

WhatWood? Ghana Edition: Enhancing a Wood Identification Field Manual with Smartphone Functionality

Kyatt Spessert Frank C. Owens Adriana Costa
Alberta Asi Ebeheakey Alex C. Wiedenhoef

Abstract

In the late 2010s, the Timber Industry Development Division (TIDD) of the Ghana Forestry Commission sought to acquire International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 17020:2012 accreditation. To meet the standard's requirements, the TIDD, in cooperation with the US Department of Agriculture Forest Products Laboratory, published a standardized wood identification field manual entitled *Field Identification Manual for Ghanaian Timbers*. To increase the accessibility and utility of this resource for inspectors in the field, this study transformed the printed manual into a smartphone application called *WhatWood? Ghana Edition*. The app was built with Microsoft's .NET Multi-platform App UI (.NET MAUI) framework in Visual Studio 2022 and is freely available on Android, iOS, and macOS. Ergonomic improvements over the source publication include display optimization to fit smartphone screens, adjustable font sizes, zooming and panning of images, and a colorblind mode. Automating dichotomous key-decision routing and navigation from terminal decisions to species pages has eliminated the need to manually flip pages. *WhatWood? Ghana Edition* is also the first smartphone app with a national scope equipped with wood feature identification quizzes. As an app, the manual has increased utility and accessibility over the original publication by adding smartphone functionality while maintaining the original content and methods that fulfilled ISO/IEC accreditation requirements.

Illegal logging is one of the leading contributors to forest loss and degradation in Ghana (Hansen and Treue 2008, Appiah et al. 2009, Marfo 2010, Osei-Tutu et al. 2010, Boaky 2015, Acheampong et al. 2019, Poku et al. 2024, Global Forest Watch 2025). In the interest of maintaining access to export markets that demand evidence of due diligence in wood material sourcing, Ghana has introduced various initiatives, including a Voluntary Partnership Agreement with the European Union to ensure timber legality throughout the supply chain (Beeko and Arts 2010, Aggrey et al. 2015, McDermott et al. 2020, Arts et al. 2021). To support these initiatives, timber inspectors from the Ghana Forestry Commission audit timber products to ensure the accuracy of species declarations (Aggrey et al. 2015, Arts et al. 2021, International Tropical Timber Organization 2025). Their work instructions for identifying lumber (Eshun et al. 2017) reference methods and species descriptions outlined in a wood identification field manual that they would later publish in collaboration with the US Department of Agriculture Forest Products Laboratory in Madison, Wisconsin, USA, the *Field Identification Manual for Ghanaian Timbers* (Arévalo et al. 2020). This study transforms the printed field identification manual into a smartphone application to increase the accessibility and utility of this resource for users in the field.

Background

Established in the 1990s, the Ghana Forestry Commission is a public service institution that works to sustainably manage and develop the forest and wildlife resources of Ghana through conservation, management, regulation, and policy coordination (Ministry of Lands and Natural Resources 2025b). In addition to a training center and a support center, the Commission comprises three divisions, including the Forest Services

The authors are, respectively, Graduate Research Assistant, Associate Professor, Assistant Professor, and Graduate Research Assistant (kgs211@msstate.edu, fco7@msstate.edu [corresponding author], adc751@msstate.edu, and aae213@msstate.edu), Department of Sustainable Bioproducts, Mississippi State University, Mississippi State, MS 39762-9820; and Research Botanist and Team Leader (alex.c.wiedenhoef@usda.gov), Center for Wood Anatomy Research, USDA Forest Products Laboratory, Madison, WI 53726-2398. This paper was received for publication in April 2025. Article no. 25-00022.

©Forest Products Society 2025.

Forest Prod. J. 75(3):258–270.

doi:10.13073/FPJ-D-25-00022

Division, the Wildlife Division, and the Timber Industry Development Division (TIDD; Ministry of Lands and Natural Resources 2025c). As frontline defenders of timber legality, the TIDD is responsible for inspecting and verifying the species, grade, origin, tally, and valuation of the nation's logs, lumber, and other timber products and for issuing export certificates and permits (Ministry of Lands and Natural Resources 2025a).

In 2016, the TIDD sought to acquire International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 17020:2012 accreditation with funding from a United Nations Industrial Development Organization (UNIDO) project entitled Trade Capacity Building Programme for Ghana (Gyala 2017). The ISO/IEC 17020:2012 standard specifies requirements for entities performing inspections to ensure competence, consistency, and impartiality (International Organization for Standardization/Committee on Conformity Assessment 2012, Gyala 2017). As part of these efforts, an external audit of wood identification processes, capacity, and workflows was conducted in May 2016 by Alex C. Wiedenhoeft with UNIDO funding, and a white-paper summary by Wiedenhoeft was submitted to UNIDO. That report identified a lack of scientifically based wood identification

capacity at TIDD—both at a provisional screening level in the field and at a forensic or preforensic level in the laboratory. It described the need for TIDD to increase cooperation with the Forestry Research Institute of Ghana (FORIG) in performing forensic identifications and training current and future staff. This cooperation would serve to develop a formal forensic workflow and work instructions in collaboration with FORIG and to compose a field manual for wood identification targeting species commonly traded in Ghana for use by their timber inspectors.

In addition to the white paper, Wiedenhoeft proposed a capacity-building program of work to empower TIDD to develop field screening and laboratory forensic capacity in-house to verify products in the supply chain with anatomical wood identification methods. With subsequent UNIDO funding, a four-person delegation of three TIDD inspectors and one researcher from FORIG spent 3 months in 2018 undertaking the suggested capacity-building activities in the Wiedenhoeft laboratory (Fig. 1). Shortly after the delegation returned to Ghana, the TIDD was awarded ISO/IEC 17020:2012 accreditation in December 2018 (Ebeheakey, personal knowledge).

In 2020, the four delegates co-authored the *Field Identification Manual for Ghanaian Timbers* (Arévalo et al. 2020).

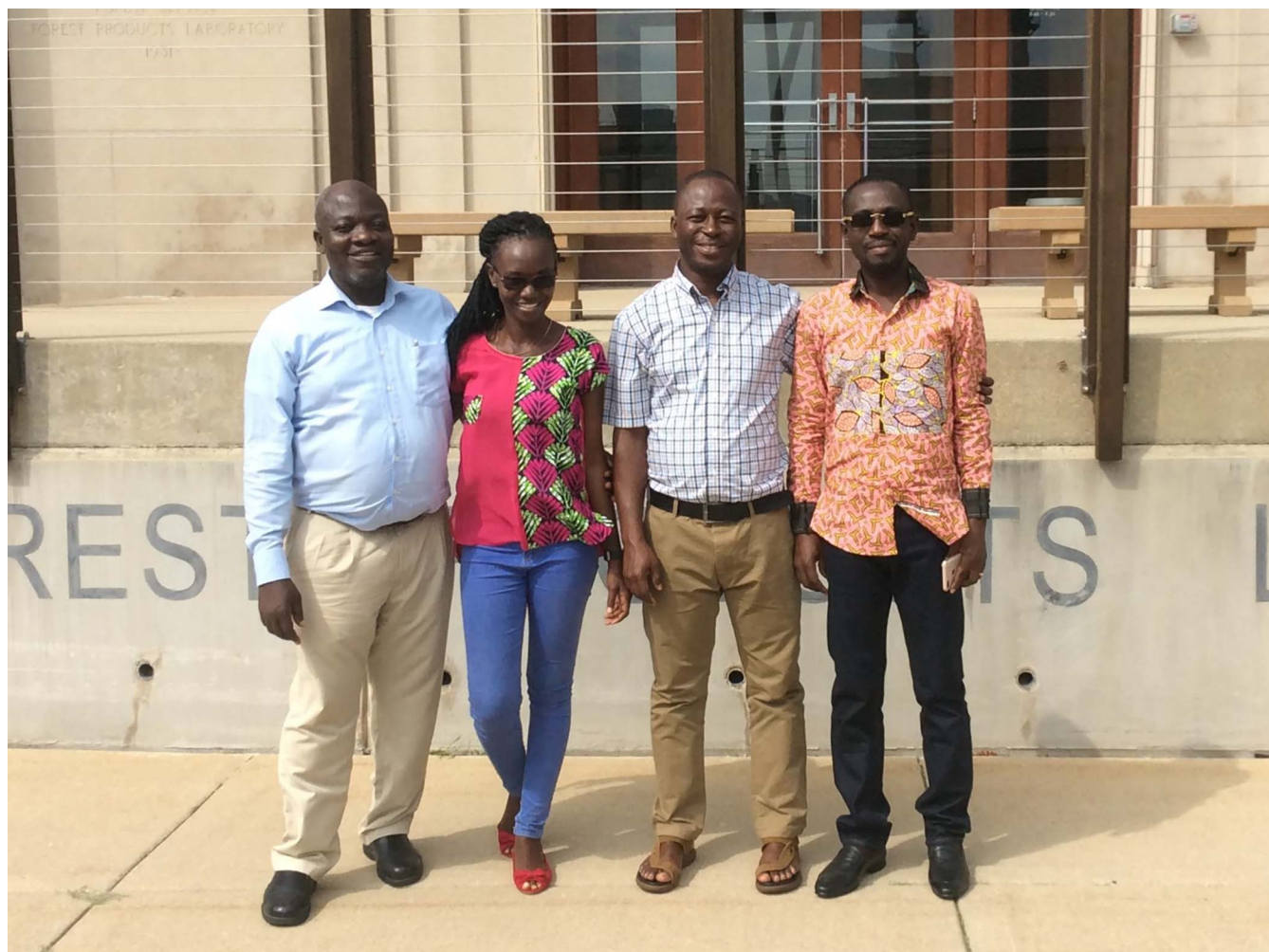


Figure 1.—The four-person delegation from Ghana in front of US Department of Agriculture Forest Products Laboratory: Emmanuel Ebanyenle (Forestry Research Institute of Ghana), Alberta Asi Ebeheakey, Ophilious Lambog, and Kofi Bonsu Abban (Ghana Forestry Commission).

The Ghanaian co-authors embarked on a national tour from 2021 to 2022 to train more than 100 timber inspectors across Ghana on conventional macroscopic wood identification methods using the field identification manual. Although each inspector was issued a print version of the field identification manual, many preferred to download the PDF version to their smartphones. In practice, both formats presented ergonomic challenges: The printed manual was cumbersome to carry and necessitated manual page turning, whereas the PDF version, which was easier to view on the much larger screens of a desktop or laptop, was not easy to use on the small screens of smartphones because it necessitated two hands for zooming and panning. Despite these limitations, the field identification manual remained the standard reference for wood identification in inspections, although the implicit need for a more user-friendly format for the field manual's content remained.

Existing wood identification apps for smartphones

On the Apple App Store and/or Google Play Store, 15 smartphone apps are currently available for wood identification. They differ in the number and regional purview of woods they cover and in the identification methods they employ. The apps can be roughly divided into two groups: automated apps and manual apps; the former use computer vision and machine learning to analyze and classify images of wood specimens, and the latter provide anatomical information in the form of species descriptions and/or identification keys to help a human inspector identify woods with a hand lens. Details about the apps mentioned here are summarized in Table 1, and all the apps feature an English translation.

The *WhatWood? Ghana Edition* project aimed to redevelop the *Field Identification Manual for Ghanaian Timbers* (Arévalo et al. 2020) as a smartphone application, reimagining how best to deliver the technical content of the original publication but with the flexibility, functionality, and greatly increased accessibility inherent to smartphone apps. *WhatWood? Ghana Edition*, while maintaining the original content and methods that fulfill the requirements for maintaining TIDD's ISO/IEC 17020:2012 accreditation, also greatly increases the utility and availability of the technical content. Specifically, this project sought to accomplish the following:

1. Reformat the text and images of the manual to fit any smartphone screen;
2. Enable one-hand navigation and scrolling;
3. Automate decision routing within the wood identification key;
4. Add zoomable and pannable reference images to the wood identification key options;
5. Allow for content revisions to be immediately pushed to users' smartphones when updates become available;
6. Encourage the authors of the manual to continue to improve content, which occurs by virtue of the comparative ease of the aforementioned updates;
7. Have the software be free and downloadable on any iOS or Android device;
8. Deliver all content in a native app without the need for internet connectivity in the field; and

9. Introduce educational content in the form of wood feature identification quizzes to help users reinforce what they learned in the face-to-face instructional workshops or from reading the training chapters.

Materials and Methods

Source publication

Most of the content for *WhatWood? Ghana Edition* came from the original source publication entitled *Field Identification Manual for Ghanaian Timbers* (hereafter "the field identification manual" or simply "the manual"; Arévalo et al. 2020). The manual comprises nine chapters that contain instructions for performing macroscopic wood identification, including wood anatomy basics, use of a hand lens, specimen surface preparation, and wood characters used in identification. It also contains a dichotomous wood identification key, description pages for 86 species groups (hereafter referred to more simply as woods), and an index of local and trade names for each wood.

Images

Specimen images were extracted directly from a high-resolution PDF version of the manual at 675 by 675 pixels and saved with Adobe Acrobat (Adobe Inc. 2024). Images of tables and figures were acquired with screenshots and saved at 1,920 by 1,080 pixels. In total, 51 images of tables and figures and 261 images of wood specimens were used in the app.

Text

Text for the app was taken directly from the field identification manual. Chapters 1 through 5 and Chapter 8 contain instructions for and information about performing macroscopic wood identification (Arévalo et al. 2020). Text from these chapters was saved to resource (.resx) files. Chapters 6, 7, and 9 of the manual contain the dichotomous identification key, species description pages, and an index of local and trade names, respectively (Arévalo et al. 2020). Text from these chapters and the key's navigation routes were saved to text (.txt) files. All text and resource files were saved with Adobe Acrobat (Adobe Inc. 2024).

Framework

The app was built with Microsoft's .NET Multi-platform App UI (.NET MAUI) framework in Visual Studio 2022. This framework compiles projects into native iOS, Android, macOS, Windows, and Samsung Tizen apps from a single code base (alvinashcraft et al. 2025, davidbritch et al. 2025). Of these operating systems, a compiled app in iOS, Android, and macOS was realized. .NET MAUI uses the XAML and C# languages for markup and code-behind, respectively. It also provides resulting apps with backward compatibility to iOS version 12.2, Android version 5.0 (Lollipop), and macOS version 11.0.

Database

From the text and resource files, text was read into an SQLite database (SQLite Developers 2025). The SQLite database is managed by Microsoft's object-relational mapper Entity Framework Core (EF Core; SamMonoRT et al. 2024). EF Core enables access to the SQLite database within the code of a .NET MAUI app.

Table 1.—*Functionality comparison of wood identification apps for smartphones.*

App	Version tested	Operational? ^{a,b}	Platforms and release dates	Price ^b	Automated? ^{a,b}	Key type ^b	Requires internet? ^{a,b}	Wood count ^{c,d}	Geographic scope ^c	Wood description pages? ^{a,b}	Value adds ^b
Xylorix Inspector	3.3.2	✓	iOS: May 16, 2018 Android: Nov 13, 2018	—	✓	—	✓	32 free, 13 paid	Malaysia, Madagascar, India, Southeast Asia, Ghana, France	—	Verify mode
Xylorix PocketWood	iOS: 1.9.2 Android: 1.9.1	✓	iOS: Oct 23, 2020 Android: Sep 13, 2020	—	—	—	—	455	Global	✓	—
Xylorix Enforcer	1.10.0	✓	iOS: Apr 20, 2022 Android: Apr 20, 2022	—	With approved account	—	For account login	465	Global	✓	Verify mode
macroHOLZdata	2.1.3	✓	iOS: Sep 21, 2016 Android: May 1, 2022	—	—	Multi-entry	—	153	Global	✓	—
CITEswoodID	1.1.2	✓	iOS: Dec 23, 2020 Android: Oct 19, 2020	—	—	Multi-entry	—	85	Global	✓	Comments subsections
Wood Id – Wood Identifier	iOS: 1.0 Android: 2023.05.03.20	✓	iOS: Mar 15, 2025 Android: Jan 26, 2025	US\$4.99/yr	✓	—	✓	~	~	—	—
ID Wood	4.1.4	✓	iOS: Aug 11, 2009	US\$9.99	—	—	—	205	Global	✓	Calculators, reference pages, map
MyWoodPremium (MyWood-ID)	1.0.0	—	iOS: Jan 23, 2018	—	✓	—	✓	≤100	Malaysia	✓	—
WoodID App	1.0.6	✓	iOS: Jun 19, 2024	—	✓	—	—	126	Vietnam, Africa	✓	Offline operation
Wood Identifier: AI Scanner (Richard Schoerner)	1.0.4	✓	iOS: Nov 18, 2024	US\$12.99/mo	✓	—	✓	~	Global	—	Tree checker mode
Wood Identifier AI Scanner (Nikhil Kumar)	1.2	✓	iOS: Mar 21, 2025	US\$29.99/yr	✓	—	✓	>500	Global	—	—
AIKO-KLHK	2.2.0	✓	Android: Aug 27, 2019	—	✓	—	✓	823	Indonesia	✓	—
ID Maderas	1.0.20	—	Android: Aug 10, 2021	—	—	Multi-entry	First launch	20	Central and South America	✓	—
Wood Identifier: AI Scanner (Artnvsid)	1.0.8	✓	Android: Feb 27, 2025	US\$29.99/yr	✓	—	✓	~	Global	—	Tree identification
Wood Identification App	1.0.0	✓	Android: Apr 9, 2025	—	✓	—	—	Thousands	Global	—	Reasoning explanations; offline operation
WhatWood? Central America Ed.	1.0.0	✓	iOS: Dec 3, 2024 Android: Mar 11, 2025	—	—	Dichotomous	—	138	Central America, Mexico, the Caribbean	✓	Wood feature quizzes
WhatWood? Ghana Ed.	1.0.1	✓	iOS: Jan 20, 2025 Android: Feb 19, 2025	—	—	Dichotomous	—	87	Ghana	✓	Wood feature quizzes

^a Check marks indicate the presence of functionality.^b An — denotes absence of functionality.^c Tildes indicate unknown values.^d No. of classes of macroscopically separable woods included in the apps; classes can each describe one, many, or an ambiguous number of individual wood species.

Anatomical feature quizzes

Two interactive quizzes were developed for the app to help users learn the wood anatomical features employed in the manual's dichotomous identification key: the choice quiz and the feature selection quiz. The choice quiz names an anatomical feature and shows images of two woods, asking users to choose the image that exhibits that feature, whereas the feature selection quiz shows an image of one wood and a list of anatomical features, asking users to select every feature displayed in the image.

To allow images to be queried by anatomical features, numerical feature codes for the characters mentioned in the species description pages were added to the database for each wood. For example, *Tectona grandis* was coded for the presence of distinct growth-ring boundaries (coded as 1), semi-ring porosity (coded as 4), tyloses (coded as 56), medium-to-narrow rays (coded as 97), average ray abundance (coded as 115), paratracheal vasicentric parenchyma (coded as 79), and marginal parenchyma (coded as 89). In addition, anatomical features were grouped by category. For example, the features ring-porous, semi-ring-porous, and diffuse-porous were categorized as porosity features, whereas few rays, average ray abundance, and numerous rays were categorized as ray abundance.

Choice quiz.—For the choice quiz, each question page is generated by an in-app initialization process. First, an anatomical feature code is randomly selected (e.g., 89), and the quiz question is formed by displaying the name of that feature (e.g., marginal parenchyma) preceded by the text, “Which species displays. . .” (Fig. 2, upper-right screenshot). Next, the database is queried with that feature code to randomly select two woods: one that exhibits the selected feature (e.g., *T. grandis*) and another that does not (e.g., *Anthocleista nobilis*). Then, the database is queried again to select an image for each wood. The image exhibiting that feature is randomly placed on either the right or left, and the image without that feature is placed in the other position. Each image is labeled with its scientific and common names. Upon image selection by the user, a results window appears, indicating a correct or incorrect answer. The next question is generated by the same initialization process.

Feature selection quiz.—For the feature selection quiz, the question pages are generated by a different in-app initialization process. First, the database is queried for a wood at random (e.g., *T. grandis*), returning a list of that wood's anatomical features (e.g., distinct growth ring boundaries, semi-ring-porous, tyloses, medium-to-narrow rays, average ray abundance, paratracheal vasicentric parenchyma, marginal parenchyma). A second query returns a list of all the feature categories represented in that wood's feature list (i.e., growth-ring boundaries, porosity, ray width, ray abundance, paratracheal axial parenchyma, and banded parenchyma). These two lists, along with a third that contains all possible anatomical features for all categories, are passed to a function that creates a section for each category represented in that wood's feature list. A final query returns a list of exemplar images for that wood. The page is populated by an initial image selected from that list appearing in a fixed position at the top of the page headed by the scientific and common names of the wood (Fig. 2, upper-middle screenshot). Under the exemplar image appears a scrollable list of feature choices, each preceded by a check box, organized into sections by feature category. Upon feature selection and submission by the user, a results window appears, indicating a correct or incorrect

answer. The next question is generated by the same initialization process.

As a result of the randomization that takes place with each initialization, the user is unlikely to experience the same questions in the same order with the same exemplar images, thus keeping the content novel to the user. A stock set of questions is never used because the questions are generated *de novo* with each initialization, giving an essentially unique quiz experience every time the user applies these functions.

Results

WhatWood? Ghana Edition is available for free download on the Apple App Store for iOS (Kyatt Spessert 2025a) and on the Google Play Store for Android (Kyatt Spessert 2025b), requiring 99 megabytes of storage on-device, but further internet access is not necessary for use. The .NET MAUI source code is also available on GitHub (MSU-WhatWood 2025).

Features of the user interface

Buttons that appear in pages of the app are displayed in Figure 2. References to these buttons in the following text are in **bold** type and are presented here to facilitate explanation of the app's functionalities.

The app comprises five main components, each represented by a tab in the **tab bar** at the bottom of every page: Book, Quiz, Key, Species, and Settings. The Book tab (book icon) contains the text and images from the original field identification manual separated by chapter. The Quiz tab (lightbulb icon) contains the two anatomical feature quizzes for user self-study. The Key tab (magnifying glass icon) houses the interactive dichotomous identification key. The Species tab (dog-eared document icon) contains all the species description pages from the source manual. The Settings tab (gear icon) provides user adjustments to the interface of the app, as well as a Credits page.

Book tab

The Book tab contains the contents from the original field identification manual, including text and images. The main page shows the table of contents of the manual by chapter (Fig. 3A). Chapters can be opened and read by tapping the **chapter buttons**. When tapped, all images open to a separate page, allowing for zooming and panning with pinch and drag gestures, respectively. Chapters 6 (Identification Key) and 7 (Species Description Pages) contain short descriptions of the chapters' content along with a link allowing the user to navigate directly to the Key and Species pages.

Quiz tab

The Quiz tab offers two interactive quizzes to help users master the kinds of features mentioned in the dichotomous key: the choice quiz and the feature selection quiz. The choice quiz shows users the name of an anatomical feature and asks them to select which of two images exhibits that feature (Fig. 4A). Wide yellow arrow buttons allow the user to cycle through additional images of the same wood for each choice. Each time the user selects an image, a pop-up message appears telling the user whether the answer was correct or incorrect, along with a running total of correct responses per questions attempted (Figs. 4B and 4C).

The feature selection quiz displays an image of a wood and asks users to select **check boxes** next to the anatomical features they see in the image (Fig. 4D). Users access this

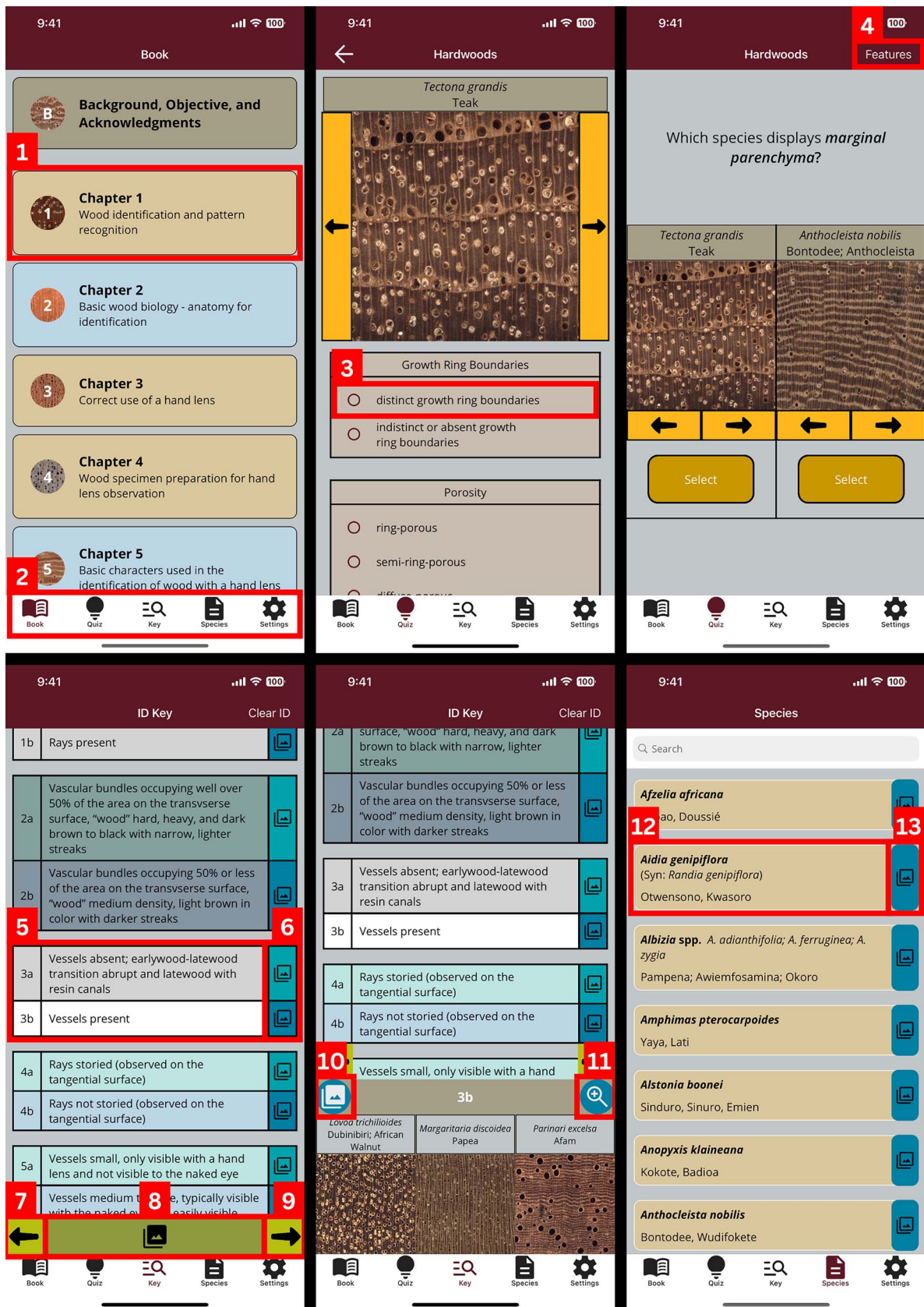


Figure 2.—Buttons that appear in the WhatWood? Ghana Edition app. References to these buttons are in bold type. (1) Chapter button. (2) Tab bar. (3) Check box. (4) Features button. (5) Option buttons. (6) Blue example buttons. (7) Back button. (8) Image button. (9) Forward button. (10) Blue image button. (11) Magnifying glass button. (12) Wood button. (13) Blue preview button.

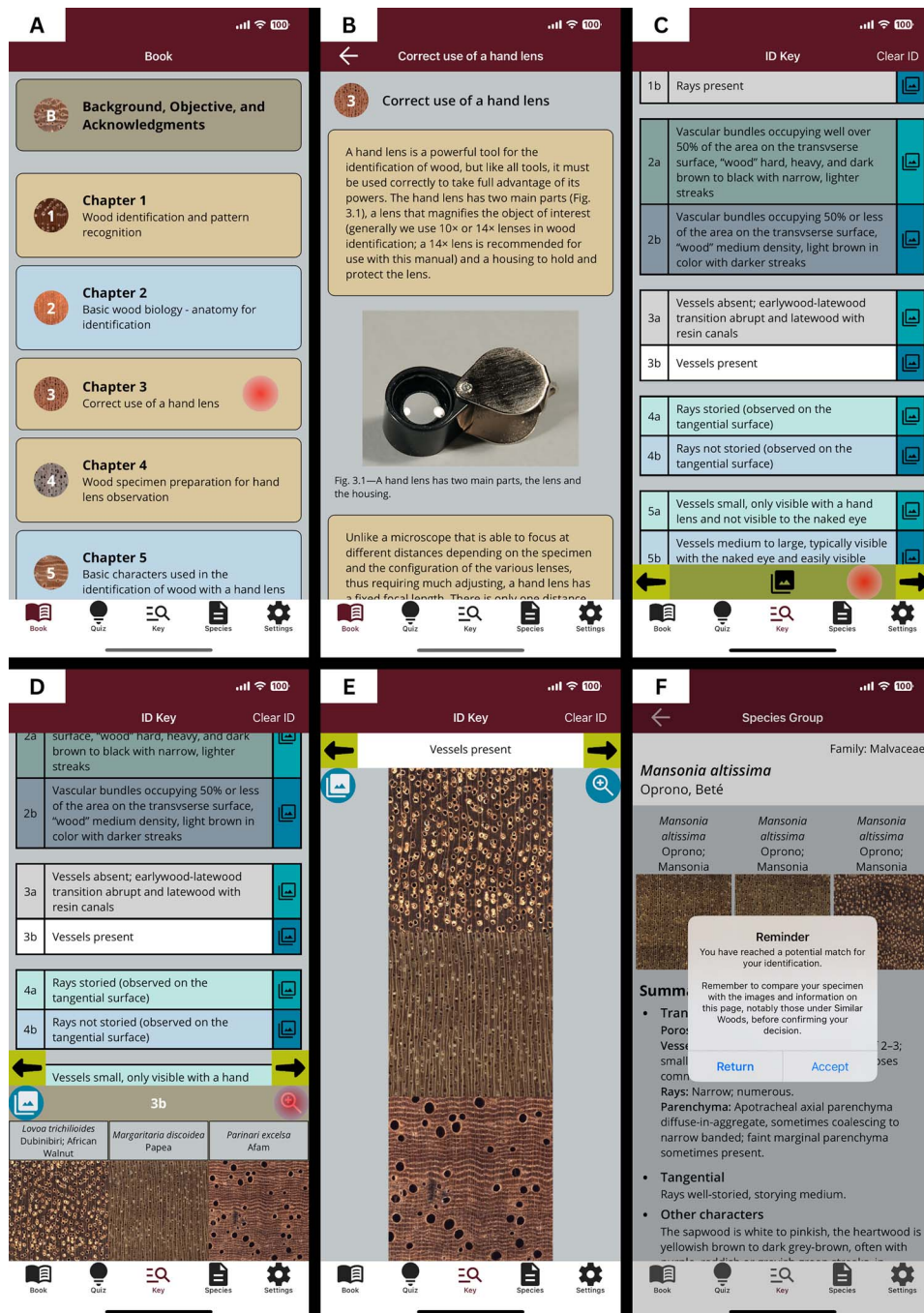


Figure 3.—Screenshots of pages on the Book tab (A, B) and pages in the Key tab (C, D, E, F) of the WhatWood? Ghana Edition app. Bright red, circular highlights on (A), (C), and (D) denote a user's tap and the subsequent in-app navigation to the following screen-shotted page. (A) Table of contents for the Book tab. (B) Book chapter page. (C) Interactive wood identification key; choice options appear in pairs from which the user must choose one to advance to the next option pair. (D) Images in expanded view of the interactive key. (E) Full-screen images in the interactive key; images can be zoomed and panned with Pinch and drag gestures, respectively, allowing users to inspect the minute anatomical features in detail. (F) Pop-up reminding the user to also check similar, easily confused woods before making the final classification.

quiz by tapping the **Features** button in the top right of the choice quiz page (Fig. 4A). As with the choice quiz, tall yellow arrow buttons allow the user to cycle through the other images belonging to the same wood, and, similarly, after each submission, a pop-up message appears telling the user the number of features they correctly identified (out of the total possible) as well as which correct features were missed and which incorrect features were mistakenly selected (Figs. 4E and 4F).

Identification key tab

The identification key tab opens to a scrollable set of **option buttons** organized in couplets. Each button corresponds to a choice in the dichotomous key and is labeled with text describing the anatomical feature(s) for that option. As options are selected, the key automatically navigates to the next couplet, skipping all options excluded from the current decision tree along the way. To allow users to retrace their steps in the key

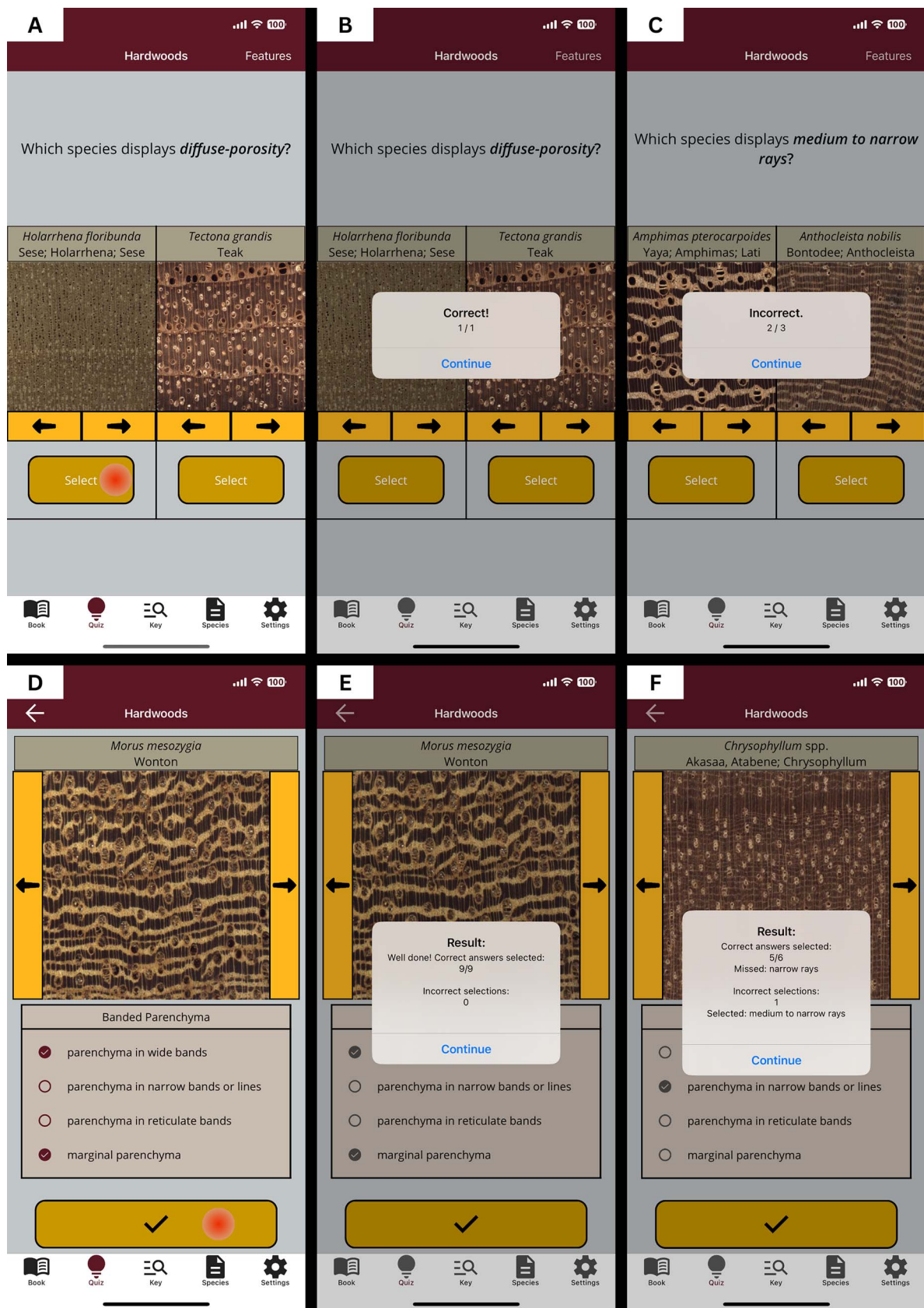


Figure 4.—Screenshots of the choice quiz page (A, B, C) and the feature selection quiz page (D, E, F) in the WhatWood? Ghana Edition app. Bright red circular highlights on (A) and (D) denote a user's tap and the subsequent in-app navigation to the following screenshoted page. (A) Choice quiz; wide yellow arrows under each image allow the user to cycle through additional images from the same wood. (B) Pop-up feedback for the choice quiz with running correct responses per total questions attempted. (C) Pop-up feedback for the choice quiz displaying the result of an incorrect user selection. (D) Feature selection quiz; tall yellow arrows to the

without having to start over at the initial couplet, black-on-green **back** and **forward buttons** are positioned just above the **tab bar** at the bottom of the screen (Fig. 3C).

To supplement the text descriptions in the key, the user has the option to tap the dark green **image button** with the black image icon just above the center of the **tab bar** (Fig. 3C), opening an expanded view at the bottom of the page showing images of woods exhibiting the feature(s) described in the **option button** (Fig. 3D). The user can toggle back and forth between images for each couplet by tapping the **blue example button** with the black image icon to the right of each **option button** (Fig. 3D). Tapping the **magnifying glass button** in the expanded view (Fig. 3D) opens a separate page that shows full-screen versions of the exemplar images, allowing for zooming and panning with the pinch and drag gestures, respectively (Fig. 3E). The expanded view can be closed by tapping the **blue image button** in the upper left (Figs. 3D and 3E).

When a terminal decision is reached, the key automatically opens the species page that corresponds to that taxon, and a message appears reminding users to compare their specimen with the images and information on the species page, as well as with the similar woods listed and hyperlinked at the bottom of the page for ease of comparison, before confirming the identification (Fig. 3F).

Species tab

The Species tab provides users access to the species description pages. The species index page exhibits a series of **wood buttons** each labeled with the scientific (bold italic font) and common name(s) (regular font) of a wood (Fig. 5A). The user has the option to tap the **blue preview button** to the right of each **wood button** to reveal preview images for that wood (Fig. 5A). Each preview image can be individually tapped to open a full-screen view that can be zoomed and panned with the pinch and drag gestures, respectively.

A search bar at the top of the index page allows users to filter the woods by scientific name, synonym, or common name. As each letter is typed, the database is queried for matches of the entire string of entered text, which remain, while all mismatches are hidden (Fig. 5B).

Tapping a **wood button** opens the description page for that wood (Fig. 5C). At the bottom of this page, links to similar woods allow the user to compare characteristics of the current wood with those of lookalikes. A large text box is also available, allowing users to type and save their own notes about the wood. Notes saved in these boxes are retained by the app and will be available only to the user of that device until they are edited or removed by the user.

Settings tab

The Settings tab allows users to adjust the interface (Fig. 5D) and view the credits (Fig. 5F) via the Credits button. For accessibility, the font size can be adjusted from 8 to 24 point, and the color scheme can be switched to colorblind mode. The colorblind mode should enhance accessibility particularly for users with color vision deficiency (CVD) because it increases

the visual contrast of text and buttons in the **tab bar** and the navigation bar (Jamil and Denes 2024; Fig. 5E). Buttons appearing within the pages of the app are labeled with icons or text, adhering to the guideline published by the World Wide Web Consortium specifying that color should not be used as “the only visual means of conveying information . . . or distinguishing a visual element” (World Wide Web Consortium 2024). A visual scrolling animation for navigating between decisions in the Key can be enabled (default) or disabled. With this option enabled, tapping an **option button** in the Key visibly shifts the list of **option buttons** upwards to arrive at the next couplet. Disabling it causes a tapped decision to navigate directly to the next couplet without shifting the list. The launch page can be selected from among the Key (default), Book, Quiz, and Species tabs.

Discussion

The *WhatWood? Ghana Edition* app substantially enhances the utility and accessibility of the *Field Identification Manual for Ghanaian Timbers* (Arévalo et al. 2020). The app is downloadable for free on both iOS and Android from the world’s two largest smartphone app stores, the Apple App Store and Google Play Store, making it instantly accessible to anyone, anywhere, on any smartphone in the world; furthermore, it is also compatible with macOS (Kyatt Spessert 2025a). Unlike a printed or digital document, content revisions can be pushed to users as needed through automatic software updates, eliminating the need for reprints and PDF revisions and thus encouraging authors to continue to make improvements. It is a native app, so it does not require an internet connection other than for installation, making it usable even in remote locations without cellular data or WIFI access. The app retains the entire contents of the original source publication, so it continues to fulfill the requirements for TIDD to retain their ISO/IEC 17020:2012 accreditation and, as such, is currently the only wood identification app in the world that supports ISO/IEC accreditation.

WhatWood? Ghana Edition also offers a host of ergonomic improvements over the original source publication (Arévalo et al. 2020). Text and images are automatically sized and spaced to fit any size smartphone or tablet screen, so users view the publication’s content visually optimized for their various mobile devices. Further optimizations are provided by the settings page, wherein users can adjust font size point-by-point and, notably for those with CVD, enable a colorblind mode for increased visual contrast. Images can be zoomed and panned as needed, allowing users to examine both instructional figures and wood anatomical features in detail. Using the dichotomous key eliminates the need to manually flip and visually scan pages through automatic decision routing and navigation from terminal decisions to species pages, which has enhanced the key’s ease-of-use. These automated routing features also eliminate inevitable human error in selecting the subsequent couplet in the key. Additional improvements to ease-of-use are present in portrait orientation, where the scrolling of pages and display or hiding of reference images can be executed with the thumb of one hand, allowing users to hold a wood specimen or hand lens in the other (Fig. 6).

sides of the image allow the user to cycle through additional images from the same wood. (E) Pop-up feedback for the feature selection quiz showing the result of a user selecting every correct feature and no incorrect features. (F) Pop-up feedback for the feature selection quiz showing the number of features correctly identified (out of the total possible) as well as which correct features were missed and which incorrect features were selected.

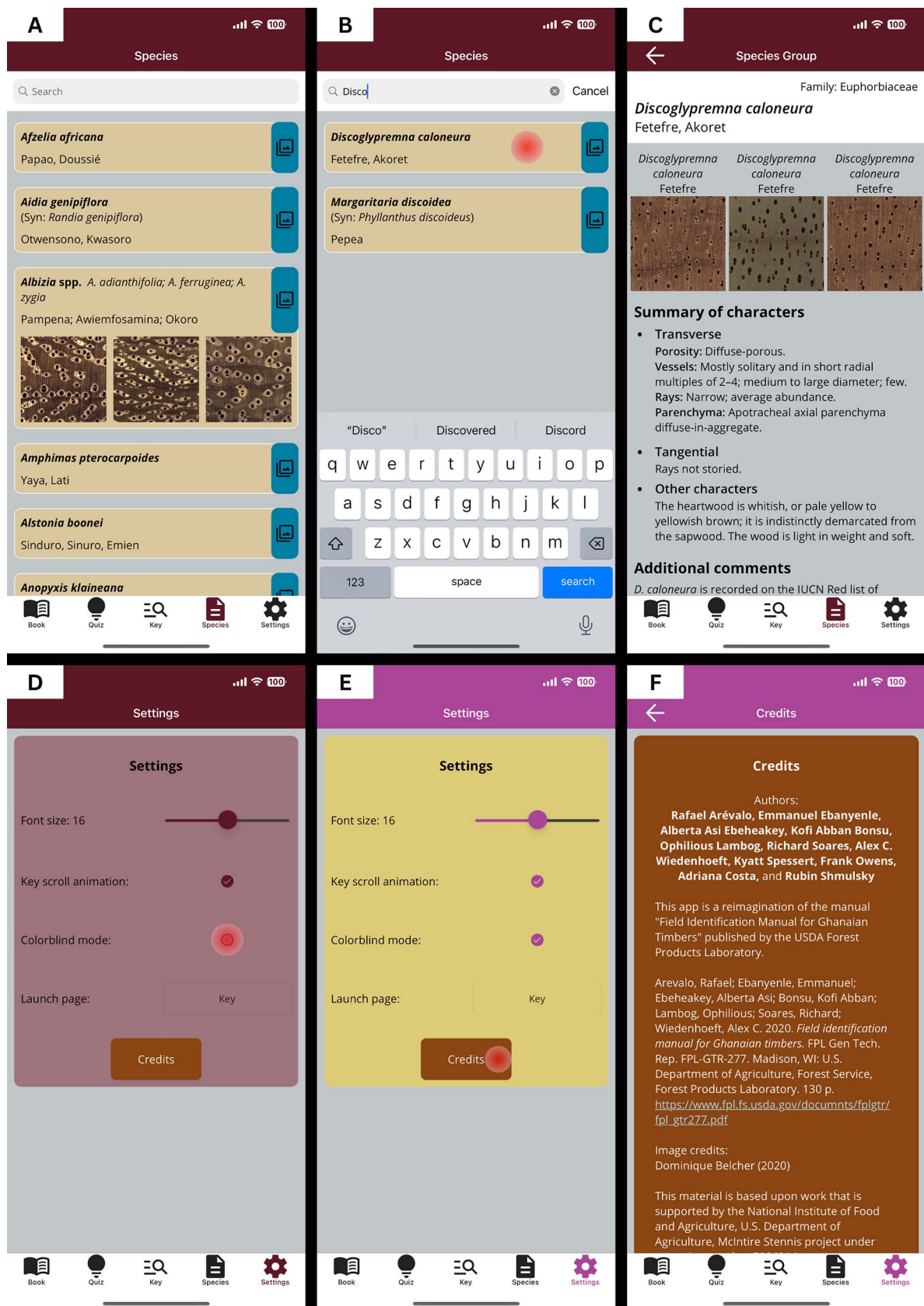


Figure 5.—Screenshots of the Species tab (A, B, C) and the Settings tab (D, E, F) in the WhatWood? Ghana Edition app. Bright red circular highlights on (B), (D), and (E) denote a user's tap and the subsequent in-app navigation to the following screenhotted page. (A) Species index page with preview images for *Albizia spp.* revealed. (B) Example search for "Disco..." on the species index page. (C) Species description page including images and descriptions for *Discoglypremna caloneura*. (D) Settings page. (E) Settings page with colorblind mode enabled. (F) Credits page.

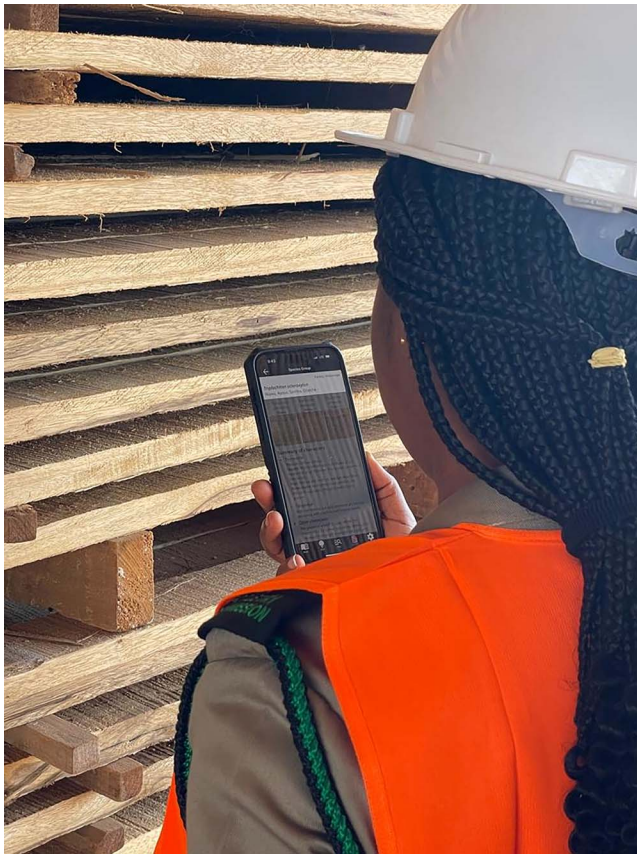


Figure 6.—One-handed use of WhatWood? Ghana Edition by a Timber Industry Development Division inspector in the field in Dormaa, Bono Region, Ghana.

WhatWood? Ghana Edition is currently the only wood identification app with a national scope that offers quizzes to help users acquire and maintain the level of anatomical character recognition needed for proper implementation of the wood identification key. By adding gamified elements such as badges, personal best scores, and skill rankings, the interactive functionality of the quizzes could be further enhanced to increase user engagement, understanding, and retention (Kapp 2012, Hamari et al. 2014, Bai et al. 2020). The quiz features transform the app from a mere reference tool into one with self-study functionality. This feature potentially lessens the need for face-to-face refresher instruction, possibly obviating the need for initial in-person training, and could conceivably be used in wood anatomical instructional settings in university courses on wood anatomy and identification.

Incorporating indigenous Ghanaian languages, such as Akan, Ewe, Dagbani, and Dangme, was beyond the scope of this endeavor; thus, the decision was made to develop the app in English because English is both the official language of Ghana and a lingua franca used among Ghanaian peoples from different ethnic groups who do not understand each other's indigenous languages. Furthermore, English makes the app broadly accessible to many international users.

Suggestions for future work

The published *WhatWood? Ghana Edition* app provides a range of improvements in usability over the source manual, and the nearly unlimited potential for software engineering

to facilitate digital innovation enables future work to explore many further improvements. The app currently lacks a short-form tutorial on its use, a frequently included feature in other wood identification apps. Short tutorials, particularly in video format, could serve to quickly onboard new users to the app, as well as encourage interest in wood identification.

Future work could expand on the functionality of the species search bar by not only querying the database for the names of woods but also the entire contents of each of the species description pages. This would allow users to search for specific anatomical or physical features described in the pages, filtering the list of woods accordingly. Similarly, labeling the anatomical and physical features of all included woods, as was performed for just those appearing in the quizzes, could facilitate adding a filter functionality to the list of woods by allowing users to select individual features displayed by the woods and filtering their list as a result, introducing a *de facto* multi-entry key.

Looking to the future, wood identification apps such as *WhatWood? Ghana Edition* could also include automated identification methods such as computer vision wood identification (CVWID; Yi et al. 2007, de Andrade et al. 2020, Ravindran et al. 2020, Hwang and Sugiyama 2021). CVWID could be implemented either as a final confirmation step in manual apps or at the front end of the process, with a human-in-the-loop implementation for confirmation of the CVWID result by comparison to the species description pages. Prior work developing and training models for CVWID, including a model for Ghanaian woods, could provide deployment-ready CVWID capabilities for wood identification apps without requiring further model development or extensive app updates (Yulastuti et al. 2013; Ravindran et al. 2019; Ravindran et al. 2021; Ravindran et al. 2022a, 2022b).

Conclusion

Built with Microsoft's .NET MAUI framework, this electronic revision of the *Field Identification Manual for Ghanaian Timbers* (Arévalo et al. 2020) has increased utility and accessibility of the original publication by adding smartphone functionality while maintaining the original content and methods that fulfill ISO/IEC accreditation. Downloadable without charge (and open source on GitHub) on iOS, Android, and macOS, *WhatWood? Ghana Edition* is accessible to anyone, anywhere, on any smartphone worldwide (Kyatt Spessert 2025a, 2025b; MSU-WhatWood 2025). It does not require an internet connection to operate, and content revisions are available through automatic software updates. Ergonomic improvements abound, including display optimization to fit smartphone and tablet screens, one-handed scrolling, automatic decision routing in the wood identification key, zooming and panning of images, adjustable font sizes, and a colorblind mode. As the first wood identification app with a national scope equipped with wood feature quizzes, the app potentially lessens, or perhaps even obviates, the need for face-to-face instruction. The successful conversion of the *Field Identification Manual for Ghanaian Timbers* into a smartphone app, and its open-source code, opens the door to potentially converting myriad other print publications into a more modern, accessible, intuitive, and ergonomically functional product (Arévalo et al. 2020).

Acknowledgments

This material is based upon work that is supported by the National Institute of Food and Agriculture, US Department of

Agriculture, McIntire Stennis project under accession number 7004014. This publication is a contribution of the Forest and Wildlife Research Center, Mississippi State University. The authors gratefully acknowledge the specimen preparation and imaging efforts of Rafael Arévalo, Emmanuel Ebanyenle, Kofi Bonsu Abban, Ophilious Lambog, and Richard Soares. They also thank Debora Danquah Kumi (TIDD inspector) and Edith Addo (photographer) for the image of the app being deployed in Ghana.

All authors (Kyatt Spessert, KS; Frank Owens, FO; Adriana Costa, AC; Alberta Asi Ebeheakey, AAE; Alex Wiedenhoef, AW) contributed actionable feedback that improved the presentation of the paper. KS, AW, AC, and FO wrote the paper. AAE contributed Ghanaian timeline and implementation context critical to documenting ISO/IEC certification. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The authors ask that any use or adaptation of the code for *WhatWood? Ghana Edition* will include clear reference to and citation of this paper and credit for the app source code.

Literature Cited

- Acheampong, E. O., C. J. Macgregor, S. Sloan, and J. Sayer. 2019. Deforestation is driven by agricultural expansion in Ghana's forest reserves. *Sci African*. 5:e00146. <https://doi.org/10.1016/j.sciaf.2019.e00146>
- Adobe Inc. 2024. Adobe Acrobat, version 24.005.20320. Adobe Inc., San Jose, California. <https://www.adobe.com/acrobat.html>
- Aggrey, J., K. S. Nketia, and A. P. Koranteng (Eds.). 2015. Understanding Ghana's Timber Legality Assurance System. Tropenbos International Ghana, Kumasi, Ghana. 25 pp. <https://www.tropenbos.org/resources/publications/understanding+ghana%E2%80%99s+timber+legality+assurance+system>. Accessed February 11, 2025.
- alvinashcraft, jwmsft, and eelnivla. 2025. Build Windows apps with .NET MAUI. Microsoft. <https://learn.microsoft.com/en-us/windows/apps/windows-dotnet-maui/>. Accessed March 26, 2025.
- Appiah, M., D. Blay, L. Damnyag, F. K. Dwomoh, A. Pappinen, and O. Luukkanen. 2009. Dependence on forest resources and tropical deforestation in Ghana. *Environ Dev Sustain*. 11(3):471–487. <https://doi.org/10.1007/s10668-007-9125-0>
- Arévalo, R., E. Ebanyenle, A. A. Ebeheakey, E. Kofi, K. A. Bonsu, O. Lambog, R. Soares, and A. C. Wiedenhoef. 2020. Field identification manual for Ghanaian timbers. USDA Forest Products Laboratory GTR-277, Madison, Wisconsin. 130 pp. <https://research.fs.usda.gov/treesearch/60264>. Accessed January 10, 2025.
- Arts, B., B. Heukels, and E. Turnhout. 2021. Tracing timber legality in practice: The case of Ghana and the EU. *Forest Pol Econ*. 130:102532. <https://doi.org/10.1016/j.forpol.2021.102532>
- Bai, S., K. F. Hew, and B. Huang. 2020. Does gamification improve student learning outcome? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts. *Educ Res Rev*. 30:100322. <https://doi.org/10.1016/j.edurev.2020.100322>
- Beeko, C. and B. Arts. 2010. The EU-Ghana VPA: A comprehensive policy analysis of its design. *Inter Forestry Rev*. 12(3):221–230. <https://doi.org/10.1505/for.12.3.221>
- Boakye, J. 2015. Estimation of illegal logging by the formal timber sector in Ghana: Implications for forest law compliance, enforcement and EU-Ghana voluntary partnership agreement. *Inter Forestry Rev*. 17(2):117–127. <https://doi.org/10.1505/146554815815500598>
- davidbritch, thimanshu1993, mhrastegari, jonpryor, Banovvv, and jconrey. 2025. What is .NET MAUI? Microsoft. <https://learn.microsoft.com/en-us/dotnet/maui/what-is-maui?view=net-maui-9.0>. Accessed February 11, 2025.
- de Andrade, B. G., V. M. Basso, and J. V. de Figueiredo Latorraca. 2020. Machine vision for field-level wood identification. *IWA J*. 41(4):681–698. <https://doi.org/10.1163/22941932-bja10001>
- Eshun, A. A., J. H. Quansah, and B. N. Donkor. 2017. Work Instructions for Square-Edge Sawn Timber Inspection and Grading TIDD internal document, not publicly available.
- Global Forest Watch. 2025. Ghana. <https://www.globalforestwatch.org/dashboards/country/GHA/?category=forest-change&map=eyJjYW5Cb3VuZC6dHjIjZX0%3D>. Accessed June 12, 2025.
- Gyala, L. 2017. UNIDO builds capacity of Forestry Commission timber inspectors in ISO 17020. <https://www.modernghana.com/news/767596/unido-builds-capacity-of-forestry-commission-timber-inspecto.html>. Accessed February 11, 2025.
- Hamari, J., J. Koivisto, and H. Sarsa. 2014. Does gamification work?—A literature review of empirical studies on gamification. In: 47th Hawaii International Conference on System Sciences, January 6–9, 2014, Waikoloa, Hawaii; IEEE Computer Society, Washington, D.C. pp. 3025–3034. <https://doi.org/10.1109/HICSS.2014.377>. Accessed March 20, 2025.
- Hansen, C. P. and T. Treue. 2008. Assessing illegal logging in Ghana. *Inter Forestry Rev*. 10(4):573–590. <https://doi.org/10.1505/for.10.4.573>
- Hwang, S. W. and J. Sugiyama. 2021. Computer vision-based wood identification and its expansion and contribution potentials in wood science: A review. *Plant Meth*. 17(47). <https://doi.org/10.1186/s13007-021-00746-1>
- International Organization for Standardization/Committee on Conformity Assessment. 2012. Conformity assessment—Requirements for the operation of various types of bodies performing inspection (ISO/IEC 17020:2012). <https://www.iso.org/standard/52994.html>. Accessed February 10, 2025.
- International Tropical Timber Organization. 2025. Tropical timber market report, volume 29, number 9; 1st–15th May 2025. https://www.itto.int/direct/topics/topics_pdf_download/topics_id=8289&no=1
- Jamil, A. and G. Denes. 2024. Investigating color-blind user-interface accessibility via simulated interfaces. *Computers*. 13(2):53. <https://doi.org/10.3390/computers13020053>
- Kapp, K. M. 2012. The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education. 1st ed. Pfeiffer and Company, San Francisco. 336 pp.
- Kyatt Spessert. 2025a. WhatWood? Ghana Ed. Version 1.0.1. Apple App Store. <https://apps.apple.com/iq/app/whatwood-ghana-ed/id6740234963>. Accessed February 20, 2025.
- Kyatt Spessert. 2025b. WhatWood? Ghana Ed. Version 1.0.1. Google Play Store. https://play.google.com/store/apps/details?id=com.MSU.woodID.ghanawoods&hl=en_US. Accessed February 20, 2025.
- Marfo, E. 2010. Chainsaw Milling in Ghana: Context, Drivers and Impacts. Tropenbos International, Wageningen, the Netherlands. xii + 64 pp. https://www.tropenbos.org/file.php/208/chainsaw_milling_in_ghana_marfo2010.pdf. Accessed February 10, 2025.
- McDermott, C. L., M. Hirons, and A. Setyowati. 2020. The interplay of global governance with domestic and local access: Insights from the FLEGT VPAs in Ghana and Indonesia. *Soc Nat Resources*. 33(2):261–279. <https://doi.org/10.1080/08941920.2018.1544679>
- Ministry of Lands and Natural Resources. 2025a. Forestry Commission: About TIDD. <https://fcghana.org/about-tidd/>. Accessed February 10, 2025.
- Ministry of Lands and Natural Resources. 2025b. Forestry Commission (FC). <https://mlnr.gov.gh/index.php/forestry-commission/>. Accessed February 10, 2025.
- Ministry of Lands and Natural Resources. 2025c. Forestry Commission: The Forestry Commission. <https://fcghana.org/the-forestry-commission/>. Accessed February 10, 2025.
- MSU-WhatWood. 2025. WhatWood-Ghana-Edition. GitHub. <https://github.com/MSU-WhatWood/WhatWood-Ghana-Edition>. Accessed April 4, 2025.
- Osei-Tutu, E., E. Badu, and D. Owusu-Manu. 2010. Exploring corruption practices in public procurement of infrastructural projects in Ghana. *Inter J Man Proj Business*. 3(2):236–256. <https://doi.org/10.1108/17538371011036563>
- Poku, I. A., L. Damnyag, A. Eric, E. M. Frimpong, A. Danson-Anokye, and A. Frederick. 2024. Policy responses to illegal logging in Ghana: Insights from Goaso and Nkwie forest districts. *Ann Ecol Environ Sci*. 6(2):28–40. <https://doi.org/10.22259/2637-5338.0602003>
- Ravindran, P., A. C. Wade, F. C. Owens, R. Shmulsky, and A. C. Wiedenhoef. 2022a. Towards sustainable North American wood product value chains, part 2: Computer vision identification of ring-porous hardwoods. *Canadian J Forest Res*. 52(7):1014–1027. <https://doi.org/10.1139/cjfr-2022-0077>

- Ravindran, P., B. J. Thompson, R. K. Soares, and A. C. Wiedenhoef. 2020. The XyloTron: Flexible, open-source, image-based macroscopic field identification of wood products. *Front. Plant Sci.* 11:01015. <https://doi.org/10.3389/fpls.2020.01015>
- Ravindran, P., E. Ebanyenle, A. A. Ebeheakey, K. B. Abban, O. Lambog, R. Soares, A. Costa, and A. C. Wiedenhoef. 2019. Image based identification of Ghanaian timbers using the XyloTron: Opportunities, risks and challenges. *In: Proceedings of NeurIPS 2019 Workshop on Machine Learning for the Developing World: Challenges and Risks of ML4D*. 33rd Conference on Neural Information Processing Systems (NeurIPS 2019), December 8-14, 2019, Vancouver, BC, Canada. *arXiv*: 1912.00296. <https://doi.org/10.48550/arXiv.1912>
- Ravindran, P., F. C. Owens, A. C. Wade, P. Vega, R. Montenegro, R. Shmulsky, and A. C. Wiedenhoef. 2021. Field-deployable computer vision wood identification of Peruvian timbers. *Front. Plant Sci.* 12:647515. <https://doi.org/10.3389/fpls.2021.647515>
- Ravindran, P., F. C. Owens, A. C. Wade, R. Shmulsky, and A. C. Wiedenhoef. 2022b. Towards sustainable North American wood product value chains, part I: Computer vision identification of diffuse porous hardwoods. *Front. Plant Sci.* 12:758455. <https://doi.org/10.3389/fpls.2021.758455>
- SamMonoRT, AndriySvryd, Rick-Anderson, stamminator, dennisseders, smitpatel, roji, riccicl, divega, gurmeetsinghdke, tdykstra, mairaw, bricelam, rowanmiller, and mjmilan. 2024. Entity framework core. Microsoft. <https://learn.microsoft.com/en-us/ef/core/>. Accessed February 10, 2025.
- SQLite Developers. 2025. About SQLite. <https://www.sqlite.org/about.html>. Accessed February 10, 2025.
- World Wide Web Consortium. 2024. Web content accessibility guidelines (WCAG) 2.1. <https://www.w3.org/TR/WCAG21/>. Accessed March 20, 2025.
- Yi Tou, J., P. Yee Lau, and Y. Haur Tay. 2007. Computer vision-based wood recognition system. *In: Proceedings of the International Workshop on Advanced Image Technology*, January 8–9, 2007, Bangkok, Thailand; Thai Embedded Systems Association (TESA), Ratchathewi, Bangkok, Thailand. 6 pp. <https://www.researchgate.net/publication/264886592>. Accessed March 10, 2025.
- Yuliasuti, E., S. Suprijanto, and S. R. Sasi. 2013. Compact computer vision system for tropical wood species recognition based on pores and concentric curve. *In: 2013 3rd International Conference on Instrumentation Control and Automation (ICA)*, August 28–30, 2013, Ungasan, Bali, Indonesia; IEEE. <https://ieeexplore.ieee.org/abstract/document/6734071>. Accessed March 10, 2025.