

Designing Integrated Rural Healthcare Systems: Structure Sharing-Based Approach

Renu Tewari¹, Vishal Singh¹, Ansh Ranjan¹

¹Department of Design and Manufacturing, Indian Institute of Science Bangalore, Bengaluru

Abstract: Rural healthcare delivery often relies on Primary Healthcare Centres (PHCs) and Mobile Health Units (MHUs) that operate as parallel systems, resulting in fragmented infrastructure and inefficient resource use. This paper presents a design-oriented approach for integrating these systems through structure sharing. Using functional decomposition and overlap analysis, service redundancies and complementarities between PHCs and MHUs are identified. The study then examines how resources can be co-utilised to support multiple functions. The findings reveal reciprocal infrastructural complementarities: PHCs offer stable spatial infrastructure, staff, and essential amenities, while MHUs provide mobility and flexible service capabilities. Based on these insights, the paper synthesises an integrated healthcare architecture that links PHCs and MHUs into complementary assets rather than independent components of the rural healthcare delivery system (RHDS).

Keywords: Design, Structure Sharing, Rural Healthcare Delivery System

1. Introduction

1.1 Design in complex systems

Design is an iterative activity that brings purposeful change across domains. Whether in architecture, engineering, or organizational systems, design involves the deliberate shaping of artefacts and systems to transform existing undesirable states into preferred ones. Hence, design problems are domain agnostic, i.e., to say that, while the context may vary, the underlying mechanisms to achieve desired outcomes are consistent across fields [1]. Over time, the scope of design has expanded beyond individual artifacts such as physical products, to encompass complex systems composed of multiple interrelated technical, organisational, and human elements [2]. At the systems level, design is widely used to investigate policy questions, for instance, decisions regarding resource management and operational mechanisms, which shape the system's behaviour and thus its performance [3]. Such problems are not only analytical but inherently design-oriented, as they require exploring alternative configurations rather than optimizing a fixed structure. Hence, in a complex system context, design is the blueprint that determines how individual components of a system interact to produce an outcome.

1.2 Sharing as a strategy in design

Within design, the concept of sharing has emerged as a beneficial strategy for making resource-efficient products [4]. In traditional design, every functional element of the product was assigned to its physical element. But in complex systems design consisting of multiple interacting sub-systems, this one-to-one mapping is insufficient in a resource-constrained environment. Hence, advanced design strategies such as structure sharing, multimode integration need to be employed.

1.3 Complex Systems and Sharing in Design

Healthcare delivery systems represent a particularly challenging class of system-level design problems. At the basic level, it often relies on two types of infrastructure, the stationary healthcare facilities (HCFs) such as primary healthcare centres (PHCs) and mobile health units (MHUs). Conventionally, these facilities have been designed and managed as “parallel silos” with their own individual challenges. The existing literature suggests that PHCs are typically constructed with standardised layouts, which limit their flexibility for service expansion, the integration of new technologies, and adaptation to evolving healthcare needs [5]. In contrast, MHUs are constrained by spatial, operational, and logistical limitations inherent in mobile service delivery. Studies highlight challenges related to limited space for clinical functions, dependence on external infrastructure, and constraints in accommodating auxiliary amenities to provide essential ancillary services [6], [7]. These differences in design between PHCs and MHUs influence their functional roles within the broader system and shape the way services are delivered across contexts. It is important to note that, while the PHCs provide a permanent physical footprint for delivering complex care, the MHUs are often viewed as merely “clinic on wheels,” particularly

designed for outreach services. Hence, the current RHDS is merely a fragmented collection of independent units. Even though both units exist in the same space, they do not share a common structural logic, thus exhibiting a linear growth model. In such a model, expanding healthcare coverage requires a 1:1 replication (where increasing coverage requires a proportional increase in physical assets and administrative overhead) of infrastructure, which is economically not viable for vast rural geographies, especially in the Indian context. This fragmentation leads to the functioning of these entities in silos, which results in resource duplication, structural redundancies, and the system fails to cater to the surges in demand. Addressing such a challenge requires interventions in the way these resources are designed and operated at the system level. The current study is an attempt to bridge the gap by applying the sharing in design (SiD) principles to achieve the integrated system architecture of RHDS, consisting of static HCFs and MHUs. This study aims to investigate the potential of design-led principles to synthesise an integrated architecture of the RHDS. This study seeks to demonstrate that a shared architecture between static healthcare facilities can be achieved through the application of SiD principles to the architecture. This shared architecture integrates these two assets to achieve multiple functions in different modes of operation. This study asserts that the integration of the assets is not only an organizational intent but a design outcome to achieve exponential scalability and systemic resource efficiency.

2. Related Work

2.1 Sharing in Design

Over the years, the concept of sharing in design has been applied by many researchers, both consciously and unconsciously, in the design of artifacts. Multifunctional products are a prominent example showcasing the concept of sharing in design. The sharing in design is categorized as structure sharing, function sharing, structure redundancy, and multi-mode integration [4]. Structure sharing happens when one structure performs multiple functions at the same time. Function sharing involves the fulfilment of one function by multiple structures. Multimodal integration means using one structure to fulfil one function or the other at a time; it cannot fulfil both functions simultaneously. Structure redundancy is the fulfilment of one function by one structure or the other. One of the strong implications of the concept of sharing in design is resource efficiency. Lately, the researchers in their studies have strived to develop fundamental methodologies to understand the process of designing such innovative products based on the sharing concept. Chakrabarty et al., in their study, gave a thorough explanation of the function and structure [8]. The author further gave a detailed methodology to assess the degree of structure sharing and resource effectiveness. The author further evaluated the effectiveness of the method through evaluation with some master's level students, inexperienced designers, and experienced designers. Apart from the product level, the concept of sharing in design has been successful across multiple domains. The concept of sharing in design is evident in the reversible, optional transformation of private assets into shared service resources, a service design adopted by Airbnb. In this, property owners retain the full ownership of the private asset and may dynamically choose between private residential and rental provision. Similar principles are noticeable in car-sharing platforms, where privately owned vehicles are temporarily converted into shared mobility resources; in co-working spaces, where office infrastructure is shared among multiple users with varying access arrangements; and in peer-to-peer equipment rental systems, where underutilized tools, machinery, or appliances are made available to others without completely transferring ownership. In each case, the underlying structure remains privately owned but can be selectively integrated into a broader service network according to user preferences and contextual needs. The design not only enables situation-based participation in the sharing economy but also allows users to switch roles between occupants and service providers. Such structure flexibility leads to a distributed design where individual actors actively shape service parameters, access conditions, and experiential outcomes, thereby co-creating system value.

2.2 Fixed and Mobile Healthcare Facilities in RHDS

In India, rural HCFs such as primary health centres (PHCs) represent the backbone of fixed healthcare infrastructure, serving as fixed permanent assets for basic outpatient service delivery and referrals. These facilities are ubiquitous networks, and their strength lies in continuity of care and availability of stable resources. Despite the pivotal role, the PHCs face significant challenges primarily revolving around two key aspects: Infrastructure and human resources. [5]. Apart from a deficiency in infrastructure and human resources, PHCs in rural India also often struggle with obsolescence and inadequacies, including understaffing, poor maintenance and upgrades, technology obsolescence, and lack of design flexibility and adaptability to changing spatial and service requirements [9] [10].

Mobile Health Units (MHUs) have emerged as a complementary approach to address accessibility gaps by bringing healthcare services closer to population that are geographically distant from fixed facilities or where fixed facilities are not present. MHUs are typically designed to provide periodic outreach services, conduct medical camps, or deliver targeted services. Still, MHUs suffer from the high cost of transportation and frequent relocation, staffing issues, lack of auxiliary functions like waiting areas and toilets, and so on [11], [12]. Additional operational challenges can come from poor road conditions, doctors and staff unwilling to travel daily, and a high workload [13]. Reportedly, MHU operations are also susceptible to inadequate funds for operation, interrupted supply of drugs, and routing inefficiencies [6], [7], [14]. One of the main operational disadvantages of the Mobile Health Units is the lack of continuous care for patients by medical personnel, which is why they cannot replace the fixed/permanent structures. Altogether, these studies have questioned the quality of care they provide, which is compromised. It also means that there is an opportunity to transform these MHUs from useful to adequate models by making them an integral part of the system. While MHUs enhance coverage and flexibility, they are often operated as standalone solutions, with limited interaction with fixed facilities. As a result, their deployment may be reactive, inefficient, or underutilized, and their integration into RHDS remains weak at present.

Existing approaches thus tend to treat fixed and mobile healthcare facilities as parallel solutions rather than as components of an integrated RHDS. Such a view limits the potential benefits of improved utilization of these two units through coordination and sharing. This highlights the importance of examining how these sub-systems can be integrated as part of a broader system design.



Figure 1. (a) Primary healthcare centre, (b) mobile medical units

By exploring the concept of Sharing in Design (SiD) holistically, this research aims to investigate the potential contribution of the implementation of structure sharing, one type of sharing in design, to the architectural design of Rural Healthcare Delivery Systems (RHDS) with special focus on linking static HCFs and MHUs into an interlinked service system. While the contribution of structure sharing has been significantly recognised for its significant impact on the improvement of resource efficiency through the elimination of redundancy in product-service systems, this research extends the opportunity to leverage the concept of SiD into another product-service system, which is RHDS. We hypothesize that integrating sharing principles at the design level may lead to improved performance and capacity of RHDS.

3. Methodology

The methodology consists of four sequential stages as follows:

3.1 Functional Decomposition

First, the two systems were decomposed using the Function-Behaviour-Structure ontology of design [15]. FBS framework systematic decomposition of complex systems into teleological intent (functions), measurable attributes (behaviours), and structures that exhibit the behaviours. For each system, core functions were first identified, followed by the corresponding behaviours through which these functions are realised, and the structural configurations that enable such behaviours. This decomposition allowed us to move away from viewing both the facilities merely as physical assets to functional carriers. This resulted in two formal system representations of PHCs (F_a, B_a, S_a) and MHUs (F_b, B_b, S_b), where F denotes functions, B denotes behaviours, and S denotes structures.

3.2 Functional Overlap Analysis

In the second stage, a functional overlap matrix is constructed to compare the functional capabilities of PHCs and MHUs. Functions are classified into two categories: complementary functions and asymmetric functions. The functional overlap matrix enabled the identification of potential redundancies in both systems.

3.3 Identification of Sharing Opportunities

Structural sharing opportunities are identified by analysing which functions can co-utilise the same infrastructure and resources. The FBS-based representations of PHCs and MHUs are examined to identify resources that can be co-utilised, forming the basis for the synthesis of the integrated architecture.

3.4 Integrated Architecture design

Building upon the identified shareable structures, an integrated healthcare service delivery architecture is synthesised.

4. Results

4.1 Functional Decomposition

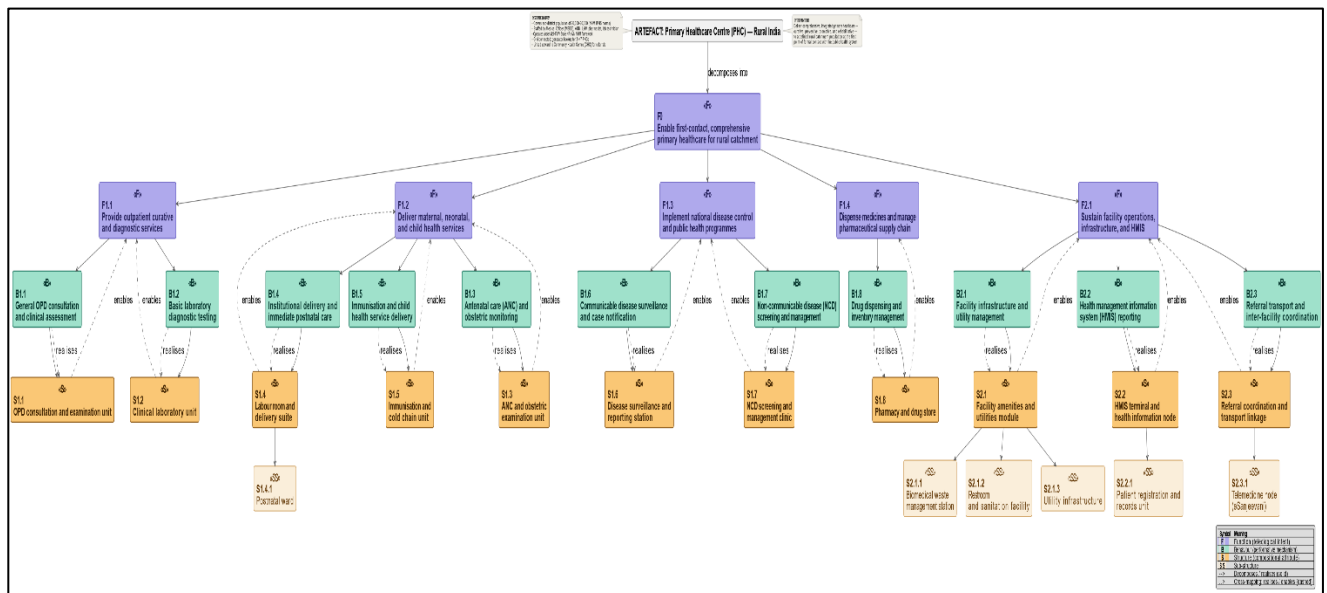


Figure 2. FBS tree of the primary healthcare centre

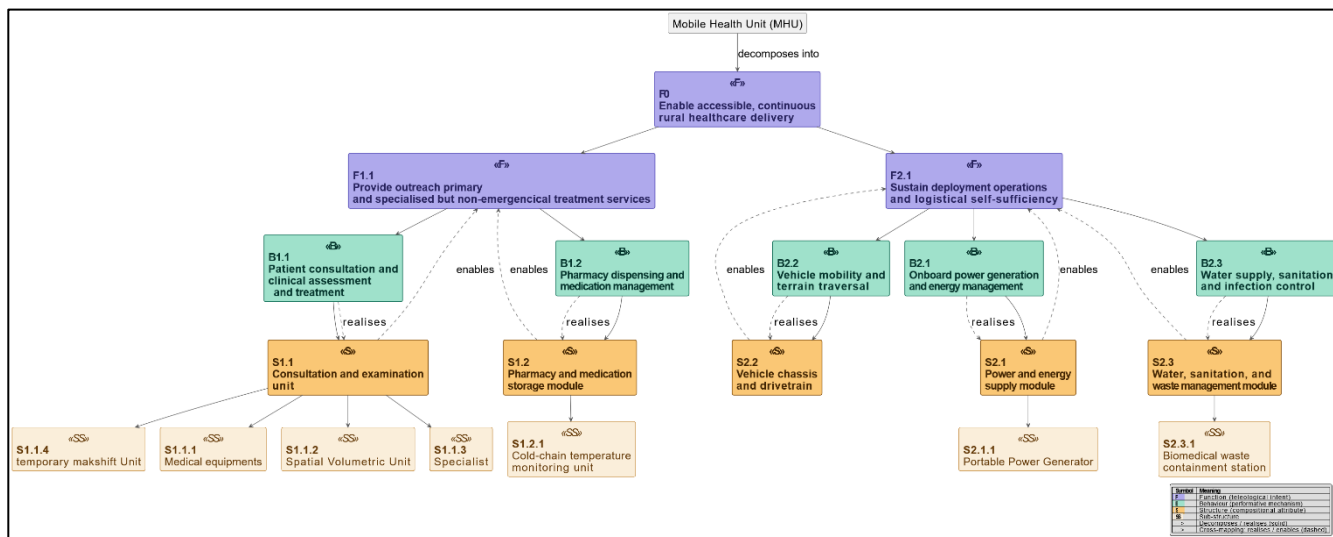


Figure 3. FBS tree of Mobile Health Units

Figure 1 and 2 represents the function-behaviour-structure tree of PHCs and MHUs, respectively. Identified core functions are mapped to the behaviours that enable these functions, and behaviours are mapped to the structures that realise these behaviours.

4.1 Functional Overlap Analysis

Functional decomposition of PHCs and MHUs, as shown in Figures 1 and 2, revealed substantial complementarity and asymmetry across some functional domains, which indicated significant potential for resource sharing as shown in Table 1. Core functions such as registration consultation, diagnostics, and pharma dispensing demonstrate complementary overlap where both systems contribute, but with different infrastructure capabilities and mechanisms. In contrast, specialised but non-emergency services such as dental and ophthalmology care are asymmetrically distributed, typically provided by MHUs but absent in many PHCs. This overlap analysis establishes the foundation for identifying integration opportunities by highlighting areas of complementarity and service gaps across fixed and mobile healthcare units.

Table 1. Functional Overlap and Shared Structure Mapping

Function Domain	PHCs	MHUs	Type of Relationship	Shared Resource
Sustain Facility operations, infrastructure	Yes	Yes	Complementary	Shared IT infrastructure and amenities, human resources
OPD Consultation and diagnosis	Yes	Yes	Complementary	Shared room/staff
Laboratory diagnostics	Yes	Yes	Complementary	Shared lab/equipment, staff
Drug dispensing	Yes	Yes	Complementary	Shared counter, staff
Dental care, ophthalmological care	No	Yes	Asymmetry	Shared service
Permanent facility amenities such as a restroom, waiting unit	Yes	No	Asymmetry	Shared waiting space, shared restroom

Geographic mobility and last-mile outreach	No	Yes	Asymmetry	Shared MHUs
--	----	-----	-----------	-------------

4.2 Identification of Structure-Sharing Opportunities

On the basis of functional overlap analysis, structural sharing opportunities are identified across PHCs and MHUs by examining which functional domains can co-utilise physical and organisational resources. Analysis of the FBS-based representations of PHCs and MHUs indicates that several infrastructural elements can be shared between the two systems. For instance, PHCs provide stable amenities and fixed infrastructure, including consultation rooms, waiting areas, restrooms, pharmacy storage, and information systems, utilities, which can support MHU operations when deployed to dock with PHCs. Conversely, MHUs contribute to mobile specialized service capabilities, outreach infrastructure, and flexible deployment mechanisms that may be limited or absent in certain PHCs. Hence, PHCs compensate for infrastructural constraints of MHUs (i.e., auxiliary amenities, utilities, etc.) while MHUs compensate for service limitations of PHCs (i.e., specialised but non-emergency service delivery), thus revealing infrastructure complementarities. This forms the basis for a shared structural platform in which infrastructure is co-utilised by static healthcare facilities and mobile health units to enhance resource efficiency.

4.3 Structure-Sharing Coupling Logic

To operationalise the identified structure sharing opportunities, the FBS representation of PHCs and MHUs was comparatively analysed. Functions were mapped across both systems to identify their presence, type of relationship (complementary or asymmetric), and corresponding opportunities for shared structural realisation, as summarised in Table 1. PHC and MHU functions such as registration, consultation, diagnostics, pharmacy dispensing, specialised service provision converged on a shared infrastructure, including registration counters, consultation rooms, clinical staff, lab equipment, mobile diagnostic units, pharmacy storage, waiting areas, and restrooms. This mapping explicitly links each function to the structures that enable it, forming the analytical basis for integration architecture synthesis.

4.4 Integrated Architecture Synthesis

Building upon the identified structural sharing opportunities, an integrated healthcare architecture is synthesised as shown in Figure 3. The proposed architecture consolidates co-utilizable structures into a coordinated system in which PHCs and MHUs have a symbiotic relationship and function as interdependent nodes within a shared structural platform. In this configuration, PHCs function as stable infrastructural anchors, providing essential amenities, utilities, and human resources while MHUs operate as mobile, flexible extensions extending outreach and specialised service capabilities. This arrangement is analogous to a desktop computer architecture, where the core system unit provides foundational processing and stability, and additional hardware components, such as external storage drives, can be attached modularly to expand functionality without altering the core structure. Similarly, MHUs are not a replacement for the PHC infrastructure, rather extensions to their operational reach through a plug-in architecture. This architecture demonstrates how reciprocal structural integration between fixed and mobile healthcare infrastructures can improve service coverage, scalability, and adaptive deployment in rural contexts. This synthesis, therefore, moves beyond the idea of the co-location of the two infrastructures and, instead, proposes a coordinated system-level design approach driven by the concept of structural sharing. The integrated architecture further supports multiple modes of sharing, including direct PHC–MHU structure sharing, inter-PHC coordination facilitated by MHUs. These design features adaptable integration model capable of responding to diverse rural healthcare contexts.

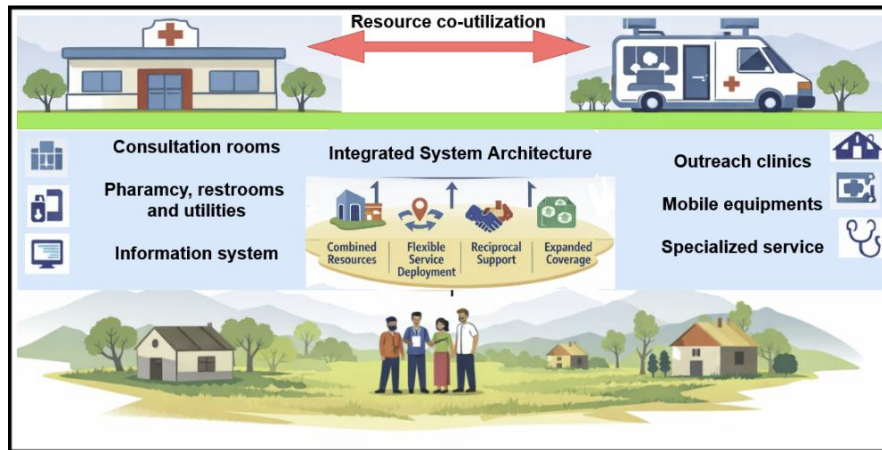


Figure 4. Integrated architecture consisting of PHCs and MHUs

5. Discussion and Implications

This study reframes the relationship between PHCs and MHUs from parallel service providing assets to complementary units. Instead of treating PHCs as fixed service assets and MHUs as temporary substitutes, this study suggests that both systems possess complementary infrastructural strengths that can be strategically integrated. PHCs provide stable physical infrastructure and essential amenities, while MHUs offer mobility and flexible service delivery. When these strengths are coordinated through structural sharing, service redundancy can be reduced, and coverage can be expanded. The findings suggest that integration should focus on the co-utilization of infrastructure rather than the duplication of facilities to address rural healthcare gaps. By analysing functional overlap before infrastructure planning, decision-makers can identify where resources can be shared. This approach also shifts the focus from infrastructure expansion to infrastructure optimisation. For designers and planners, the results highlight the importance of mapping functional overlap before proposing new infrastructure. The proposed shared structural platform offers a practical design framework for improving resource efficiency and healthcare access in rural settings. For policymakers, this means investing in coordination mechanisms and resource-sharing strategies instead of building parallel systems. Overall, the study contributes a practical and scalable framework for strengthening rural healthcare delivery through reciprocal infrastructural integration through principles of sharing in design.

6. Limitations and Future Work

This current study primarily focused on conceptual design synthesis and does not include quantitative evaluation of operational performance or clinical outcomes because of the integrated architecture. While the proposed integration architecture is analytically derived, empirical validation through simulation modelling, pilot implementation, and field-based evaluation remains a critical area for future research. Additionally, the analysis is limited to functional and structural dimensions and does not explicitly account for behavioural and socio-cultural factors that may influence real-world adoption.

7. Conclusions

This paper demonstrates how structural sharing between PHCs and MHUs can enable integrated rural healthcare delivery. By identifying functional overlaps and analysing co-utilisable infrastructure, the study synthesises an integration architecture based on reciprocal resource support rather than hierarchical attachment. The proposed shared structural platform improves infrastructure utilisation and supports scalable deployment. The findings provide a clear design-oriented framework for strengthening rural healthcare systems through coordinated structural integration.

References:

- [1] U. Kannengiesser and J. S. Gero, "Is designing independent of domain ? Comparing models of engineering, software, and service design," *Res. Eng. Des.*, vol. 26, no. 3, pp. 253–275, 2015, doi: 10.1007/s00163-015-0195-y.
- [2] L. Moreau and B. Bollmann, "The expanding scope of design Conversation : The expanding scope of design," pp. 23–28, 2024.
- [3] A. Meijer, "Applying design science in public policy and administration research," *Policy Polit.*, vol. 48, no. 1, pp. 149–165, 2019.
- [4] A. Chakrabarti, "Sharing in design-categories, importance, and issues," in *International Conference on Engineering Design (ICED)*, 2001, pp. 21–23.
- [5] A. Mustafa and C. Shekhar, "Is quality and availability of facilities at Primary Health Centers (PHCs) associated with healthcare-seeking from PHCs in rural India: An exploratory cross-sectional analysis," *Clin. Epidemiol. Glob. Heal.*, vol. 9, pp. 293–298, Jan. 2021, doi: 10.1016/j.cegh.2020.10.001.
- [6] S. Abbasi, H. Mohajer, and R. Samouei, "Investigation of mobile clinics and their challenges," *Int. J. Heal. Syst. Disaster Manag.*, vol. 4, pp. 1–5, 2016, doi: 10.4103/2347-9019.175669.
- [7] A. B. Khanna and S. A. Narula, "Mobile Medical Units—Can They Improve the Quality of Health Services in Developing Countries?" *J. Health Manag.*, vol. 19, no. 3, pp. 508–521, 2017, doi: 10.1177/0972063417717900.
- [8] A. Chakrabarti and V. Singh, "A method for structure sharing to enhance resource effectiveness," *J. Eng. Des.*, vol. DS 35, no. 1, pp. 73–91, 2007.
- [9] S. Sriram, "Availability of infrastructure and manpower for primary health centers in a district in Andhra Pradesh, India," *J. Fam. Med. Prim. Care*, vol. 7, pp. 1256–62, 2018, doi: 10.4103/jfmpe.jfmpe.
- [10] M. Taqi, S. Bidhuri, S. Sarkar, W. S. Ahmad, and P. Wangchok, "Rural Healthcare Infrastructural Disparities in India: a Critical Analysis of Availability and Accessibility," *J. Multidiscip. Res. Healthc.*, vol. 3, no. 2, pp. 125–149, 2017, doi: 10.15415/jmrh.2017.32011.
- [11] S. Chanda *et al.*, "The Design, Operations, and Feasibility of Primary Healthcare Service Delivery through Mobile Medical Units: A Way for Equitable Health Access and Achieving Universal Health Coverage in Low Resource Settings Running Title: Mobile Medical Units for UHC," *Int. J. Heal. Syst. Implement. Res.*, vol. 3, no. 2, pp. 40–47, 2019.
- [12] Government of Odisha (GoO), "Mobile Health Unit and Primary Health Delivery System under RLTA in KBK Districts (An Evaluation Study)," 2007. [Online]. Available: https://pc.odisha.gov.in/sites/default/files/2020-03/MHU_Final_Report.pdf
- [13] U. Dash, V. R. Muraleedharan, B. M. Prasad, D. Acharya, S. Dash, and S. Lakshminarasimhan, "Access to health services in underprivileged areas: A case study of Mobile Health Units in Tamil Nadu and Orissa," *SSRN Electron. J.*, 2008.
- [14] A. B. Khanna and S. A. Narula, "Mobile health units: Mobilizing healthcare to reach unreachable," *Int. J. Healthc. Manag.*, vol. 9, no. 1, pp. 58–66, 2016, doi: 10.1080/20479700.2015.1101915.
- [15] J. S. Gero, "Design prototypes : A knowledge-based schema for design," *AI Mag.*, vol. 11, no. 4, pp. 26–36, 1990.