Are Game Engines Software Frameworks? A Three-perspective Study

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ABSTRACT

Game engines help developers create video games and avoid duplication of code and effort, like frameworks for traditional software systems. In this paper, we explore game engines along three perspectives: literature, code, and human. First, we explore and summarise the academic literature on game engines. Second, we compare the characteristics of the 282 most popular engines and the 282 most popular frameworks in GitHub. Finally, we survey 124 engine developers about their experience with the development of their engines. We report that: (1) Game engines are not well-studied in software-engineering research with few studies having engines as object of research. (2) Game engines are slightly larger in terms of size and complexity and less popular and engaging than traditional frameworks. Their programming languages differ greatly from frameworks. Engine projects have shorter histories with less releases. (3) Developers perceive game engines as different from traditional frameworks and claim that engines need special treatments. Generally, they build game engines to: (a) better control the environment and source code, (b) learn about game engines, and (c) develop specific games. We conclude that game engines are different from traditional frameworks although this difference is too small to force special treatments.

1. Introduction

“It’s hard enough to make a game [...] It’s really hard to make a game where you have to fight your own tool set all the time.”
— Schreier [1] quoting a game developer on the difficulties faced using their game engine.

For decades, video games have been a joyful hobby for many people around the world [2], making the game industry multi-billionaire, surpassing the movie and music industries combined [3]. However, realistic graphics and smooth gameplays hide constant and non-ending problems with game development, mostly related to poor software-development practices and inadequate management [4]. These problems result in 80% of the top 50 games on Steam need critical updates [5] and leave a trail of burnout developers after long periods of “crunches”[6–11].

During game development, developers use specialized software infrastructures to develop their games; chief among which are game engines. Game engines encompass a myriad of resources and tools [12–15]. They can be built from scratch during game development, reused from previous games, extended from open-source ones, or bought off the shelves. They are essential to game development but misunderstood and misrepresented by specialized media and users [16] and developers due to lacks of clear definitions, architectural references [17], and academic studies. They are also the source of many problems, especially between design and technical teams [18, 19], as exemplified by the following game developer’s quote:

“Engine updates made this process [of adding content] even more challenging. Every time the Frostbite team [the game-engine developers] updated the engine with new fixes and features, BioWare’s programmers [the game developers] would have to merge it with the changes they’d made to the previous version. They’d have to go through the new code and copy-paste all the older stuff they’d build (...) then test it all out to ensure they hadn’t broke anything [...] it was debilitating [...].” — Schreier [18]

To address these problems, some researchers suggest the use of software-engineering techniques [4, 20, 21] while others consider game development as a special kind of software and propose new engineering practices or extensions to classical ones [21–28]. However, they did not study a large number of game engines, either proprietary, because only 13% of all the games on Steam describe their engines [29], or open source. They also did not survey game engine developers. The different point of views within academia about game engines impede applying software-engineering practices to game development. Therefore, we set to comparing video-game engines with traditional software frameworks can help researchers and developers to understand them better.
this article, we want to answer whether game engines share similar characteristics with software frameworks. By comparing the tools (engines and frameworks) rather than their instances (video games, traditional software systems), we provide a distinct view on game development: rather than studying how developers use games engines, we focus on how the foundations of their games are built.

We study game engines from three perspectives: **literature, code, and human** to provide an global view on the states of the art and practice on game engines. We explore academic and gray literature on game engines; compare the characteristics of the 282 most popular engines and the 282 most popular frameworks in GitHub; and, survey 124 engine developers about their experience with the development of their engines. Thus, we provide four contributions: (1) a corpus of open-source engines for this and future research work; (2) an analysis and discussion of the characteristics of engines; (3) a comparison of these characteristics with those of traditional frameworks; and, (4) a survey of engine developers about their experience with engine development.

We show that, different from what researchers and engine developers think, there are qualitative but no quantitative differences between engines and frameworks. Game engines are slightly larger in terms of size and complexity and less popular and engaging than traditional frameworks. The programming languages of game engines differ greatly from that of traditional frameworks. Game-engine projects have shorter histories with less releases. Developers perceive game engines as different from traditional frameworks and claim that engines need special treatments. Developers build game engines to better control the environment and interfaces that hide the low-level details of the implementations of games. Engines are extensible software that can be used as the foundations for many different games and allow developers to create games similar to the ones on Nintendo console. It also introduced the separation of game engine from “assets” accessible to players and thereby revealed a new paradigm for game design on the PC platform, allowing players to modify their games and create new experiences. This concept has since evolved into the “fundamental software components of a computer game”, comprising its core functions, e.g., graphics rendering, audio, physics, AI.

Carmack and Taylor [33] see a framework as a programmatic bridge between the game code and its assets and to work collaboratively on the game as a team [19, 34]. Also, they “lent” their engines to other game companies to allow other developers to focus only on game design.

In 2002, Lewis and Jacobson [36] defined game engines as “collection[s] of modules of simulation code that do not directly specify the game’s behavior (game logic) or game’s environment (level data)”. In 2007, Sherrod [15] defined engines as frameworks comprised of different tools, utilities, and interfaces that hide the low-level details of the implementations of games. Engines are extensible software that can be used as the foundations for many different games without major changes [12] and are “software frameworks for game development”. They relieve developers so that they can focus on other aspects of game development[7]. In 2019, Tofte and Engström [29] analysed and divided engines...
in four complementary types: (a) Core Game Engine, (b) Game Engine, (c) General Purpose Game Engine, and (d) Special Purpose Game Engine.

2.3. Related Works
There are few academic papers on game engines. Most recently and most complete, Toftedahl and Engström [29] analysed the engines of games on the Steam and Itch.io platforms to create a taxonomy of game engines. They highlighted the lack of information regarding the engines used in mainstream games with only 13% of all games reporting information about their engines. On Steam, they reported Unreal (25.6%), Unity (13.2%), and Source (4%) as the main engines. On Itch.io, they observed that Unity alone has 47.3% of adoption among independent developers.

Messiaoudi et al. [17] investigated the performance of the Unity engine in depth and reported issues with CPU and GPU consumption and modules related to rendering.

Cowan and Kapralos [37] in 2014 and 2016 [38] analysed the game engines used for the development of serious games. They identified few academic sources about tools used to develop serious games. They showed that “Second Life”\(^8\) is the most mentioned game engine for serious games, followed by Unity and Unreal. They considered game engines as parts of larger infrastructures, which they call frameworks and which contain scripting modules, assets, level editors as well as the engines responsible for sound, graphics, physics, and networking. They ranked Unity, Flash, Second Life, Unreal, and XNA as the most used engines.

Neto and Brega [39] conducted a systematic literature review of game engines in the context of immersive applications for multi-projection systems, aiming at proposing a generic game engine for this purpose.

Wang and Nordmark [40] assumed that game development is different from traditional software development and investigated how architecture influences the creative process. They reported that the game genre significantly influences the choice of an engine. They also showed that game-engine development is driven by the creative team, which request features to the development team until the game is completed. They observed that adding scripting capability ease game-engine development through testing and prototyping.

Anderson et al. [41] raised issues and questions regarding game engines, among which the need for a unified language of game development, the identification of software components within games, the definition of clear boundaries between game engines and games, the links between game genres and game engines, the creation of best practices for the development of game engines.

\(^8\)Second Life is not a game engine per se but a game that can be extended by adding new “things” through “mod” or “modding”.

| Table 1 | Questions and Measures. |
|---------|-------------------------|
| RQ1: Static Characteristics | |
| RQ1.1: What is the popularity of the languages in the projects? main_language: the main programming language of the project. |
| RQ1.2: What is the popularity of the licenses in the projects? license: the main license of the project. |
| RQ1.3: What are the project sizes of engines and frameworks? main_language_size: total size in MB of the files in the main language. total_size: total size in MB of all files. n_files: total number of files. |
| RQ1.4: What are the function sizes of engines and frameworks? n_funcs: total number of functions. nloc_mean: average of the number of lines per functions. func_per_file_mean: average number of functions per file. |
| RQ1.5: What are the function complexities of engines and frameworks? cc_mean: average cyclomatic complexity by function for the project. |
| RQ2: Historical Characteristics | |
| RQ2.1: How many versions were released for each project? tags_releases_count: the number of tags (versions or builds) released. |
| RQ2.2: What is the lifetime of the projects? lifespan: weeks between the repository creation and the last push. |
| RQ2.3: How frequently do projects receive new contributions? commits_count: total number of commits. commits_per_time: average number of commits per week. |
| RQ3: Community Characteristics | |
| RQ3.1: How many developers contribute in the project? truck_factor: number of contributors on which the project depends directly. |
| RQ3.2: How popular are the projects considering their main languages? stargazers_count: number of “likes” by GitHub users. |
| contributors_count: number of developers that committed at least once. |

Summary of the Literature Perspective
We could not find many academic paper on game engines or a reliable source for gray literature. We recommend to extend this work with multivocal literature review (with academic and grey literatures).

3. Code Perspective
We now present our analyses and comparison of game engines and framework along the code perspective (statically and historically). It introduces our research questions, statistical methods, and results to assess whether frameworks and game engines differ in their development.

3.1. Questions
To analyse and compare engines and frameworks, we define three research questions with related sub-questions and measurements as shown in Table 1. In RQ1: Static Characteristics, we investigate the size of the project and complexity of the functions. In RQ2: Historical Characteristics, we compare the life-cycles of game engines and traditional frameworks. Finally, in RQ3: Community Characteristics, we investigate the community of the projects in each group.

3.2. Method
Figure 1 shows the steps that we followed to mine the data to answer our questions. In Step 1, we gathered the
top 1,000 projects in GitHub related to the game-engine and framework topics, separately, storing each one in a specific dataset. In Step 2, we filtered these projects using the following criteria to remove “noise” and improve the quality of our dataset, which is a common approach when dealing with Github repositories [42, 43]:

- The project must have more than one contributor;
- The project must have been starred at least twice;
- The last commit must be at least from 2017;
- The project cannot be archived.

In Step 3, we manually analysed the remaining projects to remove those neither game engines nor frameworks according to the definitions in Section 2. In Step 4, we kept only projects supported by Lizard\(^9\): {C/C++, C#, GDScript, Golang, Java, JavaScript, Lua, Objective-C, PHP, Python, Ruby, Scala, Swift, TTCN-3}.

In Step 5, we computed the measures and stored their values in the datasets. In Step 6, we computed the truck-factor of each project, which is the number of contributors that must quit before a project is in serious trouble [43, 44]. In Step 7, we used Lizard to gather the average value of the measures related to functions. Lastly, we ordered the projects by popularity: how many “stars” they have.

Figure 2 shows an example containing the Github page of the engine Godot\(^10\). We only consider the main language of the projects but most projects are composed of multiple languages. Almost all the code of Godot is written in C++ (93%). Godot is tagged with the “game-engine” topic and, therefore, was found through our search. Godot is the most popular engine containing more than 26K votes.

3.3. Collected Data

We mined 2,000 GitHub projects: 1,000 frameworks and 1,000 engines, ordering them by stars count (Step 1). After removing noise, we obtained 458 engines and 743 frameworks (Step 2). We manually analysed all of the 458 engines and kept 358 (Step 3). We retained 282 engines for which we could compute the source-code measures (Steps 5 and 6). We applied the same data collection process for the frameworks collected in Step 1, keeping the top 282 most popular projects at the end. The final dataset consists of 564 projects. In total, we computed the values of 16 measures for this study. The dataset, scripts and all the material from this study are in its replication package\(^11\).

3.4. Analysis

We used the statistical-analysis workflow-model for empirical software-engineering research [45] to test statistically the differences between engines and frameworks. For each continuous variable, we used descriptive statistics in the form of tables with mean, median, min, and max values, together with boxplots. For the boxplots, to better show the distributions, we removed outliers using the standard coefficient of 1.5 \((Q_3 + 1.5 \times IQR)\). We observed outliers for all the measures, with medians skewed towards the upper quartile \((Q3)\). To check for normality, we applied the Shapiro test [46] and checked visually using Q-Q plots. Finally, given the data distribution, we applied the appropriate statistical tests and computed their effect sizes.

3.5. RQ1: Static Characteristics

**RQ1.1: What is the popularity of the languages in the projects?**

Table 2 shows the popularity of the programming languages in both framework and game engines, ordered by the numbers of projects. The most used languages in game engines belong to the C family: C, C++, and C#. Together, they represent about 64% of the code. For frameworks, JavaScript, 

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\(^9\)https://github.com/terryyin/lizard  
\(^10\)https://github.com/godotengine/godot  
\(^11\)https://doi.org/10.5281/zenodo.3606899.
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Figure 2: Godot engine Github page example. In this case we considered C++ as main language (A) and filtered the projects with least one commit from 2017 or newer (B) and with more than two contributors (D). Tags, provided by the developers, were used to search for the engines (C). Finally, we ordered the projects by the stars (E).

Table 2

| Language | Engine | Framework | Total |
|----------|--------|-----------|-------|
|          | N      | N         | N     |
| C++      | 107    | 10        | 117   | 20.74% |
| JavaScript | 28    | 71         | 99    | 17.55% |
| Python   | 14     | 11         | 59    | 10.46% |
| C        | 41     | 11         | 52    | 9.22%  |
| PHP      | 3      | 46         | 49    | 8.69%  |
| C#       | 33     | 15         | 48    | 8.51%  |
| Java     | 27     | 19         | 46    | 8.16%  |
| Go       | 14     | 21         | 35    | 6.21%  |
| TypeScript | 7     | 18         | 25    | 4.43%  |
| Swift    | 2      | 13         | 15    | 2.66%  |
| Scala    | 1      | 5          | 6     | 1.06%  |
| Objective-C | 1  | 4          | 5     | 0.89%  |
| Lua      | 4      | 0          | 4     | 0.71%  |
| Ruby     | 0      | 4          | 4     | 0.71%  |

PHP, and Python are the most used languages with 51% of the code. C++ and JavaScript are the most used language for games and frameworks.

The distributions of the languages differ for each group. Game engines are mainly built in C++. For frameworks, the differences between the top three languages are smaller. Because we sorted projects by popularity and most top frameworks focus on Web development, interpreted languages are used in the majority of their code.

Figure 3 shows the ranking of the top six most used languages in engines and frameworks and compare it to other three global sources of programming languages usage in 2019: GitHut 2.0\textsuperscript{12} (Third Quarter), which uses the GitHub API to query the most used languages in the public repositories, Tiobe index\textsuperscript{13} (November), which uses a set of metrics together with results from search engines, and PYPL\textsuperscript{14} (Popularity of Programming Language, December), which is a ranking created by analysing how often language tutorials are searched on Google.

C++ is the most popular language for engines but is only the 10\textsuperscript{th} most popular in frameworks, 5\textsuperscript{th} in GitHut, 4\textsuperscript{th} in Tiobe, and 6\textsuperscript{th} in PYPL. C is used in engines and is in 2\textsuperscript{nd} position in Tiobe but not so popular according to the other sources. JavaScript is embraced by the open-source community and received lots of attention in searches but Tiobe puts it in the 7\textsuperscript{th} place. The popularity of the programming languages in engines is more aligned to the Tiobe index than to the other sources. In contrast, popular languages in frameworks are more aligned to GitHut and PYPL rankings. Game engines are more aligned with the commercial market and less with open-source projects.

\textsuperscript{12}https://madnight.github.io/githut/
\textsuperscript{13}https://www.tiobe.com/tiobe-index/
\textsuperscript{14}https://pypl.github.io/PYPL.html
Table 3
Most Used Licenses.

|             | Engine N | Engine % | Framework N | Framework % | Total N | Total % |
|-------------|----------|----------|-------------|-------------|---------|---------|
| MIT License| 116      | 41%      | 142         | 50%         | 258     | 46%     |
| Other       | 55       | 20%      | 48          | 17%         | 103     | 18%     |
| No licence specified | 30 | 11% | 22 | 8% | 52 | 9% |
| Apache License 2.0 | 17 | 6% | 35 | 12% | 52 | 9% |
| GNU GPL v3.0 | 28 | 10% | 10 | 4% | 38 | 7% |
| GNU LGPL v3.0 | 8 | 3% | 5 | 2% | 13 | 2% |
| BSD 3       | 2        | 1%       | 7          | 2%          | 9       | 2%      |
| GNU GPL v2.0 | 2 | 1% | 7 | 2% | 9 | 2% |
| zLib License| 2        | 1%       | 0          | 0%          | 2       | 1%      |
| GNU AGPL v3.0 | 1 | 1% | 3 | 1% | 4 | 1% |
| BSD 2       | 1        | 1%       | 0          | 0%          | 1       | 1%      |
| GNU LGPL v2.1 | 1 | 1% | 0 | 0% | 1 | 1% |
| Mozilla PL 2.0 | 1 | 1% | 0 | 1% | 2 | 1% |
| The Unlicense| 1        | 3%       | 1          | 1%          | 2       | 1%      |
| Artistic License 2.0 | 1 | 1% | 0 | 1% | 1 | 1% |
| Boost SL 1.0 | 1 | 1% | 0 | 1% | 1 | 1% |
| CC Attribution 4.0 | 1 | 1% | 0 | 1% | 1 | 1% |
| Eclipse PL 1.0 | 1 | 0% | 0 | 0% | 1 | 0% |
| Microsoft PL | 1        | 0%       | 0          | 0%          | 1       | 0%      |

RQ1.2: What is the popularity of the licenses in the projects?

Table 3 shows the top 10 most used licenses. Differently from the languages, the distribution of licenses is similar between engines and frameworks. The MIT License is most used for both types of projects with 46%. “Other” licenses (not reported by GitHub) are the second most popular with 18%. 9% of the projects do not have an explicit license. The remaining ones form 27%.

According to GitHut 2.0, the licenses in GitHub project are ranked as follows: MIT 54%, Apache 16%, GPL 2 13%, GPL 3 10%, and BSD 3 5%, which is similar to the rankings in engines and frameworks. However, “Other” licenses are a big part of this data, which have a high chance of migrating towards Apache or GPL licenses Vendome et al. [47]. Finally, the MIT license is popular thanks to its permissive model, which fits well with most open-source projects.

The licenses might only apply to the engines or frameworks and not to the games or software. For example, games created with Godot have their creators as sole copyright owners but must include its license:

“Godot Engine’s license terms and copyright do not apply to the content you create with it; you are free to license your games however you see best fit, and will be their sole copyright owner(s). Note however that the Godot Engine binary that you would distribute with your game is a copy of the ‘Software’ as defined in the license, and you are therefore required to include the copyright notice and license statement somewhere in your documentation.”

– https://godotengine.org/license

RQ1.3: What are the project sizes of engines and frameworks?

Table 4 shows the descriptive statistics of the sizes and source-code complexities. As mentioned in the Section 3.4, we performed the Shapiro test for all variables to verify their normality, together with Q–Q plots, which, in this case present non-normal values as the p-value is less than 0.01.

We considered main_language_size, total_size, and n_files. They show larger values for engines when compared to frameworks. Considering the medians, engines have around 50% higher median values regarding size of the main language (1.09MB), total size of the project (1.22MB), and number of files (171 files). The boxplots in Figure 4 help to identify the differences among variables: game engines are larger than frameworks, on average.

RQ1.4: What are the function sizes of engines and frameworks?

We considered n_func, nloc_mean, and func_per_file_mean. The boxplots in Figure 5 show that engines have larger values when compared to frameworks. Considering medians, engines have around 30% more functions per file and 20%
Table 4
Descriptive Statistics, RQ1: Static Characteristics.

| RQs Variable      | Type     | Mean   | Std.Dev. | Median | Min  | Max  | Normality |
|-------------------|----------|--------|----------|--------|------|------|-----------|
| main_language_size| engine   | 5.78   | 14.95    | 1.09   | 0.00 | 102.10| <0.01     |
|                   | framework| 3.82   | 17.74    | 0.55   | 0.00 | 276.76| <0.01     |

RQ1.3

| Variable | Type     | Mean   | Std.Dev. | Median | Min  | Max  | Normality |
|----------|----------|--------|----------|--------|------|------|-----------|
| total_size| engine   | 7.66   | 20.31    | 1.22   | 0.00 | 155.32 | <0.01     |
|          | framework| 4.82   | 26.27    | 0.60   | 0.00 | 423.37| <0.01     |
| n_file   | engine   | 685.60 | 1853.12  | 171.00 | 1.00 | 23379.00| <0.01     |
|          | framework| 456.93 | 1053.45  | 97.50  | 1.00 | 8062.00| <0.01     |

RQ1.4

| Variable         | Type     | Mean   | Std.Dev. | Median | Min  | Max  | Normality |
|------------------|----------|--------|----------|--------|------|------|-----------|
| n_func           | engine   | 10130.74| 21627.98 | 2394.00| 1.00 | 163779.00| <0.01     |
|                  | framework| 5924.17| 14469.19 | 960.50 | 1.00 | 145288.00| <0.01     |
| nloc_mean        | engine   | 12.94  | 15.17    | 11.07  | 1.32 | 247.25| <0.01     |
|                  | framework| 12.71  | 33.89    | 8.79   | 1.00 | 539.79| <0.01     |
| func_per_file_mean| engine  | 20.60  | 40.32    | 12.34  | 1.00 | 370.14| <0.01     |
|                 | framework| 23.03  | 82.62    | 8.57   | 1.00 | 1070.13| <0.01     |

RQ1.5

| Variable        | Type     | Mean   | Std.Dev. | Median | Min  | Max  | Normality |
|-----------------|----------|--------|----------|--------|------|------|-----------|
| cc_mean         | engine   | 3.09   | 2.35     | 2.77   | 1.00 | 36.19| <0.01     |
|                 | framework| 2.68   | 3.75     | 2.14   | 1.00 | 60.22| <0.01     |

Figure 6: Boxplot of the Cyclomatic Complexity (CC).

Table 5
Statistical Tests, RQ1: Static Characteristics

| Variable         | P-value | Estimate | Effect          |
|------------------|---------|----------|-----------------|
| main_language_size| <0.01   | 0.28     | 0.189 (small)   |
| total_size       | <0.01   | 0.34     | 0.188 (small)   |
| n_file           | <0.01   | 45.00    | 0.155 (small)   |
| n_func           | <0.01   | 769.00   | 0.211 (small)   |
| nloc_mean        | <0.01   | 2.12     | 0.297 (small)   |
| func_per_file_mean| <0.01  | 3.13     | 0.208 (small)   |
| cc_mean          | <0.01   | 0.53     | 0.356 (small)   |

Summary of RQ1: Static Characteristics

Table 5 shows the results of Wilcoxon tests. The p-values < 0.01 indicate that the distributions are not equal and there is a significant difference between engines and frameworks, although this difference is small. The biggest effects are related to source code metrics, i.e., nloc_mean and cc_mean. Factoring out low-level languages, e.g., C++, the complexity of the functions are similar between engines and frameworks. The number of files and average functions per file are similar. The total number of functions, however, is different: engines have twice as many functions (median values).

Programming languages vary greatly, as the game engines are written mostly in compiled languages, while frameworks in interpreted ones. Both types of projects prefer the MIT license, very suitable to open-source projects. Although game engines are, on average, bigger and more complex than frameworks, this difference is small.

3.6. RQ2: Historical Characteristics

Table 6 shows the descriptive statistics of the historical variables: tags_releases_count, lifespan, commits_count, and commits_per_time. Engines have less versions (median 1) compared to frameworks (median 32). They also receive less commits than frameworks, on average. The differences in number of commits per week is not large.

RQ2.1: How many versions were released for each project?

Around 40% of the engines (112 projects) do not have any tag. Only 8% of the frameworks (23 projects) are lacking them. Most engines have between 0 and 11 tags while...
Table 6
Descriptive Statistics: RQ2: Historical Characteristics.

| RQs   | Variable            | Type  | Mean  | Std.Dev. | Median | Min   | Max   | Normality |
|-------|---------------------|-------|-------|----------|--------|-------|-------|-----------|
|       | tags_releases_count | engine | 15.82 | 52.20    | 1.00   | 0.00  | 657.00| <0.01     |
|       | tags_releases_count | framework | 82.24 | 216.37   | 32.00  | 0.00  | 2,678.00| <0.01     |
|       | lifespan (weeks)    | engine | 155.70| 113.39   | 135.79 | 0.00  | 530.43| <0.01     |
|       | lifespan (weeks)    | framework | 215.30| 129.79   | 182.14 | 5.71  | 590.71| <0.01     |
|       | commits_count      | engine | 2,029.93| 4,553.92| 616.00 | 7.00  | 37,026.00| <0.01     |
|       | commits_count      | framework | 3,463.88| 8,581.04| 833.50 | 20.00 | 87,774.00| <0.01     |
|       | commits_per_time   | engine | 3.44  | 7.71     | 1.04   | 0.01  | 62.68 | <0.01     |
|       | commits_per_time   | framework | 5.86  | 14.53    | 1.41   | 0.03  | 148.59| <0.01     |

RQ2.1: How many versions were released for each project?

Frameworks have between 9 to 88. Frameworks release new versions more often. Figure 7 shows the boxplots for the numbers of tags. The dots represent the outliers as the majority of the engines have zero or few tags.

RQ2.2: What is the lifetime of the projects?

Figure 8 shows the distributions of engines and frameworks lifetimes in weeks: both have similar shapes, with more projects in the last years. Considering median values, engines and frameworks are 2.6 and 3.5 years-old, respectively. Open-source engines are more recent when compared to open-source frameworks.

RQ2.3: How frequently do projects receive new contributions?

Figure 9 shows the boxplots of the amount of commits per week. The frequency and number of commits is larger for frameworks. Most engines have more than 616 commits and 47% of the engines have at least one commit per week, on average, but frameworks have more than 833 commits and 40% have at least one commit per week, on average.

Table 7
Statistical Tests, RQ2: Historical Characteristics

| Variable          | P-value | Estimate | Effect       |
|-------------------|---------|----------|--------------|
| tags_releases_count | <0.01   | -24.00   | -0.613 (large) |
| lifespan          | <0.01   | -56.29   | -0.32 (large)  |
| commits_count     | <0.01   | -175.00  | -0.198 (large) |
| commits_per_time  | <0.01   | -0.30    | -0.198 (large) |

Summary of RQ2: Historical Characteristics

Table 7 shows the results of Wilcoxon tests, showing large differences for all historical measures. Versioning does not look like a well-followed practice in engine development, with few versions compared to frameworks. Commits are less frequent and less numerous in engines, which are younger and have shorter lifetimes when compared to frameworks.

3.7. RQ3: Community Characteristics

Table 8 shows the descriptive statistics of the variables related to the communities: truck_factor, stargazers_count, and contributors_count.

RQ3.1: How many developers contribute in the project?

Table 9 shows the truck-factor values and numbers of contributors per project. The distribution of the truck-factor between engines and frameworks are similar with the majority of the projects having a value equal to one (82% for engines and 73% for frameworks). The engine with the highest truck-factor is PGZero with value of 8. Three frameworks
Table 8
Descriptive Statistics, RQ3: Community Characteristics.

| RQs     | Variable     | Type | Mean  | Std.Dev. | Median | Min  | Max  | Normality |
|---------|--------------|------|-------|----------|--------|------|------|-----------|
| RQ3.1   | truck_factor | engine | 1.32 | 0.91     | 1      | 1    | 8    | <0.01     |
|         | truck_factor | framework | 1.58 | 1.88     | 1      | 1    | 25   | <0.01     |
| RQ3.2   | stargazers_count | engine | 659.45 | 2,140.45 | 44.5   | 2    | 23,775 | <0.01     |
|         | stargazers_count | framework | 4,017.36 | 11,671.63 | 556.5  | 111  | 145,516 | <0.01     |
|         | contributors_count | engine | 18.95 | 52.66    | 3      | 2    | 435   | <0.01     |
|         | contributors_count | framework | 57.09 | 94.34    | 15     | 2    | 403   | <0.01     |

Figure 10: Popularity of the Top 10 Most Used Languages for Engines and Frameworks Ordered by Medians.

Table 9
Truck-factor values and medians of contributors.

| Truck-factor | Frameworks |          | Engines |          |
|--------------|------------|----------|---------|----------|
| Truck-factor | N Contributors | N Contributors |        |          |
| 1            | 208        | 11       | 231     | 3        |
| 2            | 46         | 46       | 35      | 13       |
| 3            | 10         | 75.5     | 7       | 47       |
| 4            | 11         | 75       | 4       | 50       |
| 5            | 1          | 355      | 1       | 216      |
| 6            | 2          | 299      | 1       | 312      |
| 7            | –          | –        | 2       | 294      |
| 8            | 1          | 69       | 1       | 32       |
| 9            | 1          | 403      | –       | –        |
| 13           | 1          | 377      | –       | –        |
| 25           | 1          | 374      | –       | –        |

have truck-factor values higher than 8: Django (9), Rails (13), and FrameworkBenchmarks (25). As a comparison, Linux\(^{15}\) has a truck-factor of 57 and Git of 12 [43].

The median of contributors follows an direct relation: the higher the truck-factor, the higher the number of contributors. The exceptions are the engine PGZero (Python) with 32 contributors and the framework Sofa (C++) with 69 contributors, both with truck-factor 8.

Table 10
Statistical Tests, RQ3: Community Characteristics

| Variable           | P-value | Estimate | Effect        |
|--------------------|---------|----------|---------------|
| stargazers_count   | <0.01   | -358.00  | -0.511 (large)|
| contributors_count | <0.01   | -9.00    | -0.459 (large)|
| truck_factor       | 0.01    | <0.01    | -0.138 (large)|

RQ3.2: How popular are the projects considering their main languages?

Figure 10 shows the popularity of the projects considering the top 10 most used languages (Table 2) ordered by median numbers of stars. Engines written in Go have the highest popularity although they are only 14. JavaScript is the second most popular language followed by the C family. Although C++ makes up the majority of the engines, it is only the fifth most popular. C# is the most popular language for frameworks, but with only 15 projects. JavaScript and C are second and third, respectively.

Summary of RQ3: Community Characteristics

Table 10 shows the results of Wilcoxon tests, indicating a large difference in all measures related to community. The truck-factor shows that the majority of the projects have few contributors. Some uncommon languages, like Go and C#, are used are popular compared to others in more prevalent projects, e.g., C++ and JavaScript.

\(^{15}\)https://github.com/torvalds/linux
4. Human Perspective

We now discuss developers’ own perception of game engines and of their differences with traditional frameworks.

4.1. Method and Questions

We conducted an online survey with developers of the game engines to understand why they built such engines and their opinions about the differences (if any) between engines and frameworks. We asked three questions:

1. Why did you create or collaborate(d) with a video-game engine project?
2. Have you ever written code for a software unrelated to games, like a Web, phone, or desktop app?
3. How similar do you think writing a video-game engine is compared to writing a framework for traditional apps? (Like Django, Rails, or Vue)

Question 1 contained a predefined set of answers that we compiled from the literature and from the documentation and “readme” files studied during the manual filtering of the datasets. The respondent could choose one or more answers. We also provided a free-form text area for developers to provide a different answer and–or explain their answers. With Question 2, we wanted to understand whether game-engine developers are also traditional software developers. Finally, Question 3 collected the developers’ point of view regarding the differences (or lack thereof) between the development of engines and frameworks.

We used an online form to contact developers over a period of three days. We sent e-mails to 400 developers of the game engines in our dataset, using the truck-factor of each project: developers who collaborate(d) most to the projects. We received 124 responses, i.e., 31% of the developers.

4.2. Results

The survey, answers, and scripts for their analyses are in the replication package 11.

**Question 1: Why did you create or collaborate(d) with a video-game engine project?**

Figure 11 shows the breakdown of the developers’ answers. Having access to the source code, freedom to develop, etc., i.e., control of the environment, is the developers’ major reason for working on a game engine while learning to build an engine is the second reason; explaining why many engines have few developers and commits.

The third reason is to build a game, confirming the lack of clear separation between developers and game designers. It is indeed common for game developers to act also as game designers, specially in independent games, e.g., the single developer of Stardew Valley.16

The next answer is about working with a specific language, also related with learning: when learning a new language, developers want to apply or test their knowledge on some projects, and game engines are interesting candidates.

Also related to the environment, the next answer concerns the features offered by existing engines: reusing or creating a new engine may be necessary for certain, particular games with specific requirements. Developers think as game designers: the game concept(s) may require a new engine.

The engine licenses are the least concern: fees and taxes from vendors, e.g., Unreal and Unity, are not important to developers because some licenses are “indie” friendly and offer low rates for indie games [29].

Finally, 19 developers provided “Other” answers: they work on game engines because “it is fun” and–or they have access to some source code, e.g., one developer who reverse-engineered a proprietary engine wrote:

“The source for the original engine was proprietary and so we opened the platform by reverse-engineering it then re-implementing under GPL3.”

Other answers include performance, platform compatibility, new experimental features, and creating a portfolio.

**Question 2: Have you ever written code for a software unrelated to games, like a Web, phone, or desktop app?**

The great majority of developers, 119 of the 124 respondents (96%), have experience with traditional software. The respondents can be considered general software developers with expertise in engine development.

**Question 3: How similar do you think writing a video-game engine is compared to writing a framework for traditional apps? (Like Django, Rails, or Vue)**

Figure 12 shows that engine developers consider engines different from frameworks: 59% of the respondents believe that engines follows a different process from frameworks. Only 20% believe this this process is similar. This is a sur-

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16 [https://www.stardewvalley.net/](https://www.stardewvalley.net/)
Table 11
Perils of Github repositories adapted from Kalliamvakou et al. [48]. (Perils 7, 8, and 9 do not pertain to this work.)

| Perils                                                   | Engines | Frameworks |
|----------------------------------------------------------|---------|------------|
| 1 A repository is not necessarily a project.             | FALSE   | FALSE      |
| 2 Most projects have very few commits.                   | FALSE   | FALSE      |
| 3 Most projects are inactive.                            | FALSE   | FALSE      |
| 4 A large portion of repositories are not for software development. | TRUE    | FALSE      |
| 5 Two thirds of projects (71.6% of repositories) are personal. | TRUE    | FALSE      |
| 6 Only a fraction of projects use pull requests. And of those that use them, their use is very skewed. | TRUE    | TRUE       |

Figure 12: Answers to Question 3: How similar do you think writing a video-game engine is compared to writing a framework for traditional apps? (Like Django, Rails, or Vue).

praising result as they have experience in developing traditional software also.

Summary of the Survey

The developers’ main reasons to work on an engine is (a) having better control over the environment and source code, (b) learning game-engine development, and (c) helping develop a specific game. Almost all the engine developers have experience with traditional software. They consider these two types of software as different.

5. Discussion

We now discuss the results of our study of engines along the three perspectives.

5.1. Perils for Engines and Frameworks

Kalliamvakou et al. [48] analysed developers’ usages of GitHub and reported a set of perils and promises related to GitHub projects. Table 11 shows the perils applying to the objects of our study: engines and frameworks.

In Peril 1, the authors distinguished forks and base repositories. In our search, we observed that most repositories are base ones. We found few forks that we removed during the manual filtering. Therefore, this peril is false for both engines and frameworks.

In Peril 2, the authors reported that the median of commits were 6, with 90% of the projects having less than 50 commits. We observed that the engines and frameworks in our dataset have medians of 616 and 833 commits, respectively, as shown in Table 6.

Peril 3 does not apply to our dataset as the projects have a median of one commit per week and because we removed projects with more than two years without commits.

For Peril 4, the authors found that about 10% of the developers used GitHub for storage. This is partially true for our dataset: we found engine repositories that were used mostly to store assets, documentation, and other files.

Peril 5 is present in this study, specifically in game engine projects: although we removed engines with less than 2 contributors, we found many warnings in read-me files stating that an engine was only for “personal use”, an “unfinished project”, or for “educational purposes” only.

Peril #6 is true for all projects. The number of pull requests for engines is lower than that for frameworks: at least 50% of the engine projects have at least 10 closed pull requests, while frameworks have 100s.

In general, the perils found in any repositories in GitHub do not apply to our dataset. Engines and frameworks seem different to the projects studied by Kalliamvakou et al. [48].

5.2. Game Engines, Frameworks, and Software

In theory, game engines and frameworks have similar objectives: they are modular platforms for reuse that provide a standard way to develop a product, lowering the barrier of entry for developers by abstracting implementation details.

We could classify frameworks in different categories, according to their domains, e.g., Web apps, mobile apps, AI, etc. In a same category and across categories, no two frameworks are the same. They provide their functionalities in different ways. Similarly, game engines also belong to different categories and are different from one another.

Traditional frameworks provide business services while game engines support entertaining games. The process of finding the “fun factor” is exclusive to game development but do not exempt developers from using traditional software-engineering practices. Game engines are tools that help game developers to build games and, therefore, are not directly concerned with non-functional requirements of games, such as “being fun”.

Figure 13 shows the relationship between game engines, games, frameworks, and traditional software: a video game is a product built on top of an engine, like a Web app is built on top of a Web framework. Engines are a specific kind of framework used to build games. Everything described is a
software: Scrumpy\textsuperscript{17} is a Web app written with Vue while Dota 2\textsuperscript{18} is a game made written with Source.

5.3. RQ1: Static Characteristics
5.3.1. Differences in the Programming Languages
Our results showed a discrepancy between the languages used in game engines, in which the majority belongs to the C family, and frameworks, developed mostly with interpreted languages. We explain this difference as follows: engines must work close to the hardware and manage memory for performance and rendering a constant 60 frames per second. Low-level, compiled languages allow developers to control fully the hardware and memory. Frameworks use languages providing higher-level abstractions, allowing developers to focus on features. Frameworks and engines are tools on which developers build their products, who choose the most effective language for their needs.

This observation highlights the needs for performance for engines, through low-level communication with hardware and memory. With the rise of WebAssembly\textsuperscript{19} and the possibility of running compiled code in Web browsers, this observation could change in the near future.

We explain the predominance of C++ for engines by a set of features of this language: abstraction, performance, memory management, platforms support, existing libraries, and community. These features together make C++ a good choice for game developers.

Engine are usually written (or extended) via their main programming language. However, to ease the design, implement, test workflow during production, game developers often add scripting capabilities to their engines. Therefore, when writing a game, game developers may not code directly with low-level languages but use scripts; sometimes with in a specific domain-specific language. For example, Unity, although written in C++, offers scripting capabilities in C#\textsuperscript{20}. Frameworks rarely offer scripting capabilities: their products are often written in the same programming languages.

5.3.2. Similarities in the Licenses
The MIT License is the most used license by both frameworks and engines because it allows reusing and distributing source and—or compiled code in open or proprietary products, with or without changes. Developers can use such these frameworks and engines to create and distribute their software and games without restriction. Also, they can extend or change the code without having to share their intellectual property.

5.3.3. Similarities in Sizes and Complexities
Our results show small differences in sizes and complexities between engines and frameworks, yet not enough to consider engines different from frameworks.

The size of a piece of code is a simplistic proxy to its quality. We expected to observe larger engines, given the eventual presence of multimedia assets. Also, regarding the languages and numbers of files, we expected that larger values for frameworks, given the numbers of configuration files and testing functions. However, we reported that engines are larger in all cases, although by a small margin.

The complexities of the functions was another surprise given the large number of small engines: engines are more complex, although by a small difference.

5.4. RQ2: Historical Characteristics
Our results showed that 40\% of the engines do not have tags, which could mean that they are still under development and no build is available.

However, our dataset contains the most important game engines on GitHub, thus there should be other reasons for the lack of engine releases. During our manual analysis, we found engines with warning messages alerting that there were incomplete, lacking some essential features. Also, we observed that about one third of the engines have only two collaborators. This fact combined with the complexity of engines could explain the difficulty to release a first feature-complete version.

Framework are released more often than engines with more commits performed more regularly when compared to game engines. There are thus meaningful differences between engines and frameworks, which could be explained by the higher popularity of the frameworks (see next section).

5.5. RQ3: Community Characteristics
5.5.1. Differences in Truck Factor
The truck-factor is i for most of the engines (83\%). Laval-lée and Robillard [50] considered that, in addition to being a threat to a project survival, a low truck-factor causes also delays, as the knowledge is concentrated in one developer only. This concentration further limits adoption by new developers. We believe that low truck-factor values are due to the nature of the engines, i.e., side/hobby projects.

In contrast, popular frameworks do not have such a dependency on single developers.
5.5.2. Differences in Community Engagement

We assumed that the numbers of stars for projects in GitHub are a good proxy for their popularity [51]. Surprisingly, engines written in Go and frameworks written in C# are most popular, even though their total numbers are low. JavaScript and C are second and third, respectively. Java is barely present despite its age and general popularity.

5.6. Threats to Validity

Our results are subject to threat to their internal, construct, and external validity.

**Internal Validity.** We related engines and frameworks with static and historical measures. As previous works, we assumed that these measures represent the characteristics that they measure as perceived by developers. It is possible that other measures would be more relevant and representative for developers’ choices and perceptions. We mitigated this threat by exploring different perspectives: literature, code, and human. Also, we divided measures along different aspects (static, historical, and community).

**Construct Validity.** We assumed that we could compare fairly projects in different programming languages, for different domains, and with different purposes, as in various previous studies. We claim that different projects can be compared by considering these projects from three different perspectives: literature, code, and human.

**External Validity.** We studied only open-source projects accessible to other researchers and to provide uniquely identifying information. We also shared on-line all the collected data to mitigate this threat by allowing others to study, reproduce, and complement our results.

**Conclusion Validity.** We did not perform a systematic literature review integrating gray literature available on the Internet. We accept this threat and plan a multivocal literature review in future work. Our study of the literature confirmed that game engines are little studied in academia.

The higher popularity of the frameworks is a concern: the numbers of contributors are larger and could lead to unfair comparisons. We ordered the dataset by the most popular frameworks and engines, so we expected such effect. In the future, we will improve the categorization of our dataset by separating frameworks and engines based on their domains (Web, security, etc., and 2D and 3D games, etc.).

We mined the dataset using the tags of GitHub with which developers classify their projects. For game engines, we used some variations like game engine, game-engine, or game-engine. We may have missed some projects if developers did not use relevant, recognisable tags. For example, the game engine Piston, written in Rust by 67 contributors, is not part of our dataset because it was tagged as “piston, rust, modular-game-engine”. However, we claim that such engines are rare and their absence does not affect our results based on 282 engines and 282 frameworks.

Regarding our survey, Question 3 is broad and could have mislead developers. Although the requirements are different, developers are still creating the building blocks that will serve to build a product. We mitigated this threat through Questions 1 and 2 and the other two perspectives.

6. Conclusion

This paper is a step towards confirming that software-engineering practices apply to game development given their commonalities. It investigated game engines, which form the foundation of video games, and compared them with traditional frameworks. Frameworks are used by developers to ease software development and to focus on their products rather than on implementation details. Similarly, game engines help developers create video games and avoid duplication of code and effort.

We studied game engines along three perspectives: literature, code, and human. Our literature review showed a lack of academic studies about engines, especially their characteristics and architectures. Yet, we showed through the code and human perspectives that game engines are quantitatively different to and perceived differently from software frameworks. Hence, game engines must be an object of study in software-engineering research in their own right.

We divided the code perspective into three points of view: static code (RQ1), history of the projects (RQ2), and of their community characteristics (RQ3). We studied 282 engines and 282 frameworks from GitHub and contributed with the first corpus of curated open-source engines. We reported no significant difference between engines and frameworks for size and complexity but major differences in terms of popularity and community engagement. The programming languages adoption differed greatly also with engines mostly written in C, C++, and C# and frameworks mostly in JavaScript, PHP, and Python. We observed that engines have shorter histories and fewer releases than frameworks.

Finally, our survey results showed that engine developers have also experience in developing traditional software and that they believe that game engines are different from frameworks. The developers’ objectives for developing engines are (a) better control the environment and source code, (b) learn, and (c) develop specific games.

| Summary of the Conclusion |
|----------------------------|
| We conclude that game engines are qualitatively but not quantitatively different from frameworks. Developers should adopt good software-engineering practices to help them in developing game engines, e.g., patterns and idioms. They should also adopt agile methods to manage feature delivery, which is lacking in game development [4, 20]. Finally, the low truck-factor suggests that more care should be given to the documentation of the engines. |

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21https://github.com/PistonDevelopers/piston
Some engines appears suitable for a deeper investigation of their core architectures. The outliers are good candidates to find anti-patterns related to engines and frameworks. While Gregory [12] presented a complex description of the architecture of an engine, it would be interesting to see how a real, successful engine architecture is similar to the one proposed by the author. Also, we did not discuss in details the most popular engines: Unity and Unreal. We could also study the differences between engines and frameworks regarding their workflow to reveal new differences between both types of software. We could also investigate engines and frameworks communities to understand why and how these projects choose their languages.

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