iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** II **Month of publication:** February 2026

DOI: https://doi.org/10.22214/ijraset.2026.77758

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue II Feb 2026- Available at www.ijraset.com

Design an Application Model using Micro-Frontends for Search Engine Optimization

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Abstract: ***Web application is the pivotal component of web development. With the growth of web applications, frontend architectures have shifted from monolithic model to micro-frontend. While micro-frontends offer independent deployment, flexibility, adaptability, extensibility, they introduce major challenges in Search Engine Optimization. Micro-frontends work on client side rendering, it uses java script frameworks and decentralized evolved teams which can negatively impact indexing, SERP ranking and page performance. In this review paper analyze the existing micro-frontend approaches and reviews best technique for improving SEO in micro frontend systems. In this study we focus on techniques such as Single- SPA integration, Server Side Rendering, Web components, I- Frames, Shared event bus, Varnish Cache and Black box react components. Existing research on micro-frontends focus on the comparatively analysis and practical implications in web development.***
Keywords: Micro-frontend Architecture, SEO (website) ranking, User Experience, Frontend Architecture, Comparative Analysis, SEO performance.

I. INTRODUCTION

Web Development has rapid evolution, shifting from static pages to dynamic and modular applications. With the development of single page applications and micro services on the backend, in the modern system mostly architecture support the independent development, deployment. Micro frontends is the best solution for the frontend. They enables to break large monolithic frontends into smaller independent units.

In adopting of micro frontends the primary challenge is to balancing modularity and performance. It extend the micro services to frontend layer, it allow the application into smaller parts and deployment frontend module. While these approach helps to improve the scalability. SEO it plays an important role in the success and visibility of modern way of web applications. In the previous time we use monolithic frontend architecture it allowed centralized control system over it allowed centralized control system over the HTML structure, routing, metadata and making SEO implementation straightforward. With the development of micro services, all frontend systems uses the micro-frontends. Micro-frontend architecture it is a modern technique to develop the web applications it helps and architectural patterns that help to balance the modular development of micro-frontend with SEO requirement.

II. TYPES OF MICROFRONTEND APPROACHES:

1) Single-SPA (Meta Framework): Single –SPA acts like as a container to carefully plan and design a project with multiple micro-frontends. It helps to manage the routing events while allowing the different frameworks to coexist. It helps to blend various framework on one page. It uses the frameworks like React, Angular, exist at the same time or place melodiously on a single page , it also help to maintain the user experience.

2) Multiple Single Page Applications with Distinct URLs: In this approach, each and every micro-frontend is able to operate independently of other hardware or software SPA with its own URL. In the place of monolithic application, this approach helps to develop separate Single Page Application. With the segmenting application into SPA, it helps in the sharing of components and it also managing the states.

3) I-Frames with postMessage API: Micro-frontends are embedded as –Frames and communicate by using browser messaging APIs. It has the capabilities of encapsulation of I-frames. In this approach data passed between main window and I-Frames. It has the methodology to balance the blend of integration and isolation. It offers a solution for building a scalable and modular and interactive web application

4) Web Components**:** Micro-frontends are implemented as standardized web components using custom elements and shadow DOM. It uses the elements which is defined by developers, it extend the HTML vocabulary, is also crate the tags and components for specific application needs.

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5) Caching Based Integration (Varnish Cache): A reverse proxy cache comprises content from micro-frontends and provides optimized responses. In this client directly request to the micro-frontends. It stored the existing data and reduces the load of the backend systems. It enhances the performance and achieves faster load times for micro-frontends.

6) Black-box React Components**:** It focus on the encapsulation and design with the help of React frame-work. This approach involves the development of React components is intentionally black-boxed. In this approach, the internal work is hidden from the broader application. The methodology of this approach is data management.

7) Shared Event Bus Architecture: Micro-frontends communicate through a shared event bus for exchange the data and synchronize the data. It is a type of communication hub (share the data without direct coupling).

III. LITERATURE SURVEY

This literature survey consists of existing literature on real time dashboards and empirical studies to understand the current research in this field.

Table 1: Analysis of research papers

S NO.	Author Names	Title	Journal/ Conference Details	Methodology	Findings	Limitation
1	Niles Savani	The future of Web Development : An In-depth analysis of Micro-frontend approaches.	Journal – International Journal of Computer Trends and Technology. Volume-7 Issue-1 Year-2023	A comparative analysis of various micro-frontend implementation methodologies, evaluate their conceptual framework and practical implications.	Different micro-frontend approaches provide clear advantages and challenges.	The paper lacks experimental testing or performance evaluation of the compared micro-frontend methodologies.
2	Davide Taibi & Luca Mezzalira	Micro-Frontends: Principles, Implementation And Pitfalls	Journal-International Journal of Advanced Research in science , Communication and Technology Volume-7 Issue- 47 Year-2022	The paper uses a illustrative and experience based review of micro-frontend principles, implementation approaches, and lessons learned.	The study finds that micro-frontends allow independent teams and scalability but increase complexity, require strong governance.	The paper is limited because it is not real and plan mainly on practical knowledge, lack of quantitative evaluation and comparative performance data.
3	Neha Kaushik & Harish Kumar	Micro Frontend based performance improvement and prediction for micro services using machine learning	Journal- Journal of Grid computing.. Volume-22 Issue-2 Year-2024	They design a new framework combining micro-frontends with backend micro services and build a machine learning model to predict performance.	Using micro-frontends improves throughput over monolithic front-ends and their ML model can predict micro service performance with good accuracy.	The study is actual but limited to the scenarios they test and may not generalize to all micro-frontend/ micro service setups.
4	Kenning Arlitsch, Patrick Obrien & Brian Rossmann	Managing Search Engine Optimization: An Introduction for library Administrators	Journal- Journal of library Administration. Volume-11 Issue-4 Year-2013	The paper uses a conceptual, descriptive approach, explaining SEO practices for libraries through literature, examples, and strategies guidance.	It finds that effective SEO significantly increases the visibility and use of digital library collections and requires organization wide strategies alignment.	The paper is limited because it does not present seen experiments or quantitative analysis, relying instead and prior experience.

5	Sungin Lee	Understanding Search engine optimization	Journal- Journal library Hi Tech Volume-34 Issue-2 Year-2016	The paper uses a descriptive, literature based review to explain SEO concepts, practices and factors influencing search ranking.	It finds that SEO effectiveness relies on optimizing content, keywords, site structure impact search engine optimization	The study is limited because it does not include empirical experiments or data analysis and secondary information.
6	Ahamad salah Alahad & Hasan kahtan	Evaluating generative AI for HTML Development	Journal- Journal of computer technologies. Volume-13 Issue-10 Year-2025	The paper uses HTML code for predefined tasks and assessing it across dimensions.	It finds that AI-generate HTML can achieve high validation scores.	The study is limited because it focus on static HTML markup and excluded CSS styling and JavaScript.
7	Krishnaprasad Awala	Comparing the performance of Flutter and ReactJS for Web Development	Journal- International Journal of Advanced Research in science communication and technology Volume-3 Issue-2 Year-2023	The study involve evaluating the performance of flutter and Reactjs across various parameters.	Flutter offers high performance compiles to native code and provides consistent UI, while ReactJS relies on JavaScript.	The study might be limited by the rapidly evolving nature of these frameworks.
8	Malviya Saurabh Rangaro & Prof.Vijaya Tulsani	Web3 Technology: The New Beginning	Journal- Research in applied Science and Engineering technology. Volume-11 Issues-4 Year-2023	The study likely involved analyzing the core components of web3, including block chain and their applications.	Web3 has the potential to give users more control over their data, identity and digital assets.	The technology is still developing and widespread adoption may take time with regulatory clarify.
9	Juho Vepsalainen & Arto hellas	The Rise of Disappearing Frameworks in Web Development	Journal- International Conference on Web Engineering Volume-13 Issue-3 Year-2023	The study involves a technical review of frameworks that comply with the definition of disappearing frameworks.	The frameworks rely heavily on code generator regularly support progressive enhancement and accessibility.	The study focused on frameworks under active development and additional research is needed to understand their performance.
10	O.M. Nikulina & K.O.Khatska	Method of Converting the Monolithic Architecture of a Front-end Application to Micro-frontends	Journal- Bulletin of National Technical University Volume-10 Issue-2 Year-2023	The study proposes a three stage method for transforming monolithic single-page application to micro-frontends.	The approach enables gradual migration to micro-frontends, reducing risks.	The method effectiveness depends on the complexity o f the existing monolithic application
11	Prianka RR & Vedaraj m & Anto Arockia Rosaline	Graph Convolution Networks for SEO	Journal- The Institution of Engineers 2025 Volume-106 Issue-1 Year- 2025	The study uses a graph involved the network with healthcare data and uses search queries to build a knowledge graph and rank search results more accurately.	The proposed method gives better search results than traditional SEO methods	The method needs high computing resource and has privacy and scalability issues because it uses large and sensitive healthcare data.
12	Touhidul Alam Seyam & Abhijit Pathak	AgriScan: Next.js powered cross platform solution for automated plant diseases diagnosis and crop health management	Journal- Journal of Electrical System and Info. Technology Volume-11 Issue-45 Year-2024	The study uses a CNN-based deep learning model trained on plant leaf images and arranged it in a Next.js and flask app to detect crop diseases.	The system accurately detects 46 plant diseases across 16 crops with an overall accuracy of about 93.45%.	The model's performance can be affected by poor image quality, lighting conditions, and device or network limitations.

13	Mohamed D. almadhoun & Nurul Hashimah Ahamed & Hassain Malim	Effect of using multi-category web pages on rank estimation of Google Search engine result page	Journal- Web Intelligence 2025, Volume-23, Issue-1, Year-2025	Collected and compared Google ranking of single category vs. multi-category web pages using selected keywords.	Multi-category pages generally rank lower due to reduced topic relevance but perform well if well-structured.	Results vary with changing Google algorithms, limited keywords, and narrow sample scope.
14	Abdullah Sulayfani & Sukru Eraslan & Yellz Yesilada	Predicting eye-tracking assisted web page segmentation	Journal- Multimedia Tools and Application Volume-84 Year-2024 Page-26293-26330	The study uses supervised ML models trained on VIPS- based web page features and eye tracking derived ground truth labels to predict web page segmentation without using eye-tracking data	Among all tester models, the KNN algorithm performed best, achieving an F1 score of 78.74% in predicting eye-tracking assisted segmentation	The model is trained on a small dataset, which may limit its external validity to diverse and more complex websites
15	Hadia Showkar & Muhammad Suhaib Kangroo & Kapil Rana	Robust page object detection network for heterogeneous document images	Journal- International Journal on Document Analysis and Recognition Volume-28, Issue-2 Year-2024	The paper proposes LR-PODNET, a lightweight YOLOv5- based network enhanced with a global attention block and hybrid dilated ASPP block to detect page objects from heterogeneous document images.	The proposed model outperforms existing methods, reach 77.5% Map 0.5:0.95 on IIT-AR-13K while using significantly fewer parameters.	The model relies only on visual features and struggles in cases where textual context or closely packed similar objects are required for precise object separation.
16	Ali A. Alan & Adi AI Azzawi	Optimizing web page retrieval performance with advanced query expansion leveraging Chatgpt and metadata driven analysis	Journal- Journal of Supercomputing Volume-81 Year-2025 Page-569	The study proposed a Google custom search based retrieval framework that uses Chatgpt for interactive and automatic query expansion and re-ranks results using cosine similarity and word mover's distance on metadata	The proposed approach significantly improves search relevance and accuracy compared to Google page-rank and Bing ranking methods	The system depends on external APIs and metadata quality and its performance may degrade for highly domain-specific or low metadata web pages.
17	Wenjing ou Peiyan chang & Jinghua zhou	The application of quality control circle in improving the accuracy of ICD coding on medical records	Journal- BMC Health Service Research Volume-25 Article no.-769 Year-2025	The study used a retrospective pre and post intervention design applying quality control circle tools based on the PDCA cycle to compare ICD coding error rates before and after implementation	Implementation of QCC significantly reduced the overall ICD coding error rate from 7.02% to 2.90% while improving both coding accuracy and staff problem solving skills.	The study was conducted in a single hospital with short term follow-up limiting external validity and long term sustainability assessment
18	Anapurna Sharma & Rohit Katla & Gurleen Kaur	Full page handwriting recognition and automated essay scoring for in the wild essay	Journal- Multimedia tools and Application Volume-83 Year-2023	The study uses a CNN-LSTM based full page handwriting recognition model combined with automated Essay scoring using handcrafted features and BET embedding in a regression framework.	Results show that even with handwriting recognition errors, automated essay scoring performance drops only slightly and remains close to human grading	The system is evaluated on a relatively small subset of in the wild handwritten essays and still high OCR error rates compared to constrained datasets.

19	Hwajun Kim	Learning based page replacement scheme for efficient i/o processing	Journal-Seoul national university of science and technology Volume-15 Article no -88736 Year-2021	The study propose a deep learning based predictive framework using features extraction and supervised machine learning models to analyze and classified complex data patterns.	Experimental results demonstrate that the proposed model outperforms existing methods in accuracy and prediction reliability.	The approach is validated on a limited dataset and lacks real time or large scale deployment evaluation which may affect external validity.
20	Firas Almukhtar & Nawzad mahmood & Shahab Kareem	Search Engine Optimization	Journal-Applied computer science Volume-1 Year-2025	Review existing literature an industry sources to analyze common on-page SEO technique and ranking factors	Identified that quality content, keyword optimization and technical SEO significantly influence search engine optimization.	Review depends on secondary data and may become outdated due to continuously changing search engine algorithms.
21	K R Laithal & Prof.Tripursundari	Adoption of Local Search Engine Optimization among small scale Entrepreneur in Chennai thematic Qualitative analysis of expert insights	Journal- Journal of Information System Engineering and Management Volume-10 Year-2025	Conducted semi-structured interviews with 25 SEO experts in Chennai and analyzed then using Braun & Clarke's six- phase thematic analysis.	Experts identified key adoption barriers like cost and misconceptions among entrepreneurs and emphasized local SEO strategies.	Based only on expert perspectives rather than direct interview with the small business owners themselves

IV. DIAGRAM: SEO FRONTEND ARCHITECTURE

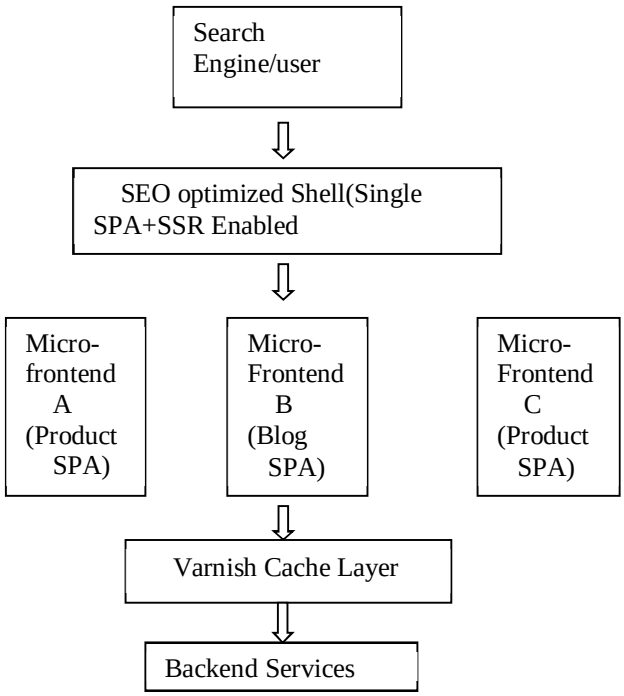


Fig.1 SEO frontend architecture

V. PREVIOUS WORK

Micro-frontends helps to improve scalability and maintainability but often degrade SEO when implemented as pure client-side SPAs. Server-Side Rendering, it improves indexing for JavaScript – heavy applications. Centralized routing and metadata management are critical for maintaining SEO consistency. Performance optimization techniques such as code splitting and caching positively impact on search engine rankings. Web components offer a promising future for SEO – safe, reusable frontend modules when content visibility is present.

VI. PROPOSED WORK

1) Firstly, selection of micro-frontend approaches: Single SPA, Multiple SPAs with distinct URLs, I- Frames based micro-frontend,
Web components.
2) Evaluate the parameters of SEO: Page load time, first input delay, URL structure, Server side rendering support.
3) Implement the same content into different- different micro-frontend approaches.
4) Ranking of the model in SEO.
5) Identify the best micro-frontend approach for SEO- Optimization.

VII. RESEARCH GAP

Although many studies have explored the use of micro-frontend For the data visualization and for the website development. Existing research explains individual micro-frontend approaches but there is lack of comparison of all major methodologies and most studies do not asses real world factor such as load time, Security implications, runtime integration issues.
Lack of SEO oriented model which can define that which is the best approach for SEO. Micro-frontend are becoming popular for improving modularity, scalability, and independent deployment of web applications, there is limited research which can focus on the Search Engine Optimization

VIII. CONCLUSION

Micro-frontend architecture is effective for the scalability, maintainability, without the SEO-optimization the performance of search engine can suffer. Existing research provides an comparison architectural, but not give any structured framework for SEO ranking. Proposed research fill this gap by introducing an SEO based comparative ranking model which helps the developer to take decision about which micro-frontend approach is best or suitable for search engine visibility and ranking. The outcome of this study helps in SEO –optimized distributed frontend system is helpful for design real world application.

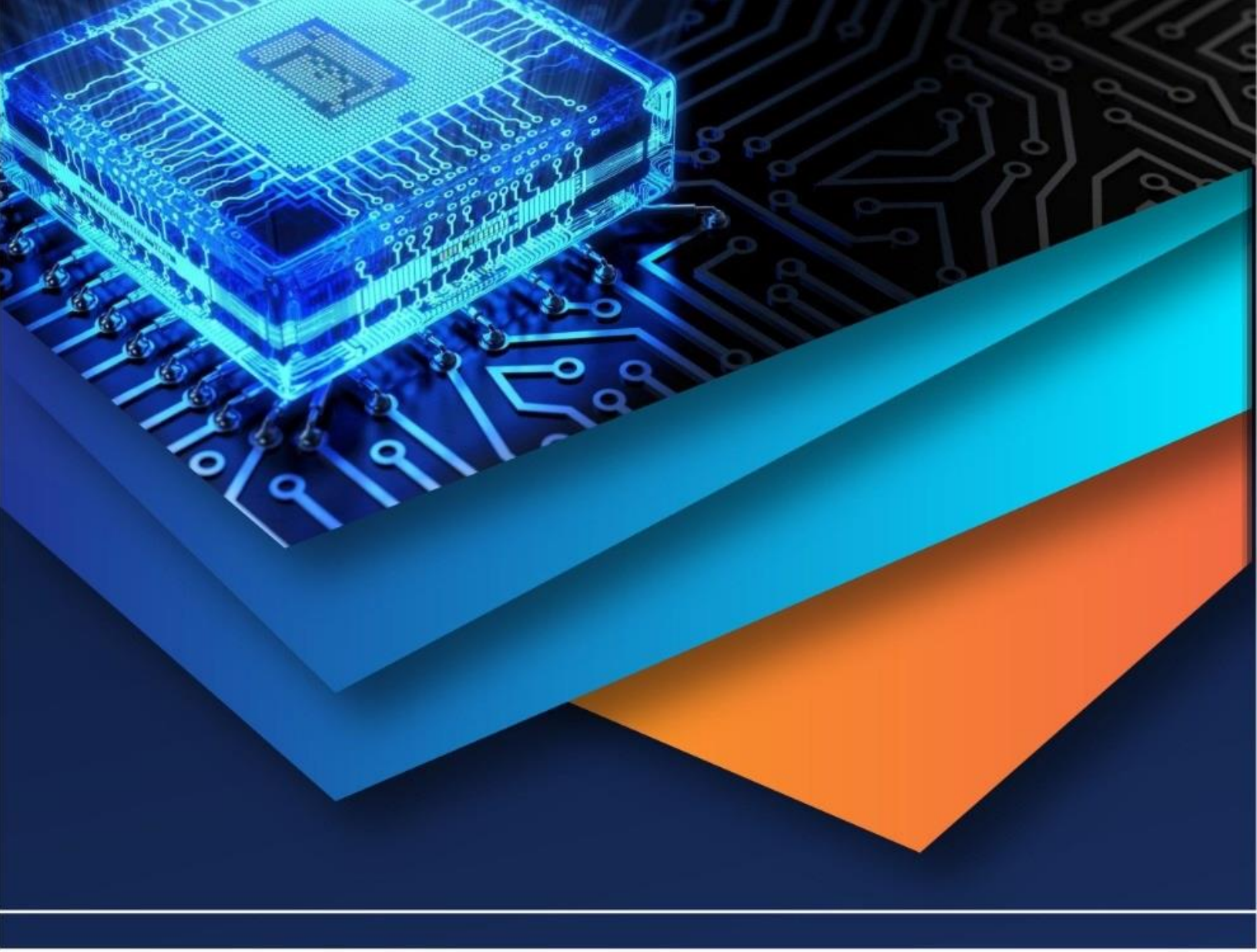
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