# Integrating AI into AAC: A Flexible Framework for Developers of Context-Aware Communication Systems

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***Abstract*—This paper presents an expert-informed conceptual framework for developers of context-aware augmentative and alternative communication (AAC) systems. Unlike many existing AAC solutions that rely on static context or rule-based adaptation, the proposed framework brings together multimodal context, personalization, and AI-driven adaptability in a single modular architecture. The framework was developed through an iterative design process informed by relevant literature, structured workshops with communication interpreters, and expert meetings to translate insights into architectural components. The proposed architecture integrates multimodal inputs, including sensor data, personal history, and user preferences, with adaptive artificial intelligence (AI), leveraging large language models (LLMs) to deliver personalized and dynamic communication support. The framework consists of five core components: input collection, context definition and prioritization, communication support, feedback, and output generation. Its practical relevance is illustrated through communication scenarios co-created with communication interpreters, which demonstrate how the framework's components map onto diverse AAC use cases. The framework provides a structured foundation for AI developers and AAC researchers to build context-aware, adaptive AAC systems with potential to enhance communication autonomy and participation for individuals with complex communication needs.**

## I. Introduction

Augmentative and alternative communication (AAC) encompasses methods and technologies that support or replace speech for individuals with complex communication needs (CCN), such as those with aphasia, autism spectrum disorder, or motor speech disorders [1], [2]. Many individuals rely on a combination of communication methods, such as natural speech, gestures, symbols, or assistive devices [2]. AAC ranges from non-tech methods (e.g., gestures and facial expressions) to low-tech AAC (e.g., communication books and display boards) and high-tech systems, such as speech-generating devices and mobile applications [3], [4]. Tablets and mobile phones with AAC applications provide accessible and flexible means of communication, while technologies such as eye tracking enable users to select words or symbols through gaze [3], [4].

However, despite technological progress, high-tech AAC systems still fall short of fully addressing users' communication needs [5], [6]. Commonly reported barriers include device complexity, limited customization for individual users and different contexts, attitudes of communication partners, insufficient support from people close to the user, and limited effectiveness in everyday social interactions [5], [7], [8]. These barriers can contribute to AAC abandonment and restrict participation in education, employment, healthcare, family life, and other everyday communication situations.

Context-aware and AI-supported approaches offer opportunities to address some of these limitations. Context-aware AAC systems can use information such as location, time, communication history, and information about communication partners to adapt communication support [9]–[12]. Recent advances in artificial intelligence (AI), particularly language models, further enable context-sensitive prediction, language generation, personalization, and multimodal communication support [13]–[17]. However, existing approaches generally address particular AAC functions or individual sources of contextual information rather than specifying how heterogeneous contextual inputs, user-specific communication characteristics, communication-partner input, adaptive AI support, and user feedback can operate together within an integrated AAC architecture.

What remains underdeveloped is an AAC-specific architectural account of how these different sources of contextual information and AI-based functions should interact within a flexible system to provide context-aware and personalized communication support while preserving the AAC user's communicative intent. This study addresses this gap by developing an expert-informed, modular framework for context-aware AI-supported AAC. The framework was developed through an iterative process combining findings from the literature, three structured workshops with 20 communication interpreters, and technical expert meetings. The aim is to provide a developer-oriented conceptual architecture that specifies the main functional components and their relationships for future implementation and evaluation.

This study makes the following contributions:

- A set of expert-informed functional requirements for context-aware AAC systems, organized around communication guidance, clarification of communication-partner input, and support for expressive communication.
- A modular developer-oriented framework that integrates multimodal input collection, context definition and priori-

tization, AI-based communication support, user feedback, and multimodal output.
- A scenario-to-framework mapping demonstrating how the five framework components accommodate different contextual and communication requirements across representative AAC situations.
- A set of implementation requirements and design considerations concerning latency and communication continuity, multimodal fusion and context prioritization, personalization and computational resources, privacy and safety, and evaluation.

These contributions constitute the principal outcomes of the study and are developed and analyzed in the subsequent sections. Together, they provide an architectural and integrative perspective on context-aware AAC development by connecting expert-informed functional requirements with a modular technical structure and practical considerations for implementation. The contribution is conceptual and engineering-oriented; the framework has not yet been implemented as a complete system or validated with AAC users.

The remainder of this paper is organized as follows. Section II reviews related research on context-aware and AI-supported AAC systems. Section III describes the iterative design methodology. Section IV presents the expert-informed functional requirements and the proposed modular framework. Section V provides a scenario-based analysis of the framework's conceptual applicability. Section VI discusses the framework's contributions, implementation considerations, and limitations. Finally, Section VII concludes the paper.

## II. Related Work

### A. Context-Aware AAC Systems

Context-aware AAC systems have been explored as a means of adapting communication support to the user's environment and situation. Early prototypes integrated global positioning system (GPS) and Wi-Fi positioning to suggest location-specific phrases [9]. The MarcoPolo system [18] extended this approach by presenting location-specific objects, where selecting an object triggered appropriate words or phrases. Chan *et al.* developed an interface that dynamically updated elements based on real-time location information, including Bluetooth beacons [11].

Other systems have incorporated multiple contextual sources. TryTalk, a smartphone-based AAC application, dynamically rearranged AAC categories and items using contextual information such as location, time, calendar information, and user interaction history [10]. Hossain *et al.* employed a rule-based approach incorporating spatial and temporal context [19], while Kane *et al.* introduced TalkAbout, which used face recognition to identify communication partners and tailor available vocabulary [12].

These studies demonstrate the potential of contextual information for adapting AAC content. However, the approaches primarily focus on particular contextual sources or predefined adaptation mechanisms. This limits how different contextual sources can be combined and dynamically prioritized according to the communication situation and individual user characteristics.

### B. AI-Supported AAC Systems

Recent advances in artificial intelligence (AI), particularly language models, have expanded the possibilities for predictive and generative communication support in AAC. Language models can support intent interpretation, word and phrase prediction, sentence generation, and personalization, potentially reducing the cognitive and motor effort required for communication [15], [16], [20], [21].

Several AAC-specific implementations have explored these capabilities. KWickChat [13], based on GPT-2 and BERT, used keywords, personal information, and conversation history to generate communication suggestions. However, the system encountered issues related to punctuation and sentence segmentation, and its evaluation did not include real AAC users. Predictive AAC with transformers (PrAACT) [14] used BERT to predict communication cards from an annotated conversational corpus. Although the approach demonstrated the potential of transformer-based prediction, its evaluation was based on offline benchmarks, leaving real-time performance and adaptability to evolving user vocabularies open for further investigation.

Generative language models have also been investigated for reducing communication effort. A prototype using ChatGPT-4 generated formal or informal utterances from short user cues [22]. SpeakFaster [15] used language models, including Google LaMDA, to expand abbreviated input into complete sentences. The system increased text-entry rates and reduced the number of required motor actions in evaluations that included people with amyotrophic lateral sclerosis (ALS), although challenges related to cognitive load, sample size, and cloud-based processing remained.

Mao *et al.* [17] introduced four AI-assisted design probes for people with aphasia, incorporating multimodal input and language models for image-based word verification, keyword-to-sentence generation, sentence correction, and narrative support. Their user studies indicated potential benefits for communication confidence and social connection, while also identifying challenges related to prototype usability, speech-recognition errors, mismatches between AI-generated output and user intent, and latency. Another emerging direction combines electroencephalogram (EEG)-based brain–computer interfaces with language models to infer user intent and cognitive workload for adaptive language generation [23]. Such approaches remain exploratory and introduce challenges related to signal noise, latency, calibration, and the handling of sensitive neural data.

In addition to model training and fine-tuning, prompt-based approaches provide another mechanism for adapting language-model output. Structured prompts can guide generation without requiring retraining on large AAC-specific datasets [21]. Valencia *et al.* [16], for example, introduced speech macros

TABLE I. COMPARISON OF EXISTING CONTEXT-AWARE AND AI-SUPPORTED AAC APPROACHES WITH THE PROPOSED FRAMEWORK

| System | Context and Personalization | Adaptation and Support |
|---|---|---|
| MarcoPolo [18] | Location; customizable vocabulary | Touch/visual input; manual customization |
| TryTalk [10] | Location, time, history; context-based | Context-driven vocabulary adaptation |
| Chan et al. [11] | BLE context; context-based | Context-dependent AAC interface |
| TalkAbout [12] | Location, partner identity; partner-based | Partner-aware vocabulary adaptation |
| KWickChat [13] | Keywords, persona, dialogue history | GPT-2 generation; persona-conditioned output |
| **Proposed framework** | Direct, dynamic, and static context; user profiles and history | Multimodal input; LLM/SLM support; two-way communication; explicit feedback |

consisting of predefined prompts for extended replies, background information, and request formulation. However, the macros were designed for relatively general contexts and provided limited user-specific adaptation.

Personalization and conversational context are also common in general conversational AI. Personalized chatbot systems can adapt responses using user profiles and previous dialogue [24]. The role of AI in AAC, however, differs from conventional chatbot interaction because AI often mediates communication between an AAC user and another person rather than acting as the communication partner itself [15], [16]. Consequently, preserving the user's communicative intent, accommodating individual communication characteristics, and selecting relevant contextual information are particularly important considerations for AAC systems.

### C. Comparison and Research Gap

Existing context-aware and AI-supported AAC systems provide capabilities such as location-aware adaptation, communication-partner recognition, personalized language generation, and multimodal support. Table I compares selected approaches in terms of their contextual information and personalization mechanisms, as well as their adaptation and communication-support capabilities. The comparison focuses on functional scope rather than empirical performance; for the proposed conceptual framework, it represents the intended coverage of the framework.

As shown in Table I , prior systems typically implement selected capabilities for particular tasks or limited contextual inputs. They do not commonly integrate multimodal context, explicit context prioritization, two-way communication support, and user feedback within a unified architecture. The proposed framework addresses this gap by organizing these functions as interconnected components.

## III. METHODOLOGY: ITERATIVE DESIGN PROCESS

Framework design progressed through multiple iterations, where insights from experts were translated into functional requirements and architectural refinements. At each stage, open questions were addressed collaboratively, ensuring that the design evolved from high-level concepts to a detailed, implementable structure.

- **Literature-Informed Background (Supporting Input):** Relevant background literature on AAC and AI integration was examined to identify state-of-the-art solutions and research gaps. While not exhaustive, it provided a baseline for aligning the framework with current trends (see Section II).
- **Expert Workshops:** Three structured workshops were conducted with 20 Finnish communication interpreters. Communication interpreters are trained professionals who support everyday interaction for people with complex communication needs. They facilitate communication in their daily lives, e.g., in healthcare, educational, and social contexts. They actively mediate interactions, adapt communication strategies to individual abilities, and promote inclusiveness in real-world contexts. Each workshop followed a structured Create–Evaluate–Develop workshop format [25] that has been successfully used to explore professional visions of future technologies [26]. Participants envisioned future AAC technologies, identified contextual factors, and co-created user scenarios. The communication interpreters' domain-specific insights were then translated into descriptions of what the envisioned technology must know or do to support successful communication. The scenarios were finally adapted into story form (e.g., assigning names to users and structuring the narratives consistently, see Section IV-B).
- **Technical Meetings:** Regular meetings with experts in AI and LLMs, computational science, speech-language pathology, assistive technology, and communication interpreting were held to translate requirements into architectural components and assess feasibility. Key design considerations included multimodal context identification and integration, personalization strategies, and system flexibility. Table II summarizes the iterative design process, including timeline, expert roles, and main discussion themes that guided the development of the proposed framework.

## IV. FRAMEWORK DESIGN PROCESS

This section describes how workshop-derived communication needs were translated into the proposed five-component framework. It summarizes the expert-informed requirements and practical scenarios that guided the design, which are later used in Section V to examine the framework's applicability across different communication contexts.

TABLE II. TECHNICAL MEETINGS FOCUSING ON THE DESIGN OF A MODULAR FRAMEWORK INTEGRATING MULTIMODAL CONTEXT AND ADAPTIVE AI FOR PERSONALIZED AAC SUPPORT.

| Month, Year | Experts Involved | Main Discussion Themes |
|---|---|---|
| Aug 2024 | IS, PR, JV | Current AAC landscape, user needs, and challenges. |
| Sep 2024 | IS, PR | Review of existing AI-driven AAC systems. |
| Oct 2024 | AR, TV, JM | Three workshops (22.10.24, 25.10.24, and 29.10.24) for communication interpreters. |
| Nov 2024 | IS, PR | Review of prior context-aware AAC systems. |
| Dec 2024 | IS, PR | Key objectives and functional blocks. |
| Jan 2025 | IS, JV, AV | Inputs, LLM integration, and framework flexibility. |
| Feb 2025 | IS, PR, JV | Framework structure and feedback placement. |
| Mar 2025 | IS, PR, JV | Communication flow. |
| Apr 2025 | IS, PR, JV | Secondary user inputs and framework extension. |
| May 2025 | IS, PR, JV, AR | Review of user stories. |
| Jun 2025 | IS, JV, TV | Finalization. |

*Abbreviations:* IS = Ishan Sen; PR = Pasi Raumonen; JV = Johanna Virkki; AV = Aygün Varol; AR = Anni Raukko; TV = Tanja Vihriälä; JM = Jaana Mäkinen.

### *A. Expert-Informed Functional Requirements for Future Context-Aware AAC Systems*

The workshop findings were synthesized to identify functional requirements for future context-aware AAC systems. The communication interpreters participating in the workshops envisioned future AAC systems as highly individualized, adaptive, and capable of continuous learning from user behavior. They emphasized ease of use, subtle interaction, and responsiveness, alongside the integration of practical tools such as clocks, calendars, cameras, and maps. The envisioned systems should combine multimodal input recognition, including gestures, facial expressions, and emotional cues, with dynamic context awareness, such as location, communication-partner identification, and conversation flow. Personalization was considered essential: the system should account for user-specific communication styles, functional abilities, and preferences while adapting to changing contexts.

The synthesis identified three main functional requirements: (1) guidance in communication situations, (2) clarification of communication-partner input, and (3) support for the user's expressive communication. The specific capabilities associated with these requirements are summarized in Table III.

TABLE III. FUNCTIONAL CAPABILITIES FOR NEXT-GENERATION CONTEXT-AWARE AAC SYSTEMS, DERIVED FROM WORKSHOP MATERIALS WITH FINNISH COMMUNICATION INTERPRETERS. THE CAPABILITIES SUMMARIZE RECURRING SUPPORT NEEDS RELATED TO COMMUNICATION GUIDANCE, COMPREHENSION SUPPORT, AND EXPRESSIVE COMMUNICATION.

| Functional Area | Capabilities |
|---|---|
| Offers guidance | • Guides communication situations through speech and provides information about the user's communication.<br>• Offers support for executive functioning (e.g., breaking tasks into smaller steps).<br>• Describes the surrounding environment. |
| Clarifies the secondary user's communication | • Picks out the essential content from speech and notes it (text, images, plain language).<br>• Clarifies words and offers synonyms.<br>• Translates speech into sign language. |
| Supports the user's expressive communication | • Translates hard-to-understand speech, AAC use, thoughts, and signs into spoken language.<br>• Generates narratives from photos and locations.<br>• Suggests initiating contact and helps express turn-taking.<br>• Offers suitable alternatives or related cue words to clarify intent.<br>• Recognizes repetitive patterns and breaks them with cues (e.g., vibration). |

### *B. Workshop-Derived Practical Use Scenarios*

The scenarios are composite illustrations developed from workshop-generated materials. They do not describe individual real users, but combine recurring communication barriers, contextual factors, and support needs identified by communication interpreters. Their purpose is to make the functional requirements concrete and to support the scenario-based walkthrough of the proposed framework. This section presents four practical scenarios co-created with communication interpreters to illustrate real-world communication challenges and expectations for next-generation AAC systems. These scenarios represent diverse contexts, healthcare, education, and social life. The scenarios also provide the basis for the scenario-based analysis of the proposed framework presented in Section V. The scenarios are summarized in Table IV.

### *C. Framework Design*

Based on the functional requirements identified from the workshops and the subsequent technical design process, these requirements were translated into the proposed modular context-aware AAC framework. The framework defines how contextual information is collected, prioritized, processed through AI-based communication support, refined through feedback, and delivered as communication output. Its modularity allows sensing, processing, AI, feedback, and output technologies to be replaced while preserving the overall component structure and information flow.

TABLE IV. REAL-WORLD SCENARIOS ILLUSTRATING FUNCTIONAL REQUIREMENTS OF AI-ENHANCED AAC SYSTEMS. EACH SCENARIO HIGHLIGHTS HOW THE PROPOSED FRAMEWORK SUPPORTS PERSONALIZED, CONTEXT-SENSITIVE COMMUNICATION ACROSS HEALTHCARE, EDUCATION, AND SOCIAL ENVIRONMENTS. THESE SCENARIOS WERE DEVELOPED BY SYNTHESIZING MATERIALS GENERATED IN THREE WORKSHOPS WITH FINNISH COMMUNICATION INTERPRETERS.

| Scenario | Description |
|---|---|
| **Story 1:** Alli's exciting summer story | **Setting:** Day activity/work program (∼30 participants, noisy). **Primary user:** 34-year-old Alli, aphasia, single-word use, frequent naming errors. **Secondary users:** Instructor, interpreter, 8 peers. **Scenario:** Alli's AAC system helps her join group chats by recognizing her style—e.g., turning "häh?" (similar to "huh?") into "Could you repeat that, please?" It uses her summer photos, maps, and calendar to support storytelling, suggests social prompts, and helps her follow others' stories. It recognizes who is present so she can direct comments, and reminds others to give her time and accommodate her communication style. |
| **Story 2:** Mikko has something to say at school | **Setting:** Vocational school, 10 students, new teacher. **Primary user:** Mikko, young adult, limited speech (yes/no, some words), needs support in new contexts. **Secondary users:** Paraprofessional, teacher, interpreter, classmates. **Scenario:** Mikko's AAC system supports communication with his teacher and classmates by being programmed with lesson topics and new vocabulary. When Mikko wants to speak, the system gives a clear signal and continues his sentence using pre-entered keywords in his preferred style (e.g., "Hey, I have something to say."). If needed, it can clarify others' messages. It also adapts to special situations (celebrations, work placements) by adjusting suggestions based on context. |
| **Story 3:** Ordering food and chatting | **Setting:** Noisy restaurant with music and many customers. **Primary user:** Laura, autistic, non-speaking, cannot read/write. **Secondary users:** Friends, support worker, restaurant staff. **Scenario:** Laura's AAC system helps her order food and join table conversations. It uses a social story to guide her, shows illustrated menus and drink lists, and accounts for allergies and venue details. It uses clear visuals and simple language so Laura can order independently (including sending orders to the kitchen). It supports conversation by translating messages for staff and adapting to her communication style, and can take into account whether a support worker is present. |
| **Story 4:** Eetu's dental visit | **Setting:** Dental clinic. **Primary user:** Eetu, intellectual disability + language disorder, unclear speech, difficulties with comprehension. **Secondary users:** Dentist, assistant, support worker, interpreter. **Scenario:** Eetu's AAC system helps him prepare using a personalized social story based on temperament and past experiences. At the clinic, visuals support comprehension of procedures. The system shares clear information about Eetu's communication needs and required support so staff can adapt. It also logs what was done during the visit so Eetu can later share his experience, while highlighting that data privacy is a key challenge. |

Fig. 1 illustrates the dual communication paths between the primary AAC user and their communication partners (i.e., secondary users): natural interaction (speech, gestures, and facial expressions) and augmented interaction through the AAC system. In real-world situations, both paths may operate simultaneously, with the AAC system providing additional support when natural communication is insufficient.

This communication model underpins the proposed architecture (Fig. 2), which consists of five i nterconnected components: input collection, context definition a nd prioritization, AI-based communication support, feedback, and output generation. The input block gathers multimodal data from user actions, sensors, and personal history. The context block processes and prioritizes these inputs to identify relevant contextual information. The AI-based communication support block uses the prioritized context to generate personalized communication suggestions. The feedback block allows users to accept, reject, or modify generated suggestions, supporting adaptation and personalization. Finally, the output block delivers the selected message in the user's preferred communication mode, such as speech, text, images, or symbols.

A corresponding architecture for communication initiated by secondary users is shown in Fig. 3. In this configuration, personal information from the primary AAC user is excluded from the input block, and the feedback block is omitted. Together, the two configurations define a modular architecture for supporting context-aware communication between AAC users and their communication partners.

### *D. Input Block*

This block is the first component of the framework, responsible for acquiring and organizing multimodal data to infer the user's communicative context. Inputs are categorized into three types: direct, dynamic, and static. Direct inputs include user-generated signals such as speech, text, drawings, symbols, images, and gestures, for example, capturing an image or selecting a symbol to initiate communication. Dynamic inputs represent real-time contextual data, including sensor readings (e.g., GPS, camera, microphone, biosensors), environmental conditions (e.g., noise level, lighting), and online sources such as calendar events or weather updates. Static inputs consist of personal information, historical communication logs, and user preferences (e.g., vocabulary style, food habits), enabling personalization and continuity across sessions.

### *E. Context Defining and Prioritization Block*

The block transforms heterogeneous inputs from the previous stage into structured, ranked context data for adaptive communication support. Raw signals are normalized and converted into machine-readable formats using modality-specific preprocessing techniques such as speech-to-text, image-to-text conversion. Robustness can be achieved through adaptive fallback strategies: if a modality fails, such as camera input in low-light conditions, the system prioritizes alternative cues like GPS or recent communication history; similarly, when speech recognition confidence falls below a threshold, gesture-based or text-based inputs are prioritized. To support real-time responsiveness, the block employs asynchronous data handling and lightweight feature extraction, allowing rapid updates when environmental or conversational conditions change. Contextual relevance is computed using a composite

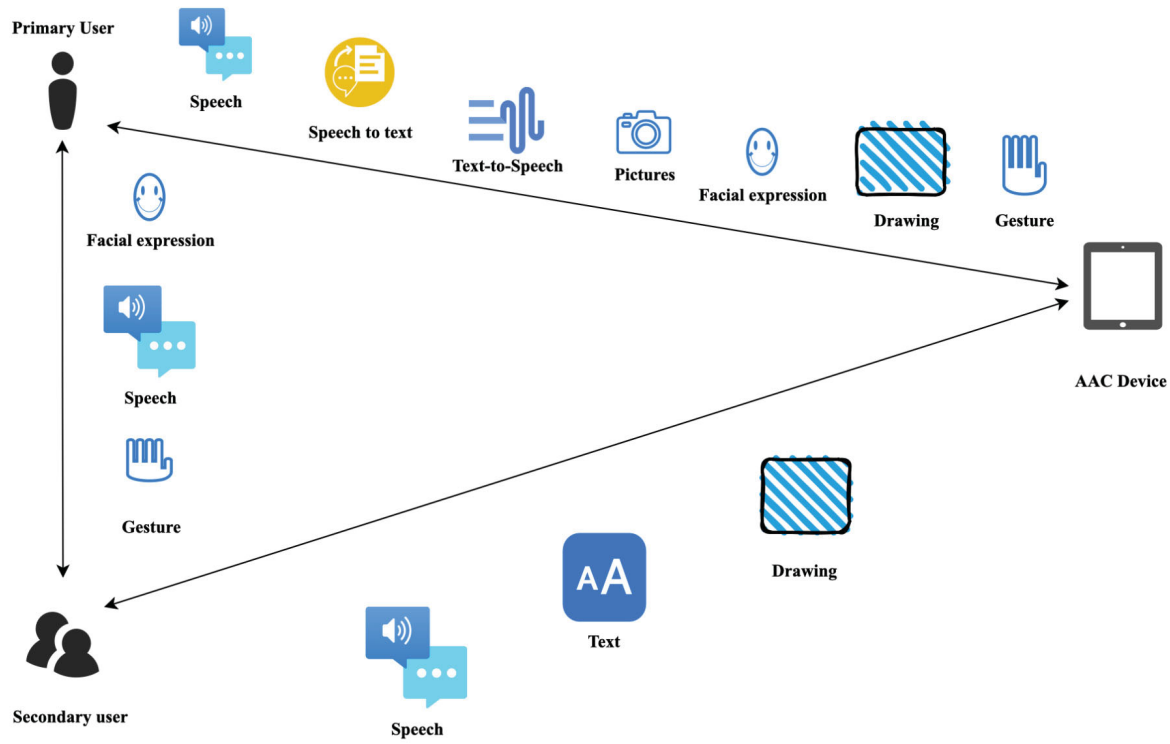



Fig. 1. Communication flow between primary and secondary AAC users with or without an AAC system. With an AAC system, communication flows in multiple modes such as speech, text, and drawing. Without an AAC system, communication relies on natural means such as speech, gestures, and facial expressions.

scoring approach that considers confidence levels, temporal recency, semantic alignment with the current interaction, and user preference history. Privacy-preserving design principles are critical at this stage, as sensitive data such as location and facial imagery may be processed; therefore, local computation, encryption, and consent-driven data handling are recommended. By combining adaptive prioritization with confidence-aware fallback mechanisms, this block is intended to support coherent and contextually relevant communication under resource constraints and variable input conditions.

### *F. AI-Based Communication Support Block*

In this block, prioritized contextual data are leveraged to generate adaptive, user-specific communication outputs. After receiving ranked inputs from the context defining and prioritization block, this component employs generative models, such as LLMs or SLMs, to produce contextually relevant suggestions in multiple formats, including text, speech, symbols, and images. To support real-time responsiveness, the block integrates a hybrid inference strategy: lightweight models handle frequent, short utterances locally, while cloud-based LLMs are used for complex or novel requests when connectivity and consent allow. Outputs are generated through structured prompting that incorporates user preferences, communication history, and situational metadata, enabling personalization without extensive retraining. By combining adaptive generation, hybrid deployment, and privacy-preserving design, this block is intended to support coherent and context-sensitive communication across diverse conditions and resource constraints.

### *G. Feedback Block*

This block enables iterative refinement of generated outputs and supports continuous personalization. After the AI-based communication support block produces suggestions, users can accept, reject, or modify them, providing explicit or implicit feedback that informs future system behavior. This feedback loop is critical for adapting to individual communication styles and evolving needs without requiring full model retraining. To maintain real-time responsiveness, lightweight mechanisms such as quick-select alternatives and simplified correction interfaces are employed, while more advanced strategies, such as reinforcement learning or periodic supervised updates, process aggregated feedback for long-term optimization. Confidence-aware handling provides a mechanism for responding to repeated dissatisfaction; the system can trigger fallback strategies or adjust prioritization logic based on feedback. Privacy

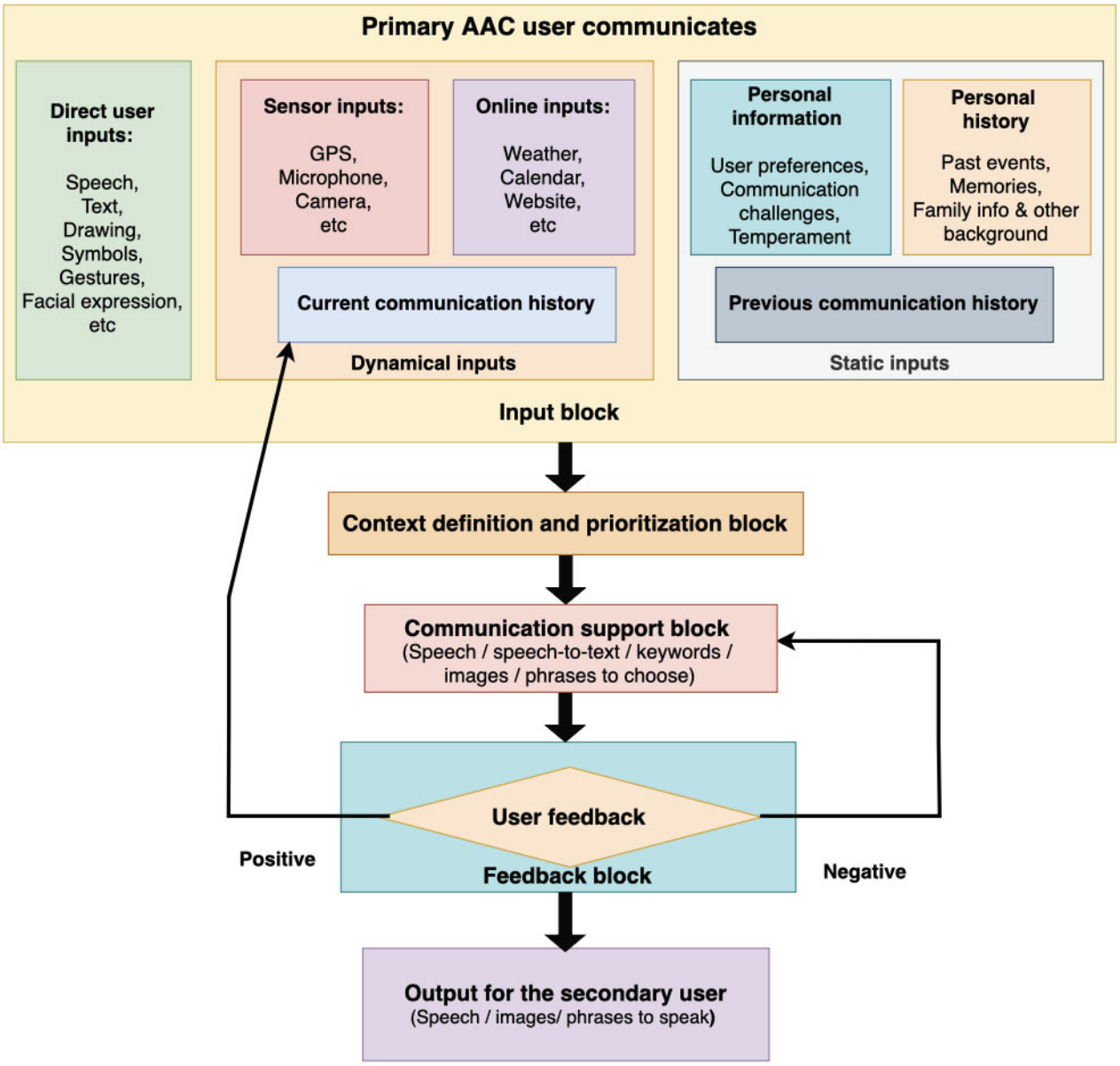



Fig. 2. AI-driven context-aware framework architecture for AAC systems when communication is initiated by the primary user. The framework includes five interconnected blocks: input collection, context definition and prioritization, communication support, user feedback, and output generation. It enables adaptive and personalized communication based on multimodal contextual inputs.

safeguards are essential, as feedback logs may contain sensitive linguistic and contextual data; therefore, encryption, local storage, and consent-driven data sharing are recommended.

### *H. Output Block*

The block delivers the accepted AI-generated message in the user's preselected communication mode, such as synthesized speech, text, images, or symbols. The system can output via the device screen, audio speakers, or emerging technologies like augmented reality (AR) and wearable interfaces. This flexibility allows communication support to be adapted across current and future platforms.

## V. Scenario-Based Analysis of Framework Applicability

The workshop-derived scenarios presented in Table IV represent recurring communication challenges, contextual factors, and support needs identified by the communication interpreters. The scenarios are used here to analyze how the proposed framework can be configured across different

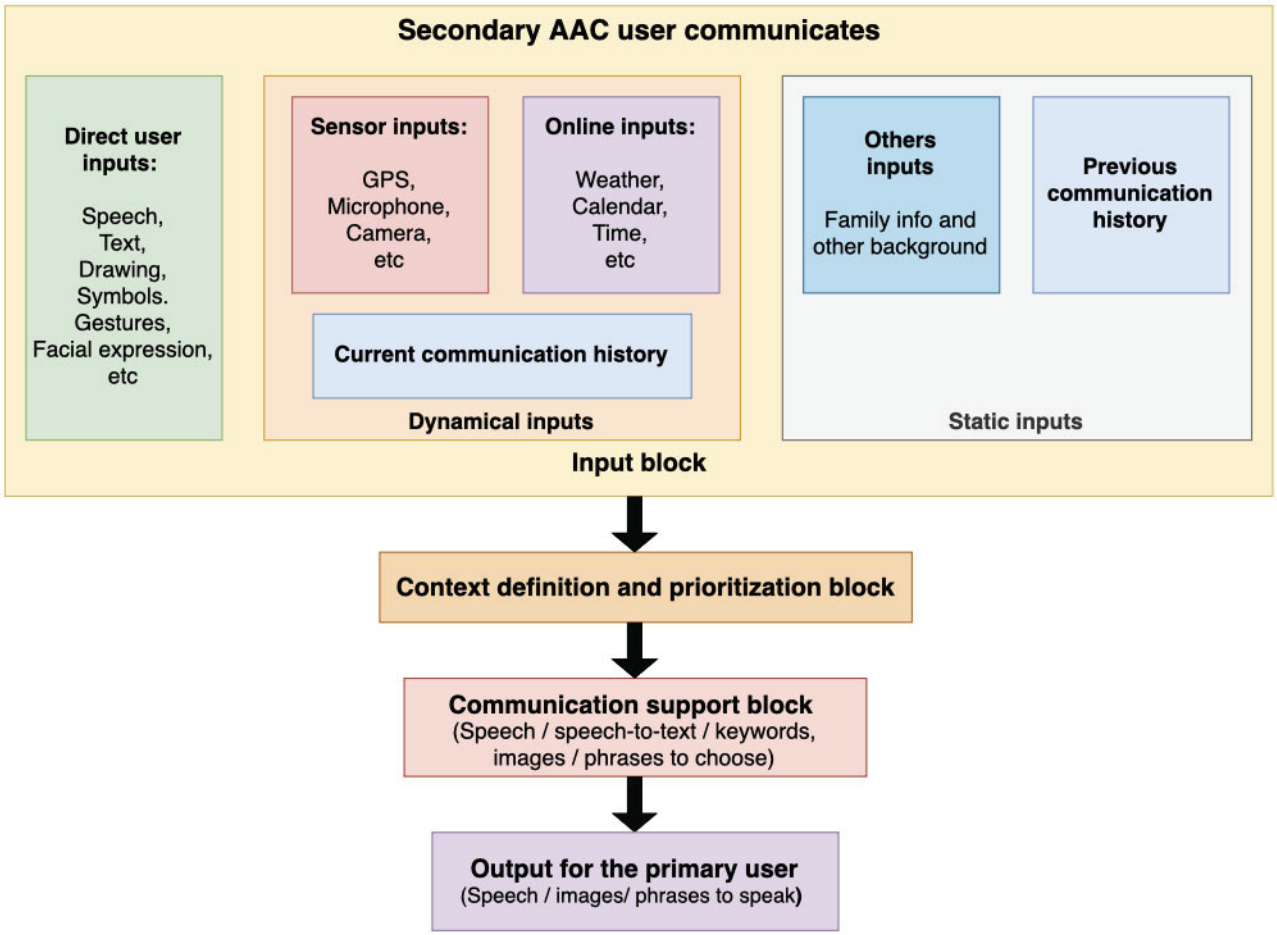



Fig. 3. AI-driven context-aware framework architecture for AAC systems when communication is initiated by the secondary user. In contrast to the primary-user version, this architecture excludes personal information from the input block and does not include a feedback block.

communication situations. Specifically, the analysis considers how the five framework components—input, context definition and prioritization, AI-based communication support, feedback, and output—relate to the contextual information and communication support needs represented in each scenario (Figs. 2 and 3). The analysis is intended to illustrate the conceptual applicability and flexibility of the framework rather than to evaluate its practical effectiveness.

*1) Scenario 1: Alli's Exciting Summer Story (Group Discussion):* In a noisy day activity center, Alli, a 34-year-old with aphasia, uses single words and often produces incorrect word choices. The input block (Fig. 2) captures Alli's vocal cues (e.g., "häh"), photos, and calendar entries. The context prioritization block emphasizes recent events and recognized conversation partners while filtering background noise. The AI-based communication support block converts unclear vocalizations into clear phrases (e.g., "Could you repeat, please?") and generates short narratives using personal history and location data. Through the feedback block, the system learns Alli's preferred phrasing for future interactions. Finally, the output block provides multimodal outputs (speech and visual) and prompts partners to allow extra response time.

*2) Scenario 2: Mikko Has Something to Say at School (Classroom Conversation):* In a school setting, a young AAC user can only say "yes/no" and a few random words. The input block detects gestures, partial words, and identifies participants via voice or face recognition. The context prioritization block highlights classroom-related topics and the current speaker. The AI-based communication support block expands intent signals into full sentences in the user's preferred style (e.g., slang). The feedback block reinforces frequently chosen vocabulary for personalization, while the output block directs messages to the correct partner and clarifies teacher's speech if needed.

*3) Scenario 3: Ordering Food and Chatting:* In a noisy restaurant, an AAC user with no speech wants to order food

and chat with friends. The input block collects GPS location, retrieves menus from online, and captures spoken input from waiters. The context prioritization block filters relevant cues such as menu items, allergies, and social interaction. The AI-based communication support block converts text menus into visual choices, generates context-specific conversation prompts, and provides real-time translation. The feedback block learns the user's food preferences over time, and the output block presents options visually and vocally, ensuring inclusive communication.

*4) Scenario 4: Eetu's Dental Visit:* At a dental clinic, a young man with unclear speech needs to understand procedures and express needs. The input block captures unclear speech, sensory cues, and spoken input from the dentist and assistant. The context prioritization block focuses on treatment steps and instructions. The AI-based communication support block simplifies professional speech into symbols or short phrases and generates visual social stories. The feedback block logs completed communication actions and user responses to support adaptive personalization in future visits, while the output block provides visual aids for the user and verbal clarifications for professionals.

Across the four scenarios, different combinations of contextual information and communication support functions are relevant, while the overall five-component structure of the proposed framework remains applicable. The analysis illustrates how the roles and priorities of individual components may vary according to the communication situation and support needs. These observations suggest conceptual flexibility across the considered scenarios; however, practical applicability and effectiveness remain to be established through implementation and evaluation with AAC users and communication partners.

## VI. Discussion

### A. Framework Contributions and Implications

The proposed framework provides a modular structure for integrating heterogeneous contextual information and AI-based communication support within AAC systems. Rather than prescribing a specific set of sensors, models, or output modalities, the framework organizes these elements into interconnected components for input collection, context definition and prioritization, AI-based communication support, feedback, and output generation. This modular structure allows different input modalities and AI components to be selected according to the user's communication needs, available resources, and communication context.

A key implication of the framework is its flexibility in handling different communication situations and levels of available contextual information. Multimodal inputs may include user-generated data, such as speech, gestures, and facial expressions; sensor information (e.g., location, motion, and ambient audio); communication history; and external contextual sources, such as calendar events and weather. When some contextual sources are unavailable or unreliable, the remaining sources can still contribute to context definition and prioritization. Structured communication history can further support the identification of recurring patterns by incorporating previous interactions, frequently used expressions, and contextual metadata such as time and location.

The framework also considers communication as a two-way process. When a communication partner initiates or responds to an interaction, AI-based support can be used to simplify, translate, or otherwise represent the partner's input in a form that is more accessible to the AAC user. Similarly, contextual information and AI-based support can assist the AAC user in constructing expressive output. This extends context-aware support beyond message generation by considering both the AAC user's expressive communication and their understanding of communication-partner input.

The contribution of the framework is primarily conceptual and architectural rather than algorithmic. It translates the expert-informed functional requirements identified through the workshops into a structured architecture connecting multimodal input, context definition and prioritization, AI-based communication support, feedback, and output generation. In this way, the framework provides a developer-oriented basis for implementing and systematically evaluating context-aware AI-supported AAC systems. Its contribution therefore lies in organizing these functions and their interactions within a coherent AAC-specific architecture rather than proposing a new individual AI algorithm or model.

The scenarios presented in Table IV further illustrate recurring communication and support needs identified by the communication interpreters. Across the scenarios, four areas emerged as particularly relevant for the design of context-aware AAC systems:

- **Multimodal input recognition:** support for interpreting communicative intent from inputs such as gestures, vocalizations, and partial speech.
- **Contextual integration:** incorporation of contextual information from sources such as calendars, location, time, and other relevant external data.
- **Communication-partner support:** support for functions such as partner recognition, speech simplification, and interaction between communication partners and AAC users.
- **Adaptive learning and communication history:** use of previous interactions and feedback to support personalization and continuity across social, educational, and healthcare contexts.

The proposed framework incorporates these areas through its multimodal input, context definition and prioritization, AI-based communication support, feedback, and output components. The framework therefore provides an architectural structure for translating the identified communication needs into system functionality, while its practical effectiveness remains to be established through implementation and evaluation with AAC users.

### B. Personalization and Feedback

Personalization is essential for accommodating the diverse communication needs of AAC users. Many individuals may produce ambiguous speech or rely on gestures, necessitating flexible interpretation. The system should incorporate user-specific data, such as preferred vocabulary, communication style, and recurring interaction challenges, to generate contextually appropriate outputs. Temperament further enhances personalization by allowing the system to adapt its tone and phrasing.

Dynamic personalization is achieved through feedback loops, where user, communication interpreter, or family member responses, accepting, rejecting, or modifying suggested phrases, inform future system behavior. Positive feedback reinforces accurate predictions, while negative feedback prompts the generation of alternatives, refining output over time. Feedback integration can be implemented through rule-based adaptation, where accepted or rejected outputs influence future suggestions. More advanced approaches include reinforcement learning, which treats feedback as reward signals, and supervised learning, which uses feedback logs for periodic model retraining.

### C. Implementation Considerations

A wide range of AI components can already be integrated into AAC pipelines. For speech processing, robust automatic speech recognition (ASR) and multilingual transcription/translation are available (e.g., Whisper) [27]; natural and low-latency text-to-speech (TTS) can be achieved with neural systems such as Glow-TTS [28] and FastSpeech 2 [29]. For visual augmentation, text-to-image generators (e.g., DALL·E-style models) enable rapid creation of supportive visuals, including pictograms and personalized social stories [30], [31]. Modern mobile devices provide rich sensor suites (GPS, microphones, cameras, inertial and bio-sensors) that can supply contextual cues (e.g., location, ambient noise, activity) for the framework's input and context blocks. In parallel, large and small language models (LLMs/SLMs) offer prompt-based or few-shot personalization for the AI-based communication support block, enabling intent expansion, style adaptation, and partner-aware phrasing [13]–[16], [20], [21]. These building blocks make it feasible to prototype end-to-end, context-aware AAC experiences on commodity hardware with hybrid edge–cloud execution.

In practice, low-latency components (wake-word detection, endpointing, basic ASR, gesture recognition) can run on-device, while computationally intensive generation (long-form text, multimodal reasoning) is offloaded opportunistically to the cloud [32]. Event-driven dataflow—buffered, asynchronous streams from sensors and user inputs—feeds the context definition and prioritization block, which publishes a ranked context state to downstream generators (Figs. 2, 3). Local caching of frequently used utterances and templates, together with incremental updates of personal preferences, reduces perceived delay during interaction.

Despite this favorable tooling landscape, several practical obstacles remain for real-time AAC:

- **Latency and Continuity under Degradation:** Heterogeneous inputs (speech, vision, sensors) create contention on resource-constrained devices. Even small delays can disrupt turn-taking. The system must (i) prioritize critical streams (e.g., user speech/gestures) over background updates, (ii) use edge preprocessing and caching to bound end-to-end latency, and (iii) implement smooth, non-disruptive fallback when modalities are missing or low-confidence (e.g., replace camera cues with GPS and recent dialog history; switch to symbol-based prompts when ASR confidence drops). These fallbacks should be confidence-thresholded and reversible to avoid confusing state oscillations.
- **Multimodal Fusion and Adaptive Prioritization:** Real-time ranking across modalities requires balancing semantic relevance, recency, and model confidence. Lightweight fusion architectures and hierarchical pipelines are needed so that the context block can re-rank rapidly when conditions change (e.g., noise spikes, speaker change) without depleting computational resources needed by the communication support block or generating contextually inconsistent suggestions.
- **Personalization vs. Resource Constraints:** Deep personalization improves usability but increases memory and compute footprints. On-device SLMs and distilled models can cover common intents, while cloud LLMs handle rare or complex generations; however, this hybrid approach must manage model selection, caching, and consistency so that user style and safety constraints are preserved across contexts [13]–[16], [20], [21].
- **Privacy, Safety, and Compliance:** Static inputs (medical details, preferences, history) and biometric signals (voice, face) are sensitive. Implementations must adopt privacy-by-design: local processing by default, encryption at rest and in transit, granular consent and data minimization, and auditable logs to meet GDPR obligations [33]; recent EU guidance also tightens restrictions on real-time biometric and emotion recognition, which affects sensor use and model choice [34]. These protections can conflict with cloud offloading, necessitating selective redaction, on-device inference, or federated/partitioned learning.
- **Data Scarcity and Evaluation:** AAC-specific corpora that pair contextual inputs (e.g., location, ambient audio, calendar) with structured outputs (phrases, symbols, style) remain limited, hindering fine-tuning and benchmarking. Synthetic augmentation and few-shot strategies are promising, but their suitability should be carefully examined with end users to avoid bias and mismatches in communicative intent [13], [14], [16], [21]. Clear, scenario-grounded metrics—such as communication speed, selection effort, success rate with communication partners, and subjective workload—are needed to quantify benefits beyond offline accuracy.

Together, these five areas constitute the principal implementation requirements for translating the conceptual framework into a practical AAC system. Addressing them may require efficient edge-first implementations, confidence-aware fallbacks, and privacy-preserving personalization. The framework's modular design provides a structure for considering these issues across its components; for example, the input and context blocks can incorporate latency and failover policies, while the communication support block may use on-device SLMs or cloud LLMs depending on task complexity, user consent, connectivity, and available resources. Further implementation and evaluation are needed to determine the feasibility and importance of these considerations in practice and to identify additional requirements that may emerge.

### D. Limitations and Future Work

Despite proposing a comprehensive framework, several limitations must be acknowledged. First, the framework is primarily expert-informed and has not yet been validated with end users. While insights from communication interpreters provide valuable interactional understanding, they cannot fully substitute the lived experiences, preferences, and adaptive strategies of AAC users. Furthermore, all 20 workshop participants were Finnish communication interpreters. Differences in language, cultural communication norms, and assistive technology practices may limit the transferability of the identified requirements to other settings. Therefore, the framework requires further refinement through direct involvement of AAC users, their families, and other communication partners from diverse linguistic and cultural backgrounds to ensure its practical relevance and usability.

Future research should focus on implementing the proposed framework in multiple stages, beginning with the development of an AAC-specific dataset that captures diverse contexts and user preferences for training and evaluating AI models. Comparative analysis of lightweight and large-scale architectures will help balance efficiency and accuracy. Further work is needed on adaptive context prioritization, privacy through consent and legal compliance, and the integration of explicit and implicit feedback for continuous personalization. Offline functionality using lightweight models should also be explored to support low-connectivity and privacy- sensitive environments. Subsequently, a multimodal user interface should be designed to support intuitive interaction via touch, eye gaze, and gesture, with real-time output in text, speech, symbols, and images. User viewpoint must be addressed by involving end users early in the design process through co-design workshops and iterative prototyping. Future evaluations should use measurable criteria for real-world effectiveness, comparing communication speed with existing AAC systems and using interpreters to assess contextual relevance and semantic appropriateness. Together, these measures can provide a broader assessment of the framework's potential to support more autonomous communication.

## VII. Conclusion

This study presented a flexible framework for the development of context-aware AI-supported AAC systems. Workshop findings with communication interpreters were synthesized into functional requirements centered on guidance in communication situations, clarification of communication-partner input, and support for expressive communication. These requirements informed a modular architecture comprising multimodal input, context definition and prioritization, AI-based communication support, feedback, and output generation. The scenario-based analysis illustrated how the same architecture can be applied across different communication situations while accommodating different combinations of contextual information and communication needs. The study also outlined relevant implementation considerations, including latency and communication continuity, multimodal fusion and context prioritization, personalization and computational resources, privacy and safety, and data availability and evaluation. Together, these contributions provide a conceptual and developer-oriented basis for future implementation and evaluation of context-aware AAC systems.

The proposed framework remains expert-informed and has not yet been validated with AAC users. Future work should therefore focus on implementing the framework and evaluating its feasibility, usability, and communication outcomes with AAC users and communication partners across diverse contexts. Such evaluation will also be necessary to refine the proposed architecture and identify additional requirements and implementation considerations that may emerge in practice.

## Acknowledgment

This work was supported by the Finnish Ministry of Education and Culture's Pilot for Doctoral Programmes (Pilot Project: Mathematics of Sensing, Imaging and Modelling), the Jane and Aatos Erkko Foundation, and the Research Council of Finland through the Flagship of Advanced Mathematics for Sensing, Imaging and Modelling (grant no. 359185).

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