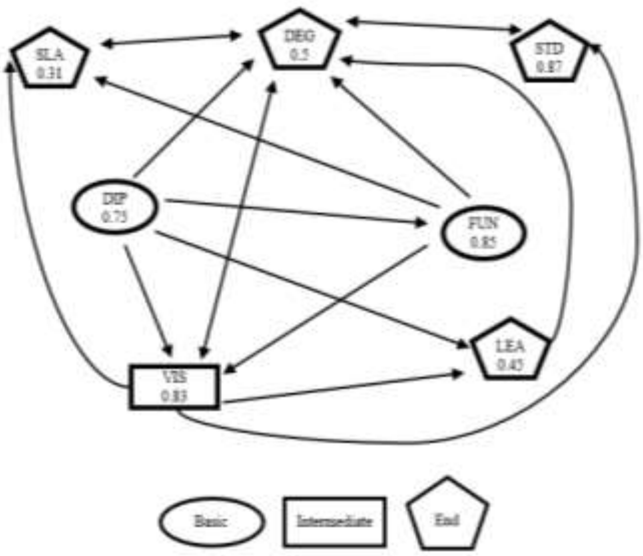

Figure 3. Relationships between the principles and scores at the ED.

4.2.5 Improvement opportunities for system re-design

Results from the prior stages were re-interpreted in light of opportunities for work system re-design (Table 5). Despite the format of Table 5, some improvements are directly related to two or more principles, which is expected due to their relationships. For example, the development of models that account for the perspectives of all affected parties is related to both FUN and DIP, and also STD as users' inputs tend to make work standards fit to the nature of the functions. In the group interview with ED representatives, the relevance of these opportunities was confirmed as exemplified by the following remark from a physician: "*the results made it clear that design supports the success of individual and team resilience…when we do not have this support, there is always a reduction in the quality of our services or the costly use of extra resources*". Participants also pointed out that the framework use requires collaboration between a multidisciplinary team of ED staff and resilience experts. To some extent, this is what occurred as the researcher actively sought for staff perspectives.

The identified improvements should be interpreted as a starting point for work system re-design, rather than solutions ready for implementation. Several of the improvements involve tangible costs (e.g., increasing staffing levels during weekends and night shifts) and, like any other change in a complex system, they interact with other system elements (Perrow, 1999), creating possible trade-offs and unintended consequences - e.g., using diverse perspectives in functional modelling can take time and reduce the efficiency of this activity (Straub et al., 2023).

Table 5. Improvement opportunities for work system re-design at the ED.

Principles	Opportunities
There must be functional models of the system **(FUN)**	- SOPs should be more user-friendly (e.g., including images) and accessible to employees - Expand possibilities for the customization of models according to the preferences of users - Models should account for the perspectives of all affected parties, and they should be updated more frequently
Make variations in performance visible (VIS)	- Real-time updating of patient charts based on remote monitoring of vital signs could be extended to all ED units - Huddles for non-critical patients could be held in the units rather than in the hallway. It would make it easier to obtain real-time information on patient.
Use the type of standardization that best fits the nature of the function (STD)	- Some procedures performed by leaders could be standardized and documented (e.g., what leaders should do in face of overcrowding) - Revise some nursing protocols to make them more relevant to workers

Design slack resources and strategies **(SLA)**	- Variabilities anticipated in functional models should be used as a basis for designing slack – e.g., number and types of adapted beds according to the level of overcrowding and patient profile - Huddles could also occur on weekends - Staffing levels during night shifts and weekends could be increased
Design for acceptable performance even under degraded conditions **(DEG)**	- Use of visual management devices outside the building to announce the ED occupation in the case of full capacity, and indication of alternative care facilities to obtain care
Design must involve leveraging diverse perspectives **(DIP)**	- Encourage the active participation of more members during huddles – i.e., share information and clarify doubts
Design to support continuous learning at the individual and organizational level **(LEA)**	- Lessons learned from huddles, best practices, and everyday work could be recorded and disseminated to all staff - Results of performance indicators (e.g., safety incidents, patient transfers between ED units) could be widely disseminated and better used for decision-making

5 Discussion

The assessment of principles and practices at the ED made it clear the different abstraction levels of these two elements of DfRP theory. It also empirically demonstrated that principles interact with each other as well as the same occurs with practices. Thus, the framework is consistent with the system thinking values (Wilson, 2014) that underpin the human factors discipline. The knowledge structure of DfRP is complemented by concepts that set a philosophical foundation for the other levels (Figure 4).

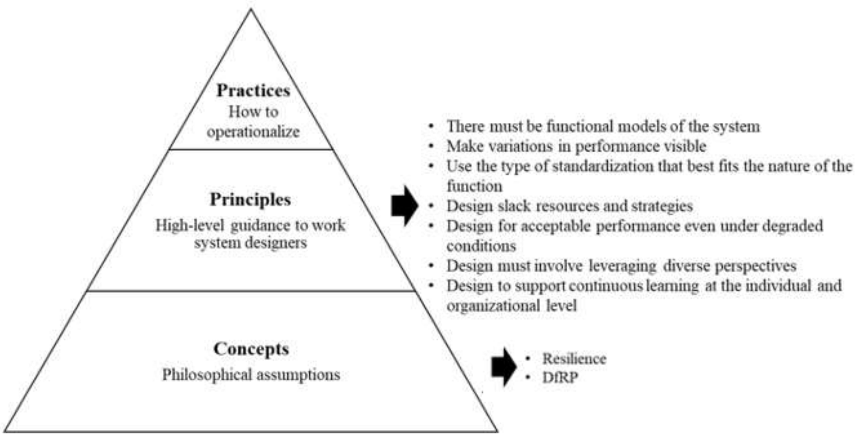

Figure 4. Knowledge structure of DfRP.

The framework is based on a critical realist philosophical position that combines realism and constructivism (Archer et al., 1998). On the one hand, this view posits that there is a reality independent of our thinking, in line with realism. It conveys that resilience is real, can be measured even if indirectly, and supportive conditions to RP can be designed into systems. On the other hand, this view recognizes that all observation is fallible, accepting a constructivist premise (Trochim, 2006). Hence, what counts as effective DfRP is contingent on factors such as the viewpoints of those affected by design, time horizon, and system goals (Aase, 2022). For example, the high number of man-hours spent in huddles may be regarded by managers as more valuable in a teaching public hospital, in comparison to the view of managers in a private business-oriented hospital. This example raises the issue of the costs of DfRP: both the design activities (e.g., huddles) and the designed measures (e.g., extra beds) demand resources that can be costly. Saurin et al. (2023) argue that the most cost-effective manifestations of RP require little or no investment and give rise to mostly desired outcomes whose benefits are long-lasting and reaped by both patients and caregivers. These insights underlie the first proposition that supports the framework application as follows.

Proposition 1: practices of DfRP, in order to be sustainable at the long-term, must be perceived as cost-effective by designers and users of designs.

The study also pointed out that systems have complexity characteristics that cannot be changed by design. For instance, the sudden demand variations typical of EDs make it difficult for their performance to degrade slowly and gracefully, as advocated by Woods (2018). However, these same variations can imply in widely different demands across the ED units, favouring the reciprocity (Woods, 2018) that occurs when ED units serve as slack to each other. Loow (2020) adds that regulations mandate that certain aspects have a specific design. As a drawback, regulatory requirements are often too low and may not suffice to support RP (Marczyk et al., 2023). Creative designers devise solutions that exploit the opportunities and mitigate the disadvantages from the system's nature – e.g., an architect, when faced with sloping terrain, designs a building that nicely fits this condition. The second proposition results from this discussion.

Proposition 2: DfRP is bounded by system complexity (e.g., degree of stability, degree of coupling, diversity of elements, interactions with the external environment), which is a source of both opportunities and constraints.

The resolution level of DfRP also matters. Although the huddles played out at the meso or hospital level, they stemmed from a macro level initiative led by the Ministry of Health. Micro level decisions were related to issues such as the place where the huddles occurred, the participants, and the forms they brought to the meeting. RP depends on decisions made at several levels – e.g., lack of macro level design might hinder the provision of resources to deploy practices at the meso level. Nevertheless, connections across levels are not always designed and resilience at one level can shape resilience at other levels in complex ways (Ellis et al., 2023; Øyri and Wiig, 2022). The third proposition, stated below, arises from this background.

Proposition 3: DfRP tends to benefit from interconnected designs at the macro, meso, and micro levels.

This investigation also revealed aspects of the principles and practices that had not been explored in the prior studies. One of these refers to practices that create opportunities for decision-making based on the local conditions (e.g., huddles at the bedside) and short control cycles (e.g., morning and afternoon huddles), consonant with the dynamics of complex systems (Austin et al., 2022). This differs from the approach for technical infrastructures such as buildings, in which design, after materialized as a product or process, is revised much less frequently. Based on this, the fourth proposition is stated below. Note that this proposition is not exclusive with designing technical infrastructures supportive of RP. For example, it is known that the built environment design (e.g., layout, equipment, signage) is highly relevant to RP in hospitals (Khalil et al., 2022; Ransolin et al., 2020).

Proposition 4: DfRP tends to benefit from short control cycles, playing out as a manifestation of the learning principle.

Moreover, the huddles produced customized designs for each participant as they left the meetings with their own handwritten notes of what to do during the coming hours and days. Thus, there seems to be a type of effective practice with an initial centralized but participatory decision-making instance (e.g., huddles) followed by decentralized and customized planning. This same point applies to reflective meetings similar to the huddles as they are small group gatherings to make sense of complexity – e.g., morbidity and mortality meetings in hospitals

(Verhagen et al., 2020), and toolbox safety meetings in manufacturing and construction industries (Jeschke et al., 2017). The fifth proposition below follows from this discussion.

Proposition 5: DfRP tends to benefit from decentralized and customized designs that meet needs and preferences of designers, playing out as a manifestation of the standardization principle.

The effectiveness of frequent redesigning, decentralization, and customized designs, depends on accurate informational inputs for designers. This narrows the gap between work-as-imagined and work-as-done (Hollnagel, 2017), especially when inputs for designers are from direct sources (e.g., the patient and their vital signs) and gathered in real-time (Perrow, 1999). The huddles relied on this type of input, concurrently producing and using the same information for decision-making. This background sets the stage for the sixth proposition.

Proposition 6: DfRP tends to benefit from information gathered in real-time from direct sources, with a time lag as low as possible between collection of information and decision-making. The uptake of this proposition plays out as a manifestation of the principle on giving visibility to performance variations as these can be accurately identified and quickly dealt with.

Finally, it is worth noting that the framework can be used in combination with existing tools created to analyse and enhance RP. For example, the use of FRAM can produce information for assessing the principles and practices. Conversely, obtaining insights from FRAM models is not a straightforward task (Patriarca et al., 2020), and the framework can direct the analyst to relevant principles and likely improvement opportunities. Similarly, systems that use practices deliberately conceived to influence RP such as the resilient performance enhancement toolkit in healthcare (Wahl et al., 2022), can be analysed in light of the framework. This can shed light on the impact of the practices on the system and offer insight into their validity.

6 Conclusions

This study investigated the question of how to assess the use of the principles and practices of DfRP. This question was addressed by the assessment framework, the six propositions, and the knowledge structure of DfRP. Jointly, they are steps towards the development of DfRP theory, laying down what is DfRP, its main constructs (i.e., concepts, principles, and practices), how the constructs relate to each other (i.e., this is explicit in the knowledge structure and in the relationship model), and how the theory can be operationalized (i.e., through the framework, propositions, and practices). These are prescriptive contributions, complementary to the studies that identify patterns and describe RP. Such descriptive studies are crucial for the continuous revision of the prescriptions as they can illuminate aspects of RP that have been either concealed or poorly understood.

Some limitations of this research need to be mentioned. First, there was only one case study of applying the framework, limiting the understanding of its strengths and weaknesses. However, the logic and stages of the framework are domain-independent. Second, the cost-effectiveness of DfRP was not assessed, although there were pieces of evidence that the huddles were beneficial for RP. Third, this was essentially a cross-sectional study, and thus it was not possible to investigate how the adoption of the principles and practices changed over time. Fourth, there was no analysis of the association between DfRP and outcome measures such as safety and efficiency.

This work also gave rise to several possible future studies such as: (*i*) to apply the framework in systems with complexity characteristics and DfRP practices markedly different from those at the ED; (*ii*) to assess the cost-effectiveness of DfRP; (*iii*) to apply the framework from time to time (e.g., after significant changes in work organization or technologies), in order to capture how variation-patterns change over time; (*iv*) to explore the combined use of the framework with resilience engineering tools such as FRAM, RAG, and others; (*v*) to analyse the association between outcome measures and sources of RP, whether from design or self-organization; and (*vi*) to identify and analyse the influence of factors that moderate the relationship between DfRP and outcomes. Some of these factors are likely to be implicit in the propositions such as characteristics of system complexity and the costs of DfRP.

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APPENDIX. Forms for the assessment of the principles of DfRP.

Evaluator(s):	**Evaluation period:**
Evaluated system:	
Data sources: ( ) Observations ( ) Documents ( ) Interviews ( ) Others:	
Characterization of the socio-technical sub-systems	
Work organisation	**Social**
Technical	**External environment**
Resilience rationale	
For what	**To what**
Of what	**Through what**

Principle	Attributes	Comments	Score
1. There must be functional models of the regulated system	*1,1 There are one or more documented functional models of the system*	There are SOPs for most activities and care protocols. The electronic patient chart is also a functional model of the patient.	1.0
	1.2 The models include visual or physical (e.g., prototypes) representations of the system's functioning instead of being only text-based	SOPs are in text format and care protocols are in flowchart format. Patient charts involve a mix of text and numbers. Exams can be accessed as reports and images.	0.5
	1.3 The models represent the system functioning under both normal and degraded operational conditions	The patient chart is updated as the patient's health condition changes and contains a record of clinical history. SOPs and care protocols neglect degraded conditions at the system level such as overcrowding.	0.75
	1.4 The models acknowledge the main interactions with the external environment	The SOPs and patient charts refer to interactions with other activities and hospital units such as pharmacy and radiology.	1.0

	1.5 The models are easily accessible to all relevant stakeholders during everyday work, so as they can be useful for the daily decisions related to DfRP	All employees have access to SOPs and care protocols through the intranet. The level of access to patient chart varies according to the employee's position and professional category. For example, nurses are not able to request exams.	1.0
		Score principle 1	**0.85**
Principle	**Attributes**	**Comments**	**Score**
2. Make variations in performance visible	*2.1 Variations in performance can be identified in real-time*	Critically-ill patients are monitored through vital signs monitors. Portable monitoring devices are used when necessary and available. Electronic and bedside printed patient charts are updated at least once a shift. A dashboard presents information on the occupancy of all EDs in the city, which is accessed by the responsible for patient triage.	0.75
	2.2 Information on performance variation is easily understandable by the relevant stakeholders	Information displayed on monitors, charts, and dashboards demand domain specific knowledge, which is not a problem given the staff qualification.	1.0
	2.3 The extent of performance variation is displayed, making it clear whether performance is close to the acceptable limits	The monitors of vital signs have aural alarms that go off when the signs exceed thresholds. In the critical patients' unit, monitors displaying patient information are located at nursing stations. Huddles and shift handovers assist in exchanging information. The city-wide ED dashboard is of public domain. Electronic charts include a report on vital signs and fluid balance, displaying the maximum and minimum values observed. ED occupancy is informed through the intranet system. The full capacity plan indicates thresholds of degradation and closure to new patients	0.75
			0.83
Principle	**Attributes**	**Comments**	**Score**
3. Use the type of standardization that best fits the nature of the function	*3.1 There are standards or procedures for tasks carried out by all hierarchical levels, from the sharp end to the blunt end*	SOPs and care protocols apply to those directly involved in patient care and immediate support. Unit leaders and ED management do not have any type of standardized procedure to guide their routine.	0.75

	3.2 The level of detail of the work procedures follows the logics below: *- The more complex the task, the more goal-oriented (i.e., sets goals but not the procedures to achieve them) and process-oriented (i.e., supports decision-making, indicating who makes decisions and based on what criteria) are the corresponding procedures* *- The more linear the task, the more action-oriented (i.e., detailed and step-by-step specification) is the corresponding procedure*	The level of detail in the SOPs and protocols varies according to the type of activity. Some examples: - Handovers and huddles are longer for more complex patients; - More complex patients are monitored through electronic sensors in comparison to the visual monitoring of less critical patients; - The electronic chart provides open fields for data entry, allowing some flexibility and customization	1.0
			0.87

Principle	Attributes	Comments	Score
4. Design slack resources and strategies	*4.1 There are deliberately designed slack resources and strategies*	Stretchers and chairs are used as improvised beds. ED units serve as backups to each other. Morning and afternoon huddles are partly redundant. The same information can be accessed in different parts of the electronic chart.	0.5
	4.2 There are versatile slack resources and strategies which can address a wide range of variabilities	The aforementioned resources and strategies cope with overcrowding, which may have a variety of causes and is hard to predict.	0.5
	4.3 The unintended consequences of the designed slack resources and strategies were anticipated in design and guarded against	The normalization of the aforementioned resources and strategies for coping with overcrowding tend to increase workload and stress among professionals, besides providing sub-optimal care. No measures to cope with these problems were detected.	0.25
	4.4 The amount of the slack resources was determined based on explicit criteria such as risk assessments or cost-benefit analysis	There was neither cost-benefit analysis nor risk assessment for any of the slack resources and strategies	0.0
		Score principle 4	**0.31**

Principle	Attributes	Comments	Score
5. Design for acceptable performance even under degraded conditions	*5.1 There are mechanisms to support workers when trading-off and prioritizing goals when the system is operating under degraded conditions (e.g., risk warnings)*	The triage changes according to ED occupancy. For example, if the full capacity plan is activated, self-referred patients are not accepted. Decisions made in huddles involve the destination of patients, prioritizing discharges.	1.0
	5.2 Vital functions remain operational even though support functions are compromised	The ED frequently operates under the most critical levels of the full capacity plan, continuing to care for patients	1.0

	5.3 Process stages are, in general, loosely rather than tightly-coupled (e.g., fairly independent processes, slack in-between processes)	ED processes are highly interdependent; this is intrinsic to the system. For example, the success of treatment depends on information from different areas, such as triage, nursing, and exams. Small mistakes such as a misspelling of the patient's name, can be harmful. There was the case of a patient called Ana Maria registered only as Maria by the reception. This patient received morphine as it was the medication prescribed for another patient named Maria.	0.0
	5.4 Performance degradation occurs slowly rather than abruptly	Performance can degrade rapidly, which is intrinsic to the system.	0.0
		Score principle 5	**0.5**
Principle	**Attributes**	**Comments**	**Score**
6. Design must involve leveraging diverse perspectives	*6.1 There are decision-making and management structures that allow for the consideration of diverse perspectives during everyday work*	A strength of the huddles is their multidisciplinary character.	1.0
	6.2 There are mechanisms to counter-balance the power differences that tend to arise from the formal hierarchy	The huddles involve people from different professional categories and hierarchical levels. However, few people participate actively.	0.5
		Score principle 6	**0.75**
Principle	**Attributes**	**Comments**	**Score**
7. Design to support continuous learning at the individual and organisational level	*7.1 There are proactive (leading) indicators for learning*	Care is based on proactive data from exams and past records. Records of ED occupation are proactive in the sense of being theoretically linked to outcome measures of safety and quality.	0.5
	7.2 There are reactive (lagging) indicators for learning	There are lagging indicators derived from the risk management program such as accident rates. Part of this information is analyzed by staff from the risk management department.	0.5
	7.3 There are learning opportunities, based on data, feedback and structured management routines, for employees from all hierarchical levels	Huddles are themselves a moment for learning and correction of errors.	1.0

	7.4 There is a system to store and categorize lessons learned	The hospital has a risk management department that investigates all accidents that harm patients – less serious events are often underreported and not investigated. Lessons from these investigations are stored and analyzed from multiple perspectives.	0.5
		Score principle 7	**0.45**
		Overall score	**0.65**

6 CONCLUSÕES

6.1 Objetivos e contribuições da tese

Esta tese teve por objetivo principal desenvolver um método para avaliar o uso dos princípios e práticas de *DfRP* nos sistemas sócio-técnicos. Como objetivos específicos, dois foram propostos: a) propor um conceito e os princípios de *DfRP*; e b) avaliar o uso dos princípios de *DfRP* por práticas de reuniões reflexivas e equipes em espera.

O capítulo 2 da tese respondeu ao objetivo específico *(i)*, através da combinação de distintos métodos de pesquisa. Primeiramente foi realizada uma revisão da literatura de diversas disciplinas de fatores humanos para a criação de uma lista de princípios de projeto. Posteriormente, para definir o conceito e os princípios de *DfRP*, o método Delphi foi conduzido em três rodadas com especialistas de diversos países. Por fim, a aplicação dos princípios foi observada na prática através de um estudo de caso considerando o TRR de um hospital público. O principal resultado deste capítulo é a proposta do conceito de *DfRP* e a lista dos sete princípios, com suas respectivas descrições.

O capítulo 3 e o capítulo 4 respondem ao objetivo específico *(ii)*, através da investigação de práticas organizacionais que contribuem para o *DfRP* no trabalho diário. No capítulo 3 foi investigada a prática das *toolbox talks* na construção civil, enquanto no capítulo 4, foram estudados os *huddles* praticados pela equipe de emergência de um hospital, e a cadeia de ajuda de uma fábrica. Os resultados dos estudos demonstraram que essas práticas são exemplos de famílias de rotinas organizacionais que operacionalizam o *DfRP* no trabalho cotidiano de hospitais, fábricas e construção civil. A análise dos princípios mostrou-se útil para compreender as razões dessas rotinas serem consideradas boas práticas por estudos anteriores e pelas organizações estudadas. Além disso, os estudos de caso também demonstraram pontos fortes e fracos dessas práticas, bem como permitiram discutir, no capítulo 4, alguns aspectos de seus custos e benefícios.

O capítulo 5 respondeu ao objetivo geral da tese apresentando o método de avaliação dos princípios e práticas de *DfRP*. O método foi testado no serviço de emergência de um hospital, onde os *huddles* conduzidos pelas equipes foram a prática central de *DfRP* analisada. A principal contribuição deste capítulo é o próprio método, que permite a avaliação dos princípios através de 24 atributos, a análise de suas relações (um modelo foi elaborado com base em uma pesquisa com especialistas) e a investigação de práticas que operacionalizam os princípios. Um sistema de pontuação foi desenvolvido para demonstrar a eficácia do uso dos princípios. A tese como um todo contribuiu para o desenvolvimento da teoria de *DfRP*, além de oferecer uma nova abordagem para a avaliação da resiliência.

6.2 Limitações

Com relação ao capítulo 2, as principais limitações são: *(i)* a revisão da literatura realizada para a construção da lista inicial de princípios de projeto não incluiu a literatura geral de resiliência que aborda sistemas diferentes de sócio-técnicos; e *(ii)* apesar do painel de especialistas ter sido cuidadosamente selecionado, uma outra formação poderia ter gerado resultados distintos. Nos capítulos 3 e 4, tem-se como limitações: *(i)* não houve análise da correlação entre o uso das práticas e o desempenho operacional dos sistemas estudados, apesar de alguns dados fornecidos pelas próprias organizações sugerirem que há benefícios tangíveis e intangíveis; *(ii)* não foi possível analisar a fundo o custo benefício das práticas *toolbox talks* e cadeia de ajuda pois os dados necessários não foram disponibilizados pelas organizações; *(iii)* os estudos de casos foram realizados de modo transversal, portanto não se observou como as melhorias propostas foram implementadas. Por fim, a principal limitação do capítulo 4 é a de que o método proposto foi aplicado em apenas um estudo de caso, apesar de suas etapas serem aplicáveis em outros contextos.

6.3 Estudos futuros

Esta tese traz várias oportunidades de pesquisas futuras, tais como: *(i)* avaliar a eficácia dos princípios de *DfRP* em diferentes contextos e sistemas; *(ii)* revisar e propor novos princípios ou modificar os existentes com base em estudos de caso adicionais; *(iii)* testar o conceito e princípios no projeto real de sistemas socio-técnicos, em vez de apenas como uma ferramenta para avaliações retrospectivas; *(iv)* identificar fatores contextuais que afetam o custo-benefício de práticas de *DfRP*; *(v)* desenvolver um método para avaliar o custo-benefício de *DfRP*; *(vi)* aplicar o método em sistemas com características de complexidade e práticas de *DfRP* distintas daquelas do serviço de emergência.