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Robots and emotional intelligence: A thematic analysis

Faruk Seyitoğlu [a,b,d], Stanislav Ivanov [c,d,1,*]

[a] Department of Economics, Management, Industrial Engineering and Tourism, Research Unit of Governance, Competitiveness and Public Policies (GOVCOPP), University of Aveiro, 3810-193, Aveiro, Portugal
[b] Faculty of Tourism, Tourism Management, Mardin Artuklu University, Turkey
[c] Varna University of Management, 13A Oborishte str., 9000, Varna, Bulgaria
[d] Zangador Research Institute, 9010, Varna, Bulgaria

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ABSTRACT

The research on emotional intelligence in social robots is growing. This paper provides a thematic analysis of the studies on robots and emotional intelligence, synthesising and evaluating current knowledge and research topics. In addition, based on the thematic analysis of the studies, it also provides a conceptual framework explaining the emotional intelligence of robots that includes both actors (human and robot) in a human-robot interaction setting. The findings are based on the analysis of 252 studies published until the end of 2022 and indexed in the Scopus database. The results unveiled two main themes (robot design-technical developments and characteristics and human-robot interaction), including sub-themes and topics that emerged in the literature. Finally, the themes and sub-themes were evaluated through a critical discussion to develop a conceptual framework for robots and emotional intelligence.

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1. Introduction

1.1. Rationale

A robot is a "programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning" [1]. While robots are widely used in manufacturing [2,3] for producing goods, they find their way into agriculture [4] and the delivery of services [5–7] as well. Social robots help children with autism [8], assist the elderly [9], and redefine the meaning we put in sexual relationships [10].

One of the main directions of robotics research is on human-robot interaction (HRI) [11]. The topic has been researched in the context of industrial robots [12], service robots [13], and social robots [14]. A key component of HRI in the context of social robots are the emotions of humans and the emotional intelligence of both parties in the relationship [11,15] because emotions trigger specific affective, cognitive, and behavioural responses [16]. For example, when humans experience positive emotions in their interactions with robots, they are more likely to use robots and less likely to object to them [17]. Additionally, humans' perceptions of the emotional skills of robots are positively related to the perceived appropriateness of robot use in service contexts, e.g. museums in galleries, as found by Webster and Ivanov [18].

To elicit respective emotional reactions in humans, robots need to have some degree of emotional intelligence. Emotional intelligence (EI) is defined as "the capacity to reason about emotions, and of emotions to enhance thinking. It includes the abilities to accurately perceive emotions, to access and generate emotions so as to assist thought, to understand emotions and emotional knowledge, and to reflectively regulate emotions so as to promote emotional and intellectual growth" ([19]:197). EI has four aspects measured through the Mayer–Salovey–Caruso Emotional Intelligence Test (MSCEIT) ([19]:200, [20], [21]:281–282).

- ✓ *Perceiving emotions* – the ability to detect and decipher emotions in faces, pictures, voices, and cultural artefacts;
- ✓ *Using emotions* – the ability to use emotions to facilitate cognitive activities, such as thinking and problem-solving;

* Corresponding author. Varna University of Management, 13A Oborishte str., 9000, Varna, Bulgaria
E-mail addresses: seyitoglu.f@gmail.com (F. Seyitoğlu), info@zangador.institute, stanislav.ivanov@vumk.eu (S. Ivanov).
[1] http://stanislavivanov.com.

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- ✓ *Understanding emotions* – the ability to comprehend emotion language and to understand relationships among emotions;
- ✓ *Managing emotions* – the ability to regulate emotions in oneself and others.

From a robotic perspective, all four aspects (or 'branches' in Mayer, Salovey & Caruso's terminology) apply to robots. To be effective in their interactions with humans, social robots need to identify the emotions of people (*perceiving emotions*), to utilise this knowledge to generate relevant emotional responses in their interactions with humans (*using emotions*), to understand the reasons for humans' emotions (*understanding emotions*), to use the appropriate expressions to convey the intended emotions (*managing emotions* in themselves), to identify the consequences of their actions and their impacts on the emotions of people (*managing emotions* in others). Obviously, being inanimate entities, robots do not experience emotions, and they cannot manage what emotions they feel; however, they need to use appropriate cues (e.g. facial expression, voice tone) to convey the emotions. An emotionally intelligent robot would interact more effectively with humans because it would be more capable of perceiving, understanding, managing and using emotions in its interactions with humans.

1.2. Research aim

In light of the above discussion, this study focuses on the emotional intelligence of robots. It aims to (*i*) assess the studies related to robots and emotional intelligence in the literature to synthesise and evaluate the current knowledge and research topics, and (*ii*) formulate a conceptual framework for the emotional intelligence of robots.

This study contributes to the literature by providing a detailed evaluation of robots and EI research through thematic analysis (TA) of respective publications. It is the first research to synthesise and evaluate current knowledge and research topics on robots and EI literature. It also provides a conceptual framework explaining the emotional intelligence of robots that includes both actors (human and robot) in a human-robot interaction setting.

The rest of the paper is organised as follows. The next section presents the methodology of the research. Then, section 3 presents the results, while section 4 provides the implications, develops the conceptual framework, formulates directions for future research directions, and concludes the paper.

2. Methodology

TA was employed to examine the existing literature on the subject, discuss emerging themes and sub-themes, and formulate a conceptual framework because achieving the research aims required a detailed evaluation of the studies on the subject, and TA is an appropriate method to unveil content-rich qualitative findings [22,23]. As a qualitative approach, TA is beneficial in analysing, defining, and organising the available data by determining the themes and helping interpret different dimensions of the research topic [23]. Moreover, the data for TA can be extracted from the existing literature or qualitative interviews related to a phenomenon [24]. We followed the six stages of TA that Braun and Clarke (2006:87) suggest: "(*i*) familiarising with the data, (*ii*) generating initial codes, (*iii*) searching for themes, (*iv*) reviewing themes, (*v*) defining and naming themes, and (*vi*) producing the report."

2.1. Data collection process

The data collection process of this study started with identifying the relevant studies regarding the research topic. Scopus database was used as a data collection platform. In line with the aims of focusing on the relationship between EI and robots and reaching various perspectives on the topic, the authors did not limit the search to a specific research area. Likewise, the period of publication was not restricted. However, some criteria, such as being relevant to emotional intelligence and robots simultaneously, full-text availability, and being written in the English language, were determined. Therefore, the authors searched for studies until the end of 2022 without a time limit to the back years through the search terms "robot", "emotional intelligence", "emotional skill", "emotional robot", "empathic robot", "affective robot", and "sentimental robot" in the title, abstract, and keywords of the publications. Furthermore, conceptual and empirical studies of different types (i.e. articles, conference papers, and book chapters) were included for comprehensiveness and to maintain a holistic perspective.

In the initial phase, with the identified keywords search, 516 publications were obtained. After excluding publications in languages other than English, there were 496 publications left. In the next stage, the items were checked, and 244 of them were excluded for several reasons (i.e., 124 publications were not relevant, 28 publications were only the content of conferences, special issue introductions and workshops contents, 2 publications were editorials on the research topic, 2 publications were repetitive studies, and the full text of 88 publications was not accessible). Finally, 252 studies were left to implement TA to reveal the themes, sub-themes and topics of robots and emotional intelligence studies in the literature.

3. Results

3.1. Profile of robots and EI research

The TA shows that of the 252 studies, the majority are conference papers (148), followed by journal articles (102) and book chapters (2). The publication years vary between 1996 and 2022. Regarding the methodology, 192 items are empirical studies, and 60 are conceptual papers. From the empirical studies, experimental design research is applied in 151 publications. The rest of the studies adopted mixed method (10), systematic review (8), quantitative (8), simulation (7), and qualitative (6) approaches.

The results illustrate that the time span of the studies is 27 years (1996–2022). However, the flow of research on robotics and EI has dramatically increased since 2013. While there were only 7 publications in the period 1996–2004, the research output reached 70 publications in 2005–2013 and peaked at 175 publications in 2014–2022. This data reveals that the robots and EI literature is growing sharply. Additionally, the findings indicate that the research on robots and EI in the context of education started to grow after 2013, as there were only two studies between 1996 and 2013 but already 25 studies between 2014 and 2022. Moreover, between 1996 and 2012, there were only two publications related to the perceptions toward robots in the context of robots and EI but 18 studies were published between 2013 and 2022. Therefore, the academic interest in the topic is expanding in quantitative terms, probably due to the increased capabilities and anthropomorphism of social robots in the last decade, which made research on their emotional intelligence a much-needed and feasible research direction.

3.2. Thematic analysis of robots and EI research

The coding and theme definitions were implemented after the first stage of TA, as suggested by Braun and Clarke [23]. The coding was done manually by the authors independently following the inductive approach. As provided in Table 1, the codes were grouped into two main themes, namely (*i*) robot design-technical developments and characteristics, and (*ii*) human-robot interaction. The robot design: technical developments and characteristics include *sensory aspects* (facial expression and voice-related), *cognitive aspects and behavioural aspects*, *visual aspects*, and *other aspects*. The "human-robot interaction" category comprises two main sub-themes such as 'settings (health, education and other settings)' and 'attitudes (perceptions toward robots)'. The following sub-sections presented the themes and sub-themes in detail.

Table 1
Robots and EI (Emotional Intelligence) studies in the literature.

Themes	Sub-Themes and Topics	
ROBOT DESIGN-TECHNICAL DEVELOPMENTS AND CHARACTERISTICS	**Sensory Aspects**	***Facial Expression*** *-Hybrid-face robotic expressions and emotions* *-Facial action unit (AU) detection for emotional communication in human-robot interaction* *-Robot's awareness of human facial expressions* *-A personal wearable device with facial expressions* *-Robot facial expression and social capability* *-Facial expression recognition* *-The SMILE app for the MU-L8 humanoid robot* *-Affective facial expressions for robots* - *Facial expressions of a mechanical robot head* - *Emotional attributes (Joy, Normal or Sad) to a robot's gesture* - *A face detection method for the development of an emotional bio-robot* - *Interactional gestures with the humanoid robot* *-3D emotion expression method based on the vector for the emotional robot* *-Emotion recognition using facial expression images* *-An emotion expression system for the emotional robot* ***Voice-related*** *-Voice quality features for robots to differentiate a joke or aggressive speech* - *Storytelling potential of robots* - *Emotional storytelling robot* - *Robots' emotions with a dramatic story* - *The speech understanding system* - *The audio-based expression modality of robots* - *An affective interactive audio interface for Lovotics* - *A speech-driven information system for a humanoid robot* - *A musical language for emotional interaction between Robots (MLEIR)*
	Cognitive and Behavioural Aspects	- *The human-robot interaction (HRI) community addressing the use of vocal prosody in robot speech* - *Cognitive systems for social robotics* - *Cognition-emotion interactive model* - *Cognitive emotional regulation model in human-robot interaction* - *Artificial consciousness model and robot emotions* - *A six-layered architecture for behaviour control, Consciousness-based Architecture (CBA)* - *Emotional robots from the perspectives of psychology and neuroscience research* - *Distributed task allocation method based on self-awareness of autonomous robots* - *Affective cognitive robots for human-robot Interaction* - *Affect awareness of social robots* - *Affect recognition in human-robot interactions* - *Autonomous cognition and correction system of robot service* - *Emotion detection and recognition approach* - *Challenges of emotion recognition for human-robot interaction systems* - *Emotions in robot psychology* - *Associative memory models of emotional robots* - *Episodic memory system for an affective robot* - *Algorithm of the emotional robot: automatically infer emotional clues from non-stylized motions* - *Emotional robots' behaviours and decision-making process* - *Affective robot behaviour for enhancing user experience* - *Intelligent behaviour/emotion, and communication between human-robots*

(*continued on next page*)

Table 1 (*continued*)

Themes	Sub-Themes and Topics		
			- *Spontaneous behaviour for cooperation among distributed autonomous robots* - *An emotional behaviour generator for emotional robots* - *Robot's ability to express emotion through physical behaviour*
		Visual Aspects	- *A telepresent robot* - *DOF zoomorphic social robot called the CuddleBit* - *Humanoid head robot* - *A wearable affective robot design* - *The design of the humanoid robot head* - *Empathic anthropomorphic robot (torso)* - *Virtual neurorobotics*
		Other Aspects	- *Designing cost-effective affective robots* - *A cloud-based architecture and user-robot interaction of social robots* - *Emotion core for autonomous robots* - *Coordinating human-robot reactions and the perceived affective impact on robots* - *A robotic control architecture based on emotions* - *Presenting a system which forms and expresses the feelings of a robot* - *Computation mechanism for robot emotions* - *Theatre Arts methodologies for social robot* - *A novel tactile sensor for robots* - *Affective movement features of robots* - *Algorithm of emotional robot task allocation based on emotional constraint* - *Nonverbal emotional interaction for the EmotiRob project*
HUMAN-ROBOT INTERACTION	**SETTINGS**	**Health**	**TASKS** **Treatment of Children with ASD (autism spectrum disorders)** - *Wearable affective robot design for children with autism* - *Robot for children with autism spectrum disorders to learn emotional skills* - *Social robot Probo: helping children with autism spectrum disorders to enhance their performance in identifying situation-based emotions* - *Head design of a humanoid robot with facial expressions: advantages in the diagnosis and treatment of autistic children* - *Affective robot-assisted activity (ARAA) for fostering social interaction and communication skills among children with ASD* **Assistance & Companionship** ***Elderly-related*** - *Socially assistive robot: to provide companionship for older adults with depression and dementia through conversation* - *Social elderly assistant robot-EmIR* - *Social elderly assistant robot-RAMCIP* - *Companion robot experience design for elderly* - *Assistive robots for elderly-Matilda: a human-like affective communication (service and companion) robot in nursing homes in Australia* - *Assistive robot for elderly: emotional responses in a simulated medicine delivery task* - *Affective robot for elderly assistance* - *Robot-aided care for handicapped and elderly people* ***Children*-related** - *Robin-a social robot for diabetic children: companion* - *Multiple socially assistive robots: for interactive role-playing activities with children* - *Emotional playing robot: conversations with children* - *Empathic social robots to interact with children: playing*

(*continued on next page*)

Table 1 (*continued*)

Themes	Sub-Themes and Topics	
		chess-Social presence, engagement and perceived support in children - *Robot NAO-socially assistive emotional robot: low back pain of children* - *Nao robot-adaptive emotion expression on the interaction behaviour and opinions of children* - *Emotional robot companion for helping vulnerable children* - *Affective robot companion for children: audiology rehabilitation*
		Other Health Services - *RoBlood: taking blood from patients* - *Patient service robot* - *Affective robots towards autonomous healthcare assistant*
	Education	- *Robot behaviours in children's education* - *Design of robotic learning environments* - *A framework of educational robotics with emotional intelligence* - *Continual learning with robots* - *The emotional behaviour of a companion robot-primary school students* - *Robots-based learning* - *Empathic robot for group learning* - *Educational robotics in social-emotional learning* - *Medical education: robot-simulated patients* - *Socially interactive robots in Language teaching* - *Tutor robot: online education-affective educational interventions* - *An empathic robot tutor for 11-13-year-old school students in an educational setting* - *An empathic robot tutor (EMOTE)* - *An expressive robot to elicit an affective response in young children-play and developmental ability in young children by employing a novel interaction design with a non-humanoid robot* - *Empathic robotic tutors for personalised learning* - *An empathic robotic tutor in a map application* - *EMOTE-an empathic robot tutor-teaching* - *Empathic robotic tutor that plays a multi-person serious game with students-educational* - *Effects of emotional cognition on learning* - *A teaching assistant robot* - *Introducing a crash course on emotional robotics*
		Other Settings and Tasks - *Search and Rescue (SAR) robots* - *Robocup Rescue Simulation (RRS)* - *Robots for Use in Victim Management* - *Robot artists (drawing robots)* - *Robotic game buddy* - *Intelligent soccer robot* - *The emotionally responsive robotic dog* - *Social robot called AIDA (Affective Intelligent Driving Agent)*
	ATTITUDES	**Perceptions toward Robots** - *Human-robot interaction: gender effects on people's perception of robots* - *People's moral expectations toward robots* - *The hostility of people toward a poorly performing robot* - *Emotional intelligence, trust, and gender in human-robot interaction* - *Group influence and prosocial behaviour in a human-robot interaction* - *Human-robot interaction: social emotions from cultural and social anthropology perspectives* - *Perceptions towards the use of robots in hotels* - *Current AI and robotics service solutions in the European restaurant market* - *Service robots (barman robot): an empathic behavioural*

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Table 1 (*continued*)

Themes	Sub-Themes and Topics
	- *Home service robots-the need of consumers* - *Consumer service and experience* - *Ambient-aware human-centric indoor service robot with attributes of emotional intelligence* - *Teachers' perceptions of empathic robotic tutors* - *Human-robot collaboration: psychological theories and mind perception* - *Perceptions towards emotionally expressive social robots* - *Discussion about whether emotional robots are deceptive*

3.2.1. Robot design-technical developments and characteristics

The first central theme refers to the technical developments and characteristics of robots associated with emotional intelligence. This central theme includes sensory aspects (facial expression and voice-related), cognitive and behavioural aspects, visual aspects, and other aspects as sub-dimensions.

3.2.1.1. Sensory aspects. Emotional intelligence is the ability of individuals to identify their own emotions and the emotions of others and, accordingly, shape favourable relationships with others [25]. EI contains the capability of perceiving and understanding emotions [19]. In this regard, the EI of robots requires sensory aspects such as facial expressions and voice-related features for successful human-robot collaboration and interaction [26]. Similar to person-to-person communication, facial expressions are crucial for recognising emotional expressions in human-robot interactions because different emotions are correlated with specific facial expressions [27]. Thus, a significant part of the robot design literature on robots and EI focused on facial expressions from different angles such as hybrid-face robotic expressions and emotions, robot's awareness of human facial expressions, interactional gestures with the humanoid robot, and emotional attributes (Joy, Normal or Sad) to a robot's gesture.

According to the results of the TA, one of the earliest studies on robots and EI regarding the facial expression features of robots [28] focuses on an emotional expression system for a robot. This study proposes a method for processing information that is collected through various sensors in an intelligent robot, which can determine emotions and express corresponding actions, i.e. the robot can express a specific emotion in a form which is recognisable by a human [28]. More recently, the literature focused on a hybrid-face robotic system capable of evoking affective responses in users [26].

Furthermore, the voice-related sensory aspects of the robot design regarding the robot and EI are also a growing research direction. This literature is shaped around topics such as voice quality to differentiate a joke or aggressive speech, storytelling potential, speech understanding system, the audio-based expression modality, affective interactive audio interface, speech-driven information system, and musical language for emotional interaction related to robots. While an earlier study [29] investigates the structured sound-based language for emotional robotic communicative interaction, recent work [30] focuses on robots' capability to distinguish between aggressive and joking attitudes.

3.2.1.2. Cognitive and behavioural aspects. Being aware of the surroundings, understanding the context and intentions, and adapting the behaviours are required for social robots [26]. These features are related to cognitive and behavioural aspects of robot design in the literature. First, the cognitive part of the studies focused on cognitive systems for social robotics, artificial consciousness models and robot emotions, consciousness-based architecture, affect recognition in human-robot interactions, etc. An earlier study [31] delved into the subject of robots sensing human emotion. In the literature, the desire to activate the robots' side of human-robot interaction helped to develop different cognitive aspects to advance the robotic emotion recognition system [32]. A more recent study [33] illustrates the autonomous cognition and correction system of robot services based on emotional information and case-based reasoning. One of the latest studies on the cognitive aspects of robot design [34] proposes a self-awareness-based algorithm for a distributed affective robot pursuit task allocation that combines cognitive with emotional intelligence.

Linked to the cognitive aspects, several studies on behavioural aspects also exist in the robots and EI literature related to the technical developments and characteristics of robot design. They mainly investigated emotional robots' behaviours and the decision-making process, spontaneous behaviour for cooperation among distributed autonomous robots, and robots' ability to express emotion through physical behaviour (e.g. arm or head movements). Among this group of studies, for instance, Lee et al. [35] propose a general emotional behaviour generation module, which generates behaviour combinations expressing complex emotions. A more recent study by Rossi et al. [36] examined how emotional robot behaviours can be made more legible in order to make their decision-making process more transparent to people.

3.2.1.3. Visual aspects. Regarding the technical developments and characteristics of robot design, visual aspects are essential as they influence peoples' acceptance of and perceptions towards robots [37]. In this vein, for example, a robot's human likeness positively affects an individual's robot acceptance [38]. Moreover, a robotic chef does not have to be humanoid or zoomorphic because a machine-looking robot or a robotic hand may implement the task correctly [37]. The TA demonstrates that the visual aspects of robot design in the robots and EI literature include several topics: telepresent robot, zoomorphic social robot, humanoid head robot, wearable affective robot design, empathic anthropomorphic robot, and virtual neurorobotics. One of the earlier attempts on the subject in the literature [39] presented an empathic anthropomorphic robot that mirrored the emotions of happiness, fear, and neutrality. Furthermore, the latest study regarding visual design aspects of robots and EI investigated human interactions with telepresent robots [40].

3.2.1.4. Other aspects. The topics that emerged under this umbrella related to designing cost-effective affective robots, emotion core for autonomous robots, robotic control architecture based on emotions, affective movement features of robots, nonverbal emotional interaction for robots, computation mechanism for robot emotions, etc. Among these studies, Kuremoto et al. [41] present a system forming and expressing the feelings of a robot, while Suguitan et al. [42] developed a method for modifying emotive robot movements.

3.2.2. Human-robot interaction

The second central theme, human-robot interaction, incorporates settings and attitudes as sub-themes. 'Settings' consists of health, education and other settings and tasks, while 'attitudes' comprise perceptions towards robots.

3.2.2.1. Settings. The TA shows tasks in different human-robot interaction settings such as health, education, and other settings. Within these settings, research focuses on implementing various tasks by robots.

3.2.2.2. Health. Health is the most significant sub-theme of the settings-related studies of robots and EI literature, as it contains a wide variety of studies, including the topics on tasks such as *treatment of children with ASD (autism spectrum disorders)*, *assistance and companionship (elderly and children-related)*, and *other health services*.

A part of the health settings literature is about the treatment of children with autism spectrum disorders with topics such as wearable affective robot design for children with autism, robots for children with autism spectrum disorders to learn emotional skills, head design of a humanoid robot with facial expressions for the diagnosis and treatment of autistic children, and affective robot-assisted activity for fostering social interaction and communication skills among children with ASD. Treating children with ASD with the help of advanced technology, such as high levels of artificial intelligence (AI) integration, communication technology, computer-aided technology, and robot technology, has recently become an effective and popular method [43]. Thus, this topic is one of the main concerns of robots and EI literature. In this respect, one of the initial initiatives linked to the use of robots in the treatment of children with autism spectrum disorders [44] investigated whether social robots can help children with ASD to increase their performance in identifying situation-based emotions. Accordingly, children's performance improved with moderate to large effect sizes in identifying sadness and happiness [44]. Furthermore, Wu et al. (2019) [45] concentrate on the head design of a humanoid (emotionally interactive) robot with facial expressions to treat ASD.

The health tasks related to robots and EI literature also focused on assistance and companionship for the elderly and children. This study area of robots and EI comprises elderly-related and children-related topics. Socially assistive robots to provide companionship for the elderly with depression and dementia through conversation, assistive robots for elderly-Matilda (a human-like affective communication robot in nursing homes in Australia), and robot-aided care for handicapped and elderly people are among the topics of elderly-related assistance and companionship health tasks of robots and EI literature. The TA illustrates that as one of the earliest studies in the literature related to elderly-related assistance and companionship, Roesener et al. [46] investigated robot-aided care for handicapped and elderly people, which presented a comprehensive behaviour model for robots based on emotional evaluation mechanisms. However, a recent study [47] introduces an integration of artificial emotional intelligence in a socially assistive robot designed to provide companionship for older adults with depression and dementia.

Additionally, the topics of children-related assistance and companionship under the health setting tasks of robots and EI literature emerged as a social robot for diabetic children, multiple socially assistive robots for interactive role-playing activities with children, an emotional playing robot, a socially assistive emotional robot for children having low back pain, an emotional robot companion for helping vulnerable children, an affective robot companion for children having audiology rehabilitation, etc. For example, Saint-Aimé et al. [48] aimed to provide comfort to vulnerable children and/or children undergoing long-term hospitalisation with the help of an emotional robot companion. Furthermore, Uluer et al. [49] develop an affective robot companion for the audiologic rehabilitation of children.

Finally, "other health services" include a few studies related to patient services [50], healthcare assistance [51], and blood-taking services [52].

3.2.2.3. Education. TA shows *education* as the second sub-theme of the setting-related human-robot interaction studies. The design of robotic learning environments, empathic robots for group learning, educational robotics in social-emotional learning, socially interactive robots in language teaching, an empathic robot tutor for 11-13-year-old school students in an educational setting, an empathic robotic tutor that plays a multi-person serious game with students, a teaching assistant robot, empathic robotic tutors for personalised learning, and an empathic robotic tutor in a map application are among the topics under the education subthemes.

One of the earliest studies in the dataset was published as a book chapter [53], which investigated the development of an emotional robot as a teaching assistant. More specifically, this study presented an affective robot as a teaching assistant to facilitate instruction in the classroom in early childhood education [53]. Janarthanam et al. [54] concentrated on building an empathic robotic tutor playing a multi-person serious game with students to help them learn and understand educational concepts.

More recent literature on the subject discusses an approach to using a social robot as a teacher in learning environments [55], proposes a framework for educational robotics that incorporates emotional intelligence in the learning process [56], and suggests a computational model teaching programming and emotional intelligence to students [57]. In more detail, Stipancic et al. [55] suggest robot functionalities that provide situational embodiment, self-explainability, and context-driven interaction. Besides, Khairy et al. (2021) [56] investigate the integration of emotional intelligence robotics in e-learning in order to determine its role in interaction motivation during education. Finally, Rafique et al. (2020) [57] aim to allow students to be emotionally intelligent and cognitively healthy through a computational robotic model that teaches emotional intelligence and programming to students.

3.2.2.4. Other settings and tasks. Several topics emerged under the 'other settings and tasks' sub-theme: Search and Rescue (SAR) robots, RoboCup Rescue Simulation (RRS), robots for use in victim management, robot artists (drawing robots), an intelligent soccer robot, the emotionally responsive robotic dog, robotic game buddy, and affective intelligent driving agent.

In these works, the study of Aghaei et al. [58] introduces a new structure for decision-making in emergencies. The proposed model unites an agent's personality characteristics and emotional behaviours, and the external events that can affect it. Furthermore, Leite et al. [59], using iCat robot and chess as game scenario, developed a robotic game buddy whose emotional behaviour is affected by the state of the game. Jones & Deeming [60]'s research is on developing and evaluating an emotionally responsive robotic dog that can identify emotions in its user via acoustic emotion recognition and respond with a series of actions. Finally, Akgün et al. (2022) [61] examined the feasibility of conveying information about search and rescue situations through robots' emotions.

"Other settings and tasks" in this sub-theme demonstrate that human-robot interaction related to robots and EI literature is developing topics different from health and education. Instead, this literature advances on various settings in areas such as arts, sports (soccer), victim management, gaming, automotive (driving), and emergency rescue.

3.2.2.5. Attitudes. Attitudes, which include the single sub-theme of perceptions toward robots, was revealed as the second dimension of human-robot interaction studies.

3.2.2.5.1. Perceptions toward robots. Perception toward robots consists of topics such as people's moral expectations toward robots, perceptions towards emotionally expressive social robots, perceptions towards the use of robots in hotels, perceptions towards an empathic service robot (barman robot), gender effects on people's perception of robots, teachers' perceptions of empathic robotic tutors, group influence and prosocial behaviour in human-robot interaction, and the hostility of people toward a poorly performing robot.

According to the TA, while one of the early studies related to the perceptions toward emotional robots [62] discusses whether emotional robots are deceptive, another study [63] strives to understand the leading roles that robotic tutors can play and explore teachers' main concerns about this type of technology. Thus, this study investigated

teachers' perceptions of integrating robotic tutors into daily school practice [63].

Additionally, the study by Connolly [64] focused on group influence and prosocial behaviour in human-robot interaction. Accordingly, the study measured whether the emotional responses of a group of robots could induce participants to take prosocial action against robot abuse [64]. Chuah and Yu [15] utilised Instagram data to unveil the impact of emotional robots on potential customers' emotions by employing sentiment analysis and machine learning algorithms. Their results show that expressions of happiness and surprise are crucial in creating positive impacts on potential consumers [15].

From the attitudes studies of human-robot interaction studies, it can be inferred that attitudes towards emotional robotics is a significant subject that has been attracting scholars' attention. As the perceptions toward robots indicate the degree of acceptance and readiness to interact with or use emotional robots, this study area can be critical to obtain knowledge about the consumer side in the human-robot interaction.

4. Conclusion

This paper provided a thematic analysis of the studies on robots and emotional intelligence. The results uncovered two main: (*i*) robot design-technical developments and characteristics, and (*ii*) human-robot interaction. The robot design-technical developments and characteristics include *sensory aspects* (facial expression and voice-related), *cognitive aspects and behavioural aspects*, *visual aspects*, and *other aspects*. The "human-robot interaction" category comprises two main sub-themes, namely *settings* (health, education, and other settings) and *attitudes* (perceptions toward robots).

4.1. Implications

From a theoretical perspective, the thematic analysis of publications on robots and emotional intelligence allowed the development of a conceptual framework for the topic with the following main components.

- ✓ technical characteristics of the robots;
- ✓ humans with their characteristics (e.g. children, elderly) and roles (e.g. patients, customers);
- ✓ human-robot interaction that takes place in various settings (healthcare, education, other) where robots implement diverse tasks;
- ✓ humans' perceptions towards the robots and their emotional intelligence.

Fig. 1 presents the conceptual framework of robots and emotional intelligence derived from the TA. The framework includes two entities of the interaction - a robot and a human. Robot's design and technical characteristics (with their sensory, cognitive and behavioural, visual and other aspects) help the robot perceive, use, understand and manage emotions in others, i.e. to be emotionally intelligent [19]. Emotional intelligence helps robots perform their tasks in a specific setting (education, healthcare, hospitality, retail, museums, etc.) and understand the social context of their interactions with humans. Moreover, emotional intelligence allows robots to have behaviour relevant to the task and the setting. For example, a robot should be able to tell jokes during an entertainment event but not during a funeral. Therefore, the setting of the human-robot interaction influences the tasks robots need to do and their relevance to the social context. The rapid development of AI and the potential to incorporate generative AI (e.g. based on large language models) in robots [65] may significantly improve their emotional skills (e.g. in terms of understanding and using emotions) and, thus, the scope of tasks they can successfully perform. This will facilitate the wider adoption of robots for tasks that require significant emotional intelligence, not only in healthcare and education, which are the two dominating research settings, but also in sales, hospitality, retail, or as companion home robots. The greater emotional intelligence of robots will also allow people to assign or delegate more tasks to robots [66,67]. For example, in a recent study, Ivanov and Webster [68] found that the required emotional intelligence of the decision-maker is inversely related to the degree to which hotel managers are ready to delegate decision-making to artificial autonomous agents. Improved emotional intelligence of robots may persuade managers to delegate more tasks to them.

Humans are the second actors in the interaction. They have some demographic characteristics (gender, age, cultural background, religiosity, etc.) and play different roles (customer, patient, employee, etc.) that may influence their perceptions of robots and their emotional skills. For instance, customers usually have the freedom to decide whether to use robot-delivered services, while employees often do not have the choice of whether to use robots as their interaction with the robots would be guided by the internal operations standards of the organisation. Additionally, employees would have more interactions with the robots and, hence, have more realistic perceptions of their emotional skills compared to customers. The framework also includes the

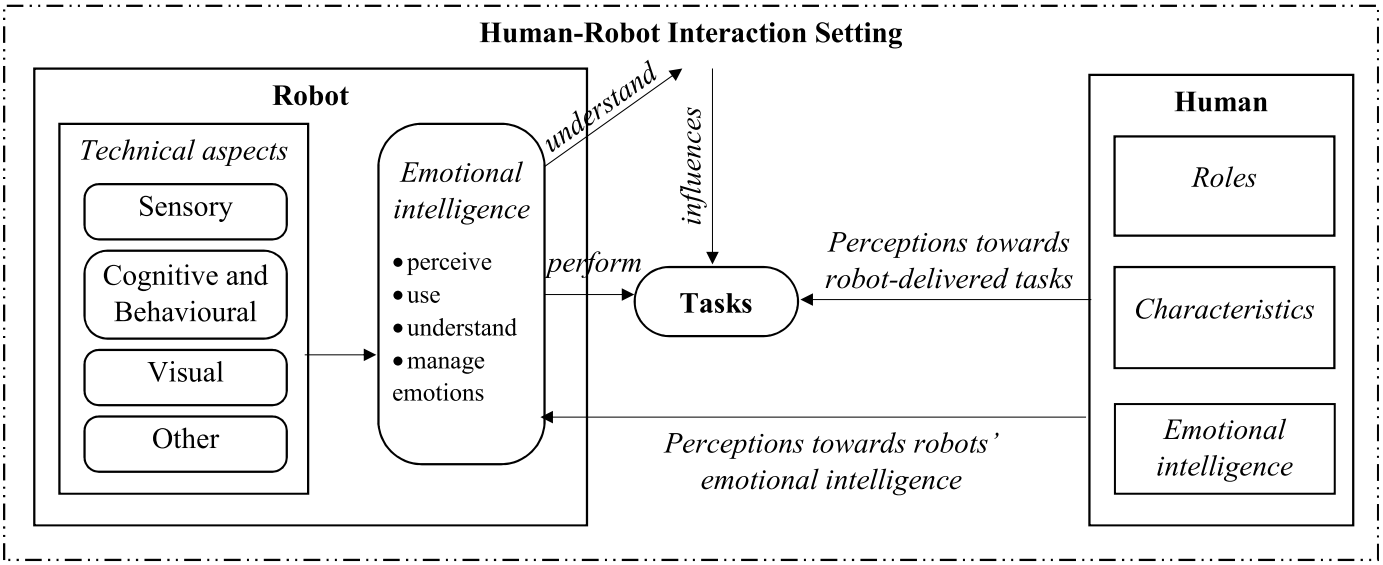

Fig. 1. Conceptual framework of emotional intelligence of robots.

perceptions towards robot-delivered tasks, e.g. are the tasks appropriate for robotisation [69] and are the tasks well implemented (e.g. efficiently, quickly, showing positive emotions, the portrayed emotions were relevant to the task). In fact, previous studies have shown that the perceived emotional skills of robots shape the perceived appropriateness of robot's use in specific service settings and tasks. For instance, Webster and Ivanov [18] find that the perceived emotional skills of robots are positively related to the perceived appropriateness of robots' use in museums and galleries.

Another theoretical implication relates to the human actor. While research on the emotional intelligence of robots has overwhelmingly focused on the robot and its interactions with humans, the emotions of humans and their emotional intelligence in the HRI are important as well. Prior research has already shown that positive emotions caused by robots stimulate customers' intentions to use robots [17]. However, partly, the degree of perceived emotional intelligence of robots may depend on the emotional intelligence of humans, hence its inclusion in the conceptual framework. For example, emotionally intelligent people may better understand the emotions that a robot tries to convey, which means that it would be easier for the robot to manage the emotions in them, which is one of the branches of emotional intelligence [19]. However, empirical studies need to confirm or reject this conjecture.

A third theoretical implication from the analysis is connected to the scope of the human-robot interaction setting. The TA revealed that most studies that considered a specific interaction setting focused on education or healthcare, while other settings that require considerable emotional intelligence skills (e.g. hospitality, retail, rescue, etc.) are largely overlooked. Research on the emotional intelligence of robots needs to expand the scope of HRI settings because each setting puts requirements about the acceptable behaviour and emotions conveyed by the robot. For example, research can focus on the emotional intelligence of sex robots [70].

From a practical perspective, the findings of the thematic analysis and the conceptual framework provide practitioners with knowledge about the robots and EI literature to be aware of robots' technical developments and characteristics that scientists are working on to develop emotional intelligence-related features of robots. Furthermore, showing the development of robots and EI related to the settings and tasks is also helpful for practitioners to understand the current intervention and use of emotional robots. The proposed framework can be helpful for practitioners to make decisions about the implementation of emotional robotics in their settings and tasks. The framework would also be beneficial to robot designers. As developing emotionally intelligent robots is technically difficult and expensive, the robot designers need to align the degree of emotional skills of robots for the tasks they need to implement and the setting they will be used in. A room service delivery robot does not need to be emotionally intelligent, but a sex robot, an educational robot or a companion robot needs to be.

4.2. Limitations and future research

The main limitation of the paper is that it includes only studies in the Scopus database and in the English language. While Scopus is an extensive and curated database of scholarly publications, it does not include all sources in the field. Moreover, the study included only publications in the English language, which is the de facto lingua franca of academia. There may be important studies published in other languages. Future review studies may include publications in other languages and from other databases as well. From a social science perspective, future research may delve into the role of emotional intelligence in the task implementation efficiency of robots. It can also investigate the impact of the human-robot interaction setting on the emotional skills requirements for robots. Additionally, research can investigate the role of the emotional intelligence of humans on robots' task efficiency. Furthermore, research can shed light on the impact of the demographic characteristics and roles of human users on their perceptions of the emotional intelligence of robots and robot-delivered tasks. Finally, studies need to focus on other settings, such as hospitality, retail, or home robots, where the emotional intelligence of robots may play a vital role in human-robot interaction.

CRediT authorship contribution statement

Faruk Seyitoğlu: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Stanislav Ivanov:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Data availability

Data will be made available on request.

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Faruk Seyitoğlu is a Researcher at the University of Aveiro, Portugal and an Associate Professor at Mardin Artuklu University, Turkey. His research interests include tourist behaviour and experience, technology and robots in tourism and hospitality, destination management and marketing, tourism planning and development, and gastronomy and food studies.

Dr. Stanislav Ivanov is currently Professor at Varna University of Management, Bulgaria (http://www.vum.bg) and Director of Zangador Research Institute (https://www.zangador.institute/en/). Prof. Ivanov is the Founder and (co-)Editor-in-chief of two academic journals: *European Journal of Tourism Research* (http://ejtr.vumk.eu) and *ROBONOMICS: The Journal of the Automated Economy* (https://journal.robonomics.science). His recent research interests include robonomics, robots in tourism/hospitality, the economics of technology, etc. For more information about Prof. Ivanov please visit his personal website: http://www.stanislavivanov.com.